Designing a robotic platform

BSc graduation project by C.K. Yong
Under the supervision of M.S. Essers

UNIVERSITY OF TWENTE.

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Preface

This document is written under the assignment of the industrial design BSc program on the University of Twente. The assignment involves the design and building of a robotic transportation solution for the relocation of a Lynxmotion AL-5D robotic arm. Under the supervision of M.S. Essers, I have navigated through a process of creation, elimination and iteration in order to design a viable solution. In other words, the process in which the platform was created required the usage of design techniques and methods taught throughout the industrial design bachelor course.

In this document, an attempt is made towards describing the phases which led to the creation of a fully operational prototype. The text has been written in such a way that a reader with minor understanding is guided through the process with visual imagery and detailed descriptions.

Problem definition

The University of Twente assigned the task of designing and building a robotic platform, capable of transporting a robotic arm. The arm may be situated on the platform permanently, or allow for a non-permanent connection. The platform will be used in the Virtual Reality lab, situated in the Horst building for testing and research purposes. The student must solve problems in order for such a platform to exist and operate efficiently. This includes resolving issues regarding stability, hardware, software and user experience.

Goal

The ultimate goal of the assignment is to conclude to and deliver the following assets:

- A fully functional system prototype for the problem, capable of transporting a robotic arm efficiently, while allowing for modifications in behavior to be made;
- A plan of manufacture, for the recreation of multiple platforms when necessary;
- A conceptual user interface, capable of controlling the mobile platform.

Also, required deliverables for the bachelor graduation course must be created, which includes (but are not limited to):

- Design report (this document);
- Presentation poster;
- Contribution to the bachelor handout (for promotion of the Industrial Design programme).

Result

The result of this project is a robotic platform, similar to an Automated Guided Vehicle in operation. A docking station and frame structure carrying the robotic arm (model Lynxmotion AL-5D) are included within the system. The system is able to transport the robotic arm towards its intended destination, while preventing issues such as toppling. The assets mentioned all are a result of the design track described further in this document, utilizing iteration, elimination and creative methods to conclude into a viable solution for the mentioned problem. A plan of manufacture, along with a bill of materials is added along with this document in order to provide further instructions for development or manufacturing purposes.

Last notes

The purpose of this document is to exhibit the methods used during the design of the prototype. One with proper understanding of design techniques, should be able to recreate or further develop a platform prototype as the one discussed in this report. Points of attention will be emphasized in such a way that the manufacture and assembly process of one or more extra prototypes should be flawless. It is assumed that the reader has at least a basic understanding of design methods and electronics.

Due to the many activities and ideas executed within the span of this assignment, several pages of detailed information have been omitted from this document. Aside from this document, an appendix document was written to contain detailed content, such as technical drawings, detailed calculation methods, and diagrams. For those interested, referrals were placed within the written text, so any omitted information can be retrieved from this second document.

Summary

The design process taught at the University of Twente's industrial design program, involves the dividing of mentioned process in multiple phases. These phases each have a milestone that acts as the final result of each phase, and marks the starting point for the next phase. This project is divided in four phases.

1. Analysis phase: In this first phase, analytic research methods were utilized in order to establish the general idea of a robotic relocation solution. By exploring market available solutions, one can attain insight of viable ideas. Also, an attempt was made not to limit the creative process too much, done by establishing specifications and requirements in a basic way. This method leaves room for creativity in the idea generation phase. The result of the analysis phase is a design brief, a list of requirements and specifications which defines the concept.
2. Concept phase: The second phase starts from the design brief generated during the analysis phase. Using the design brief, aspects from the analysis and other sources of inspiration, a creative process is executed. Through sketching, elimination and (re)iteration, a working concept is created from a wide amount of ideas. The result is a description of a concept along with a visual depiction.
3. Detailing phase: This phase further develops the concept into a model ready for manufacturing. By analyzing the weak points in the concept, and components to actuate the platform, an attempt is made to create a fully operational platform concept. This phase involves the selection of electronic components and materials of which the platform will be built. The result is a manufacturing plan which will be used in the workshop to fabricate and assemble the prototype.
4. Manufacture and evaluation: The last phase involves the execution of the detailed concept plan and evaluation of the resulting prototype. The prototype is fabricated and then tested using the design brief standards. This section also includes any recommendations for further developing iterations of the platform. The final result of this phase is a fully operational platform, able to relocate a robotic arm according to the initially established requirements.

Dividing the document into these four sections gives a clear overview about the content available in each phase. This method provides insight in goals and milestones during the reading of each chapter in this document.

Mission statement

The goal of this assignment is to design a robot transportation system, capable of transporting an Lynxmotion AL-5D robotic arm in a testing environment at the University of Twente. The robotic platform should include the following specifications (implemented by M.S. Essers):

- Freedom in movement, should be able to rotate around it's own axis
- Should be able to relocate towards a certain position within a 10 mm offset (15 mm on soft flooring)
- Capable of controlling a robotic arm, if situated permanently on top of the device
- Capable of wireless communication and control
- Capable of autonomous charging
- Able to avoid obstacles during travel
- Capable of being built using conventional manufacturing methods present in the University's workshop

At least following aspects should be present as a result from this project:

- A fully functional prototype, conforming to the given requirements
- A fabrication plan to create one or more additional prototypes

Also, the thinking and creative processes should be documented (within this document) for further insight into this assignment and grading purposes.

The robotic platform will be deployed within the University of Twente's premises, mainly the Virtual Reality lab, situated in the Horst building. An industrial manufacturing environment will be simulated in which the robot will operate and be evaluated. The following chapter describes the first phase of the development process, which involves analyzing various aspects surrounding the robotic platform.

Chapter 1: Analysis Phase

Before the platform takes on any form, extensive research should be conducted. Areas of research include existing products and their technologies. The following subjects will be analyzed and relayed towards the developement of the prototype:

- Conditions in which a platform will topple
- Suitable wheel types for the platform
- Available robot manipulators on the market
- Wireless communication technologies
- Battery requirements
- Mobile robot structures
- Existing similar products
- Control methods of autonomous vehicles

The result of the analysis is a list of design requirements and knowledge on the subject of current technologies. These parameters form the base when developing a concept platform.

1.1 Analysing impulse and toppling behaviour

To determine requirements for the prevention of toppling situations, an analysis of a relocation scenario will be made. As the mobile platform will provide for a Lynxmotion AL5D robotic arm, specifications were retrieved for this particular model. In this section, an attempt at the generation of a series of universal algorithms will be made, so required specifications for the platform can be retrieved with ease, and adapting to different types of robots can be accounted for.

Specifications of the lynxmotion al5d robotic arm

The specifications of the Lynxmotion AL5D are as follows (Lynxmotion, 2013b):

Dimensions and specifications	
Shoulder to elbow	5.75″ (146.050 mm)
Elbow to wrist	7.375″ (187.325 mm)
Wrist to gripper tip	3.375″ (85.725 mm)
Height (arm parked)	Approx. 7.25″ (184.150 mm)
Height (reaching up)	Approx. 19.00″ (48.260 mm)
Median forward reach	Approx. 10.25″ (260.350 mm)
Gripper opening	1.25″ (31.750 mm)
Alternate gripper opening	1.875″ (47.625 mm)
Payload (arm extended)	Approx. 13 oz. (368.544 g)
Weight	31 oz. (878.835 g)
Range of motion per axis	180°

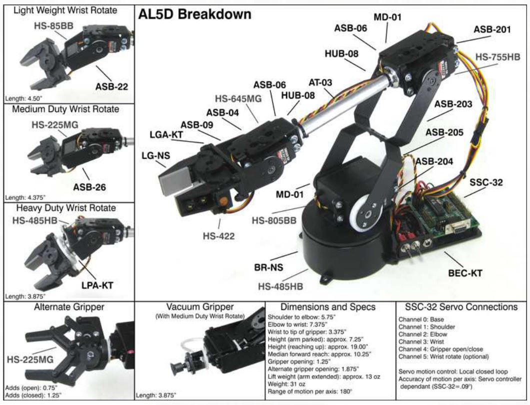


Figure 1.1: AL5D Specifications

These specifications will be used for the calculations to determine the required dimensions of the platform, so relocation of the robotic arm is made possible, while preventing toppling.

Calculating the toppling effects

To simplify this calculation, a simplified model of the robot arm situation was made. Four relevant situations have been identified in which the platform could be toppled – robotic arm system:

A. The robot arm gripper is holding a mass, while the shoulder is fully inclined and the elbow and wrist straightened. Thus, the arm is perpendicular to the floor.
B. The robot arm is on a slope, taking on the same position as the previous situation
C. The robot arm makes a quick swinging motion around the shoulder, generating an impulse and thus, a change in momentum within the system.
D. The platform's motor generates enough torque for the system to topple. This will be calculated for all aforementioned situations.

The detailed method of calculation is displayed in the appendix of this document. Using the data from the AL5D robotic arm specifications and the physics models supplied on the next page, rough estimations can be made on when the platform – robot combination may topple. Calculations may aid in defining the specifications of the mobile platform and prevention of dysfunctionality. These are displayed after the illustrations. The calculations are displayed in the appendix at the end of the document.

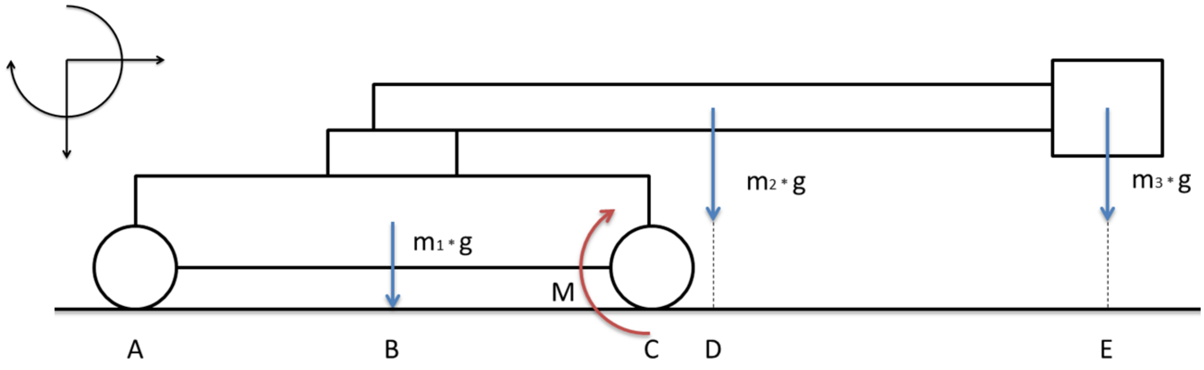


Figure 1.2: Free body diagram: situation A

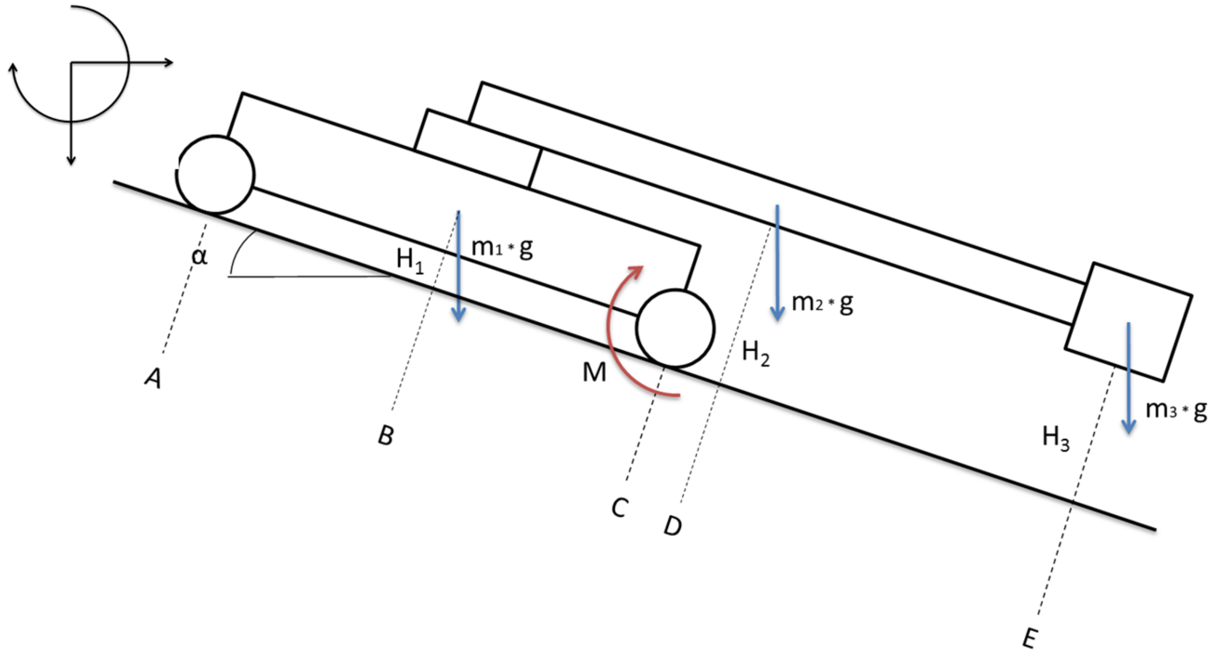


Figure 1.3: Free body diagram: situation B

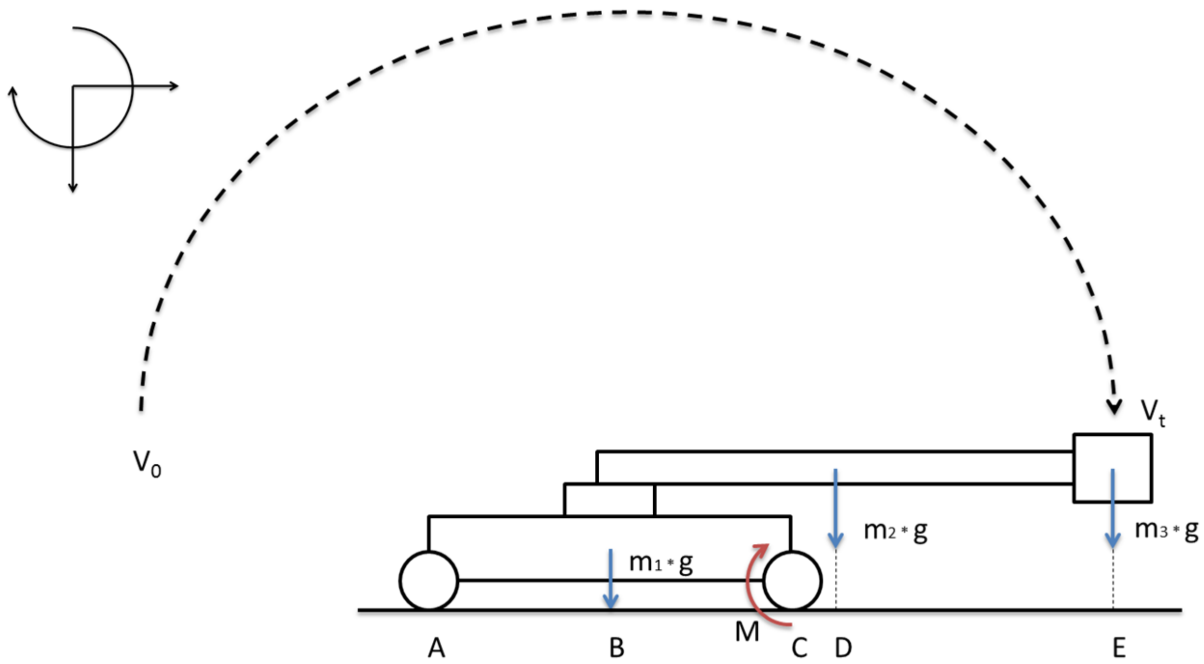


Figure 1.4: Free body diagram: situation C

Conclusion

After this analysis, a spreadsheet was compiled using the different algorithms set up in this section. The spreadsheet uses predefined equations and values to calculate required dimensions. It is important to note that most values in the grey defined boxes are defined for the Lynxmotion AL5D, but these can be used to calculate platform dimensions for any similar robot manipulator. The dimensions resulting from these values will be utilized when detailing the design. Figure 1.5 depicts the diagram which was compiled using this method..

Toppling effects formula spreadsheet

Green fields highlight editable cells, while gray cells are values defined for the Lynxmotion AL5D. The blue cell indicates the final requirement.

Parameter	Variable	Value		
Mass platform	m1	10.000	kg	
Mass robotic arm	m2	0.879	kg	
Mass payload	m3	0.369	kg	
Length robotic arm	Larm	0.419	m	
Gravitation	g	9.810	m/s²	
Motor Torque	M	2.420	Nm	
Slope angle	α	2.000	degrees	
Motor 60 degree time	t_60	0.140	s	
Time to slow down on impulse	Δt	0.023	s	
Angle of travel distance during impulse slowdown	Δs	10.000	degrees	
Force resulting from impulse	F	50.282	N	
Minimum distance platform/tipping point (static)	**Min. BC**	3.012	cm	(Situation A)
Minimum distance, motor torque added	**Min. BC (inc. M)**	**5.205**	cm	(Situation A, with engine)
Maximum height platform (static)	**Max. H1**	122.828	cm	(Situation B)
Maximum height, motor torque added	**Max. H1 (inc. M)**	**121.925**	cm	(Situation B, with engine)
Minimum distance platform/tipping point (static, on impulse)	**Min. BC (inc. Impulse)**	22.105	cm	(Situation A, with impulse)
Minimum distance, motor torque added (on impulse)	**Min. BC (inc. M + Impulse)**	**24.298**	cm	(Situation A, with engine + impulse)
Maximum height platform (static, on impulse)	**Max. H1 (inc. Impulse)**	94.212	cm	(Situation B, with impulse)
Maximum height, motor torque added (on impulse)	**Max. H1 (inc. M + Impulse)**	**93.716**	cm	(Situation B, with engine + impulse)

Figure 1.5: Spreadsheet for preventing topping behaviour.

1.2 Market research: Wheels

In order to gain insight into viable wheel designs, analysis of existing competing products is made. As accuracy is of high priority, the focus is laid upon slippage resistance of wheels. The second priority is the agility of the platform, and thus comparison of wheel types is necessary in order to choose the most efficient components.

For this purpose, the following wheel types have been selected and analyzed:

- Conventional rubber wheels
- Continuous tracks
- Meccanum wheels
- Omniwheels
- Spherical wheels

Figure 1.6: Rubber wheel

The full component details and comparison, along with their pros and cons, are displayed in the appendix of this document.

Figure 1.7: Tracked vehicle

Conclusion

After the analysis, the omniwheels represent one of the more prominent choices. Allowing for movement in two directions, it would decrease the need for workspace in the environment. The omniwheel would be more applicable for the design compared to the mecanum wheel due to their price differences. Also, little research has been found concluding a higher achieved accuracy of mecanum wheels compared to omniwheels. Due to the occurrence of slippage while driven by omniwheels, it would be wise to further investigate options which retain accuracy during these movements. This should be done through testing the theories provided by Rojas and Förster, and analyzing and documenting the results – provided that the decision is made to include this principle in the final design.

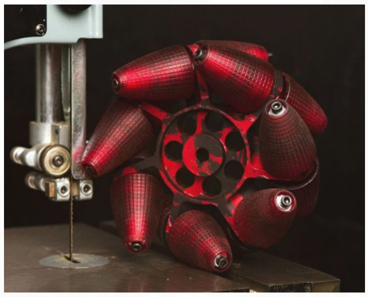


Figure 1.8: Meccanum wheel

Two other configurations are determined to be suitable for the mobile platform: differential wheeled and conventional four wheeled vehicle. In a differential wheel setup, two driven wheels facilitate movement of the vehicle, while spherical wheels or caster wheels provide balance. This setup allows for turning around the vertical axis with a small turning radius. Due to this set up requiring only two motors instead of four, it is also the most cost effective.

Figure 1.9: Omniwheel

The third configuration is the four wheeled robot, providing the most traction of the three configurations. Cheaper than the omniwheel set up due to the cost effectiveness of conventional wheels allow for a cheaper device with more traction than an omniwheel device. Steering would occur by changing the rotational movement of the wheels, also called ‘skid steering’ (four motors required), or changing the angle of one of the pairs of wheels (three motors required). This configuration, although providing the most traction, is costlier than the differential wheeled configuration and reduces mobility compared to both aforementioned configurations. In further analysis and concept development this issue is reflected upon, to prevent limitations to creativity.

Figure 1.10: spherical wheel

1.3 Market research: Robotic manipulators

The platform accommodating the robotic arms, or robotic manipulators could account for a variety of manipulator designs, thereby improving compatibility and usability. In this section, a number of robotic arm types will be discussed and analyzed to provide arguments for future design decisions in this project. This also delivers the benefit of learning the methods in which robot manipulators operate. It is important to note that the current platform will be designed to accommodate the available Lynxmotion AL5D robotic manipulators, but compatibility with other types is desired. According to RobotWorx, six categories of robots are available on the market, which include cartesian, SCARA, cylindrical, delta, polar and vertically articulated types. Each type offers a different joint or axis configuration (RobotWorx, 2013c). This section will cover examples from four robot types, and the data will be used to determine the most suitable dimensions of robotic arms the platform has to account for. The full explanation can be found in the appendix of this document.

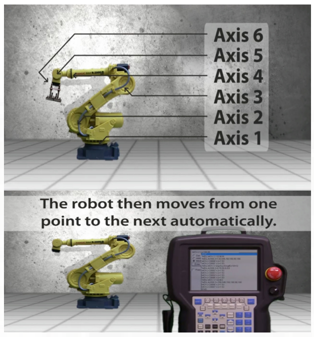


Figure 1.11: Fanuc Arcmate teaching process

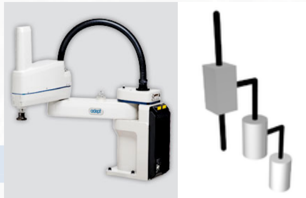


Figure 1.12: Adept S800 Cobra SCARA Robot

Average specifications

To derive dimensions for the platform, a small scale research of robot sizes has been conducted. The footprints, heights and arm lengths of a range of robots were collected from datasheets, and specifications have been acquired and documented. As already mentioned, cylindrical and polar articulated robots are treated as vertically articulated robots, and thus not mentioned. The table on the next page shows the results of this research. It is also important to note that this project focusses on light duty robots. However, it is possible to derive specifications of the platform for heavy duty robots by upscaling the platform's dimensions. The table depicting the researched robot specifications can be found in the appendix.

Figure 1.13: Adept Python Linear Module

Conclusion

After collecting data on a variety of industrial robots, estimations for an 'archetype' can be made. This archetype will represent the range of robotic manipulators which the platform will account for. It is important to note that the mobile platform will be designed solely for usage by the University of Twente, and thus must accommodate mainly for the Lynxmotion AL5D, a vertically articulated robotic manipulator. It is desired that the platform supports a range of robotic arm types, and thus a range of theoretical robotic arm specifications have been derived as follows:

Weight	Footprint	Arm length/ reach	Maximum payload	Maximum shoulder speed
30	200 x 200 mm	800 mm	5 kg	400 °/s

Figure 1.14: Fanuc M-1iA Delta Articulated Robot

The values in the list are meant for larger industrial robotic manipulators, and not for the Lynxmotion AL5D. The theoretical design, which will not be prototyped, would account for these values. The prototype to be built in this project will not reflect on these values as these would make the platform too large, thereby impairing the Lynxmotion AL5D's. Notable is that this issue only arises when the robotic arm is fixed to the platform, whereas relocating a separate robotic arm (situated on a frame) will not be affected by the platform's size.

Figure 1.15: Cylindrical Articulated Robot

1.4 Market research: Wireless communication systems

Requirements specified for the mobile platform, included the need for wireless control. In order to determine the most efficient communication method between user and platform, an analysis of current industrial uses of wireless communication systems has been conducted. Much of the specifications were derived from data sheets on automated guided vehicles (AGVs), due to the large similarity with the mobile platform. Also, current mobile manipulators have been analyzed for further insight regarding this issue.

Several wireless protocols have been selected for analysis, also considering their use in currently available robotic systems. These include:

- Wi-Fi (including Spread Spectrum Communication)
- Bluetooth
- Optical Data Transmission
- Zigbee

During market analysis, the conclusion was drawn that these wireless methods were most frequently applied to robots in both industrial and educational environments. The full analysis, along with detailed description of the wireless methods are displayed in the appendix of the document.

Conclusion

WiFi, due to its superior range and wide availability seems most efficient when the decision is made to produce multiple robots. Bluetooth presents itself as a promising competitor to WiFi, but for the current project, the latter would be more suitable to control the robot, as the project must be able to reflect on industrial usage. Optical data transmission could be chosen to include for situations in which direct line of sight is available and radio interference is present. Lastly, the ZigBee protocol is deemed unsuitable due to its focus on low power consumption, thereby compromising on data stream.

It is predicted that the mobile platform will require a constant data stream, therefore WiFi (with spread spectrum protocol) and ODT are deemed most suitable to be included within the design. The concept phase will give further direction concerning the implementation of these technologies.

Figure 1.16: Bluetooth logo

Figure 1.17: Optical Data Transmission modules

Figure 1.18: Zigbee logo

1.5 Analysis: Battery requirements

One of the requirements specified for the project is for the design platform prototype to operate at least 15 minutes without charging the battery. For this purpose, the energy consumption should be collected from the sensors and actuators present within the mobile platform. Analysis of current batteries in similar products, such as AGVs or mobile manipulators should provide further insight into the choice of battery for the mobile platform. The following manipulator platforms were evaluated based on their power supplies:

- Little Helper - Aalborg University
- Mobile Platform MP-500 - Neobotix
- SPH-2200 - Adept Technologies

The full analysis of these technologies are displayed in the appendix. This part of the analysis served for attaining general knowledge regarding currently applied platforms.

Selecting a suitable battery for prototype integration

After general knowledge was gathered, an analysis regarding the different types of batteries was conducted. The full resulting table is displayed in the appendix. The following battery types were evaluated:

- Nickel Cadmium (NiCd)
- Nickel Metal Hydride (NiMH)
- Lead Acid
- Lithium Ion (Li-ion)
- Lithium Ion Polymer (Li-ion Polymer)

Based on analysis on battery types and batteries used in current products, the most prominent battery is either a NiMH or lead acid battery. Mainly their availability and properties regarding frequent recharge/discharge makes these battery types most suitable for the prototype, as the prototype will most probably perform a short task, then relocate to its charging station.

Most cost efficient battery

To define the most cost efficient battery for prototyping use, further research was conducted on battery pricing. The batteries selected needed to qualify conforming the following requirements derived from the spreadsheet:

- Either NiMH or Lead cell battery
- Solution must provide for at least 12 V of voltage
- Solution must provide for at least 1.2 Ah of capacity
- Solution should not exceed € 30 in cost (assumption)

Based on these requirements, the battery with the highest Ah to price ratio will be considered. A spreadsheet was used to calculate these factors. The results can be found in the appendix.

Conclusion

Analysis concluded that the GP1245 provides the most prominent solution to powering the prototype. Enabling the prototype to operate for a maximum duration of 104 minutes, it exceeds requirements and allows for more flexibility when using the mobile platform. The frequent use of this type of battery confirms this decision, and further analysis into battery types points towards the cost effectiveness of this particular solution.

To accommodate the battery, the prototype’s software should include battery maintenance tasks. The prototype may not be left uncharged or operate too long in order to maximize battery cycle life. After the GP1245 has become unusable, it should be disposed properly and be replaced with a new battery of the same type. However, as the battery can operate up to 5 years in standby service or more than 260 cycles at 100% discharge rate (as an extremity), replacement should not be too much of an issue. The prototype should allow for easy replacement of the battery should the need arise.

Charging the battery will ensue autonomously at a docking station. The docking station will have an off the shelf lead acid battery charger integrated to reduce production costs.

1.6 Market research: Structure of mobile platforms

This section expands on the general structure of mobile platforms. Analysis on this subject generates further understanding on working principles of autonomously operating vehicles and benefits the overall design process of the mobile platform concept.

Figure 1.19: Koala II

Analyzed vehicles will include mobile research robots, as these robots bear most resemblance to the platform concept. Due to the versatility these robots provide, the hardware for the platform design can be derived in order to build an adaptable platform. Research will be conducted by selecting current vehicles and decomposing their structure within the following categories:

- Processing hardware
- Driving principles: wheel configuration, steering
- Principles that prevent collision: sensors, software
- Principles that establish communication canals
- Principles providing power to components

Figure 1.20: Pioneer 3-DX

All of these categories were analyzed for a total of four autonomously operable robots, after which the data will be summarized and result in a checklist for the prototype. The following robots were evaluated:

- Koala II - K-Team Mobile Robotics
- Pioneer 3-DX - Adept Technologies
- MT-400 - Adept Technologies
- Kuka Omnimove - Kuka Roboter GmbH

Figure 1.21: MT-400

Details regarding the analysis can be found in the appendix.

Reflecting onto the prototype

Reflecting the structures of intelligent logistics products on the platform prototype provides a rough image of components required to allow for proper operation. After the analysis, a table was constructed, containing required hardware and respective anticipated technologies – along with their specifications – for inclusion within the platform. The table can be found in the appendix.

Figure 1.22: Kuka Omnimove

The specifications in this table will be used for the main internal architecture of the mobile platform. The exact amount of required stepper motors and sensors will be defined in a later stage of the project, as to prevent limitations during the design process.

Conclusion

This section has expanded onto the internal structure of currently available mobile robot platforms, from which parameters for the mobile platform design were derived. Specifications in this section define the core functionality of the mobile platform – to navigate itself through an environment while preventing collision with obstacles.

Features such as transporting a robotic arm are not specified in this section, as the technical aspects of such features must be defined after a definitive concept has been selected for construction. Questions regarding the method of transportation and other features will be explained later in this report, as defining of such questions will occur in the concept phase. This results in a wide variation of generated concepts while reducing the chance of omitting ideas.

1.7 Analysis of existing similar products

An analysis on existing similar products was performed in order to attain a rough image of successful robotics, both commercial and industrial, for the purpose of a deeper understanding of autonomic robots. Two kinds of dynamically deployable robotic machines are available: mobile manipulators and automated guided vehicles.

Mobile manipulators are platforms with an active robot situated on top. The robot is transported on top of the platform towards its destination, where it takes part in the production line while still fixed on the platform. Automated guided vehicles are platforms themselves, fulfilling the transportation role exclusively. These are commonly used for autonomously lift goods and relocate these to another location within a production line. This section covers three mobile manipulators and three automated guided vehicles.

Figure 1.23: Opiflex MRP Series

Opiflex MRP10/20/40 Series

The OpiFlex series created by the identically named company, involve a mobile manipulator which increases competition by providing machine workforce where needed (Opiflex, 2012b). Allowing both manual and automatic control, the MRP series of mobile manipulators are able to automatically find their docking station for the recharging of power.

The same docking stations are situated at points where the mobile manipulator is to fulfill its task. By locking into these docking stations, the robot arm is able to execute its task in the production line, while preventing pivoting of the platform part caused by impulse from arm movements. The MRP series are supported by two conventional non-powered wheels, along with two driven rotatable wheels on the front side right and rear side left corners. This configuration allows the mobile manipulator to turn in place for increased maneuverability (Opiflex, 2012a).

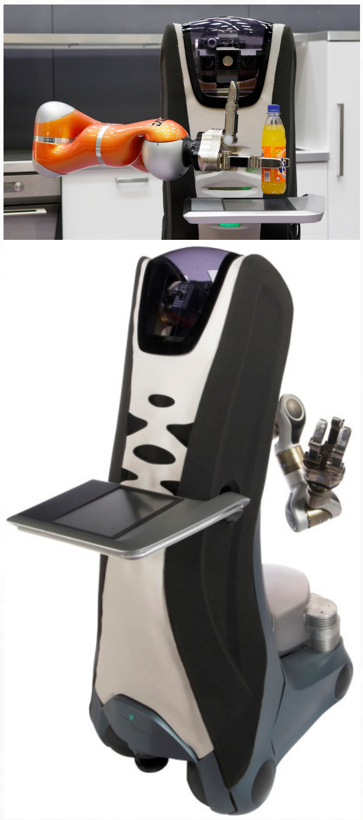


Figure 1.24: Fraunhofer Care-o-bot 3

Care-o-bot 3 - Fraunhofer IPA

Care-o-bot 3 is a robot designed for helping with tasks within households. Essentially a mobile manipulator, its form factor blends in with regular household environments. The device can be used to bring drinks or open and doors for nearby attendants. Care-o-bot consists of two aspects: the supporting platform and the robot manipulator. The manipulator is a Schunk Lightweight Arm 3 with SDH gripper, allowing the 'fingers' to rotate individually, enabling gripping of a wide variety of objects (ROS, 2010).

The platform is equipped with Fraunhofer's proprietary omni-directional driving system, allowing the robot to drive in all desirable directions by rotating its wheels around the vertical axis (Fraunhover, 2012). By combining the positioning determining modules within both arm and platform, the arm can be reliably controlled. This allows the device to move about, while keeping the arm at a fixed point in the air. The same precision can be used to perform the manipulator's gripping tasks. Lastly, the Care-o-bot includes a control panel situated on the 'tray,' allowing guests to input tasks, such as selecting a drink for the robot to serve (ROS, 2010).

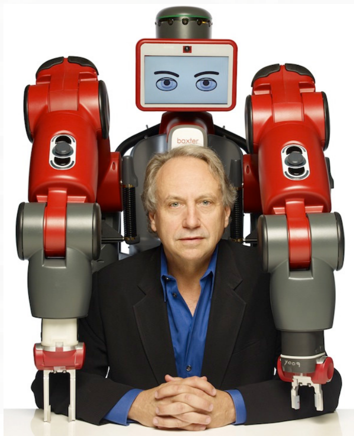


Figure 1.25: Baxter Research Robot

Baxter research robot - Rethink robotics

The Baxter Research Robot is a mobile manipulator platform intended for providing an affordable solution for academic and corporate laboratories. It can be used to automate tasks within laboratories, thereby saving time and fatigue from doing redundant tasks. Baxter is equipped with two manipulator ‘arms’, both with 7 degrees of freedom orientation, allowing more flexibility than in conventional industrial grade robotics.

Baxter is a complete system, shipped in an almost-ready-for-duty configuration, thus only minor set-up procedures are needed to install the robot for its tasks. Simulating a humanoid worker, Baxter is designed to execute mundane and labour heavy tasks while monitoring safety factors. As humans enter the robot’s vicinity, it detects them through the use of sonar sensors, and lowers its speed to safeguard safety (Rethink Robotics, 2013).

Figure 1.26: JBW Smartcart

Smartcart – Jervis B. Webb Company

Smartcart is a battery powered automated guided vehicle, guided by magnetic tape or a sensor bar. It is used in industrial environments to constantly move loads between points within a production line automatically and reliably. The Smartcart series consist of three machines, from lowest to highest load capacity: Models 100, 100HD and 200. The 200 model can handle loads up to 3600 lbs (1632 kg) or tow 4000 lbs (1814 kg) (Jervis B. Webb Company, 2005).

Similar to other AGVs, the Smartcart is capable of automatic recharging and battery level monitoring to ensure availability of power to operate the vehicle. The vehicle is supported by caster wheels and a pair of driven wheels to facilitate movement. Communication canals can be established through spread spectrum communication in order to direct the vehicle or adjust its path algorithms. Smartcart comes with software included for ease of communication and setup of the vehicle.

Figure 1.27: iBot Series and it’s drive system

iBot Series – America in Motion

The iBot series is a line of automated guided vehicles produced by American In Motion. Intended to be flexible and cost effective, the series offers towing, carrying and conveying solutions within the automation spectrum. America In Motion’s iBots are equipped with steer-drive wheel assemblies, similar to those developed by Fraunhofer IPA.

To provide self-navigation and prevent object collision, laser range finders are integrated within the front bumpers. The vehicle is guided by either magnetic tape or an embedded magnetic bar, albeit laser guidance is possible. Directions and instructions are communicated through the 802.11 a/b/g protocol (WiFi) (America In Motion, 2012).

Figure 1.28: Laser Guided Vehicle by EuroImpianti

Skilled 800 Laser Guided Vehicle (LGV) – EuroImpianti

The Skilled product line is a series of automation machines for industrial use. In particular, the Skilled 800 LGV will be discussed, due to its lifting features – the same functions that might be integrated in the final product. By placing reflectors around the workspace, the machine can detect these by sending a fan shaped array of laser beams, and calculate information based on the received lumination from the reflectors (AGV Manufacturers Blog, 2012).

The vehicles are similar to regular fork lift trucks, albeit not manually controlled. Every example in the series is capable of lifting a maximum of 2500 kg (5555 lbs), and drive at a maximum speed of 1.5 m/s.

Conclusion

The analysis holds implications for the platform design in the sense that it brings inspiration of automated vehicle archetypes. Knowledge of existing vehicles brings insight in what aspects are effective and widely used. Usage of common principles in the industry brings compatibility to existing architectures.

For the platform design, this analysis provides archetypes on which a concept can be reflected on. Issues regarding product differences with the prototype can be located and justified by comparing these products with the concept. Exact specifications will be defined later in the research track.

1.8 Analysis: control methods of autonomous vehicles

In order to determine a suitable control method for the mobile platform, market research was conducted regarding the transfer of operator commands for navigation. Based on this analysis, specifications or inspiration may be derived and applied onto the mobile platform. Additionally, aspects of these control methods might serve as the base for an entirely new command concept, adding innovation to the mobile platform. This section will describe the control principles of automated guided vehicles, mobile robots and manipulators. A selection will be made based on the type of navigational control of the products.

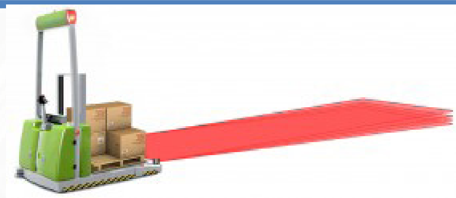


Figure 1.29: Laser target navigation

Figure 1.30: Magnetic tape navigation

A full description and explanation concerning these technologies is present in the appendix of this document.The following navigation options were retrieved from data sources:

- Wired navigation: Robot follows a radiowave-emitting wire, embedded into the workspace flooring.
- Inertial navigation: Robot utilizes gyroscope to detect it's speed and change of direction.
- Laser target navigation: Robot utilizes a laser scanner to determine angle and distance towards reflectors placed in the workspace environment.
- Natural features navigation: Robot utilizes several sensors to dynamically plan the shortest route to it's destination.
- Magnetic tape/bar guided navigation: Robot follows magnetic tape or bar trail to reach it's destination.
- Vision guided navigation: Robot utilizes cameras or other optics to determine it's position in it's environment.

Reflecting upon the prototype

Based on the analysis of the various navigation types and design discussions, it is most likely that the prototype will include a combination of vision guidance and internal calculations based on motor and infrared/sonar sensor information. Discussions involved a camera network or sensor network placed on the flooring to monitor vehicle path-following progress. Placing a camera on the vehicle would also allow the determination of its location by use of QR codes.

Conclusion

The analysis shown in this paragraph expands upon automated guided vehicles regarding their control mechanisms and navigational principles. The prototype will feature a vision based guidance system, in addition to internal processing algorithms, determining the vehicle's position according to motor values. Further investigation in the concept generation phase will determine the exact manifestation and implementation of these principles.

1.9 Specifications and requirements

To create a solid base for the creation of a concept, specifications and requirements are defined for the mobile platform. These specifications are based on results of the analysis phase. Requirements were based on discussions and documents provided by project coordinator M. Essers and results from the analysis phase.

The list will serve as a reference point for concepts, effectively reflecting upon the entire analysis phase. The left column shows the specification in 'regular' wording, while the right column assigns parameters to specifications. Further chapters will expand upon the creation of viable concepts based on these specifications.

The platform...	Parameters
Carries a robotic arm (+ frame): 1. Controls robotic arm 2. Transport a frame with robotic arm situated on top	At least a weight of 20 kg without failure* 1. Through wireless interface 2. Frame weighs no more than 15 kg
Prevents from toppling over	With total carriage; no toppling
Maneuvers in an industrial environment	750 mm x 750 mm area for turning*
Relocates robotic arm (+ frame)	Maximum speed: 1 m/s; speed met in 5 seconds*
Prevents collision into environment	Steers away from objects distanced at 200 mm* • Sonar guided
Detects objects to pick up	Detects objects distanced at 500 mm* • Vision guided
Receives commands wirelessly from computational unit	Wi-Fi 802.11 a/b/g protocol; min. 15 meters distance
Positions itself on hard surfaces	10 mm tolerance regarding end destination
Positions itself on soft surfaces	15 mm tolerance regarding end destination
Transitions between soft and hard surfaces	Max. 5 mm loss of accuracy (conforming the two requirements above)
Operates on an internal power source	Min. 15 min. battery life, more is a plus
Autonomously finds a charging point	20 mm tolerance on docking station*
Avoids objects in motion	Detects objects and avoids within 200 mm*
Should be cost-efficient	Component costs should not exceed € 100
Should be fast to manufacture	Components manufactured and assembled within 7 days*
Should be produced with conventional manufacturing methods	• 3d printing* • Laser cutting* • CNC milling* • Other available techniques*

* Assumed parameters, deemed suitable for the robot system based on earlier given requirements.

Chapter 2: Concept Phase

The analysis phase resulted in the acquirement of basic knowledge needed to develop a proper robot. The goal in the second phase is to implement this information into the creation of a mobile platform concept. The following aspects are reflected upon in this chapter:

- Generation of ideas and inspiration
- Gathering of ideas into a morphologic diagram
- Generation of three concepts from the diagram
- Visualization and specification of the three concepts
- Forming and defining a final concept

The result is a working concept model, which will be further explored in the detailing phase of the project. The detailing of the concept involves preparation of the platform for manufacture and testing.

2.1 Idea and inspiration generation

This chapter describes the steps taken before a workable concept was created. In order to create a viable concept, different technologies and information gathered in the analysis phase were to be created. Also, inspiration regarding form factor and functionality will be gathered as various manifestations of robotic relocation systems are overviewed. A design sketching process further complements the inspiration aspect. The various technologies and potential implementations are collected in a morphologic diagram, where three concepts are created through selection of random aspects or groups of aspects which show synergy between them. In this chapter, the design sketching process and inventory of ideas are expanded upon.

Design sketch process

The design sketch process is similar to a conventional brainstorming procedure. By looking at the aspects resulting from general notes and analysis phase conclusions, any ideas adding to the concept are visualized and sketched on paper. The ideas are processed and valid concept aspects are selected for integration within a concept. A design sketch process is divided into subcategories, implying that a function from the design brief is noted on a sheet of paper, and ideas flowing from the function are sketched. An example for an aspect – in this case form factor – can be seen in the image below.

After repeating the procedure for every function in the list, a morphologic diagram is created. This diagram serves as the basis for the generation of three viable concepts. A process of selection and combination should result in a final design, ready for detailing and preparing for manufacture. Further chapters will expand upon this process.

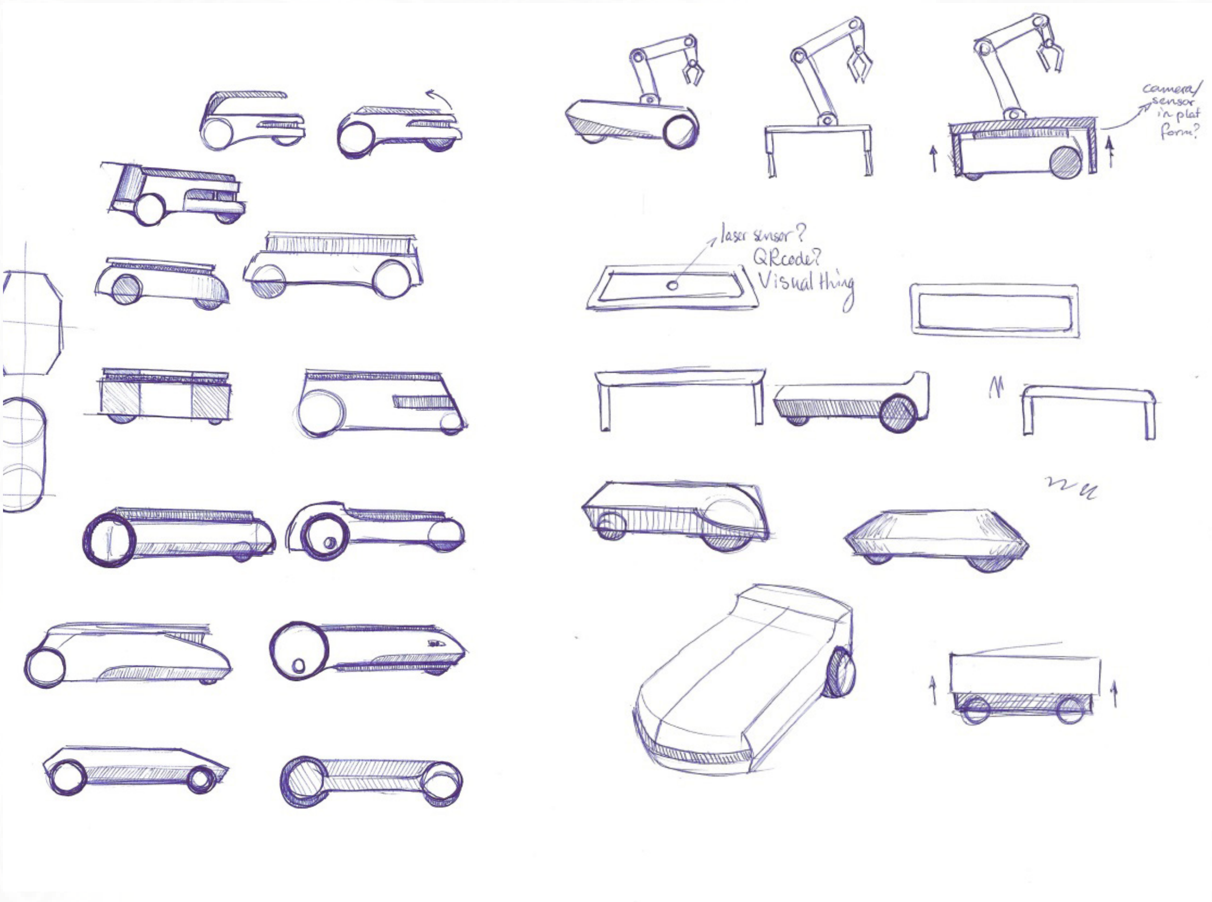


Figure 2.1: Rough sketches from the idea generation phase

2.2 Morphologic diagram

A morphologic diagram was created for the purpose of generating concepts from a wide range of product functionalities. The diagram provides a schematic overview of the different methods to performing the relocation of a robotic arm. Primary functions and product traits were retrieved from both the design brief and functional decomposition, and displayed on the left hand side of the diagram. Solutions fulfilling these functions are aligned on the right hand side of these functions.

A process of rethinking and elimination of various potential functions followed – with respect to the design brief. Three lines were drawn from top to bottom, each representing a standalone concept to be developed. This process resulted in the generation of four different concepts suitable to relocate a robotic arm. These concepts are to be evaluated and iterated upon for the creation of the final concept. The images below display the morphologic diagram, with the generated concept routes displayed on the next page.

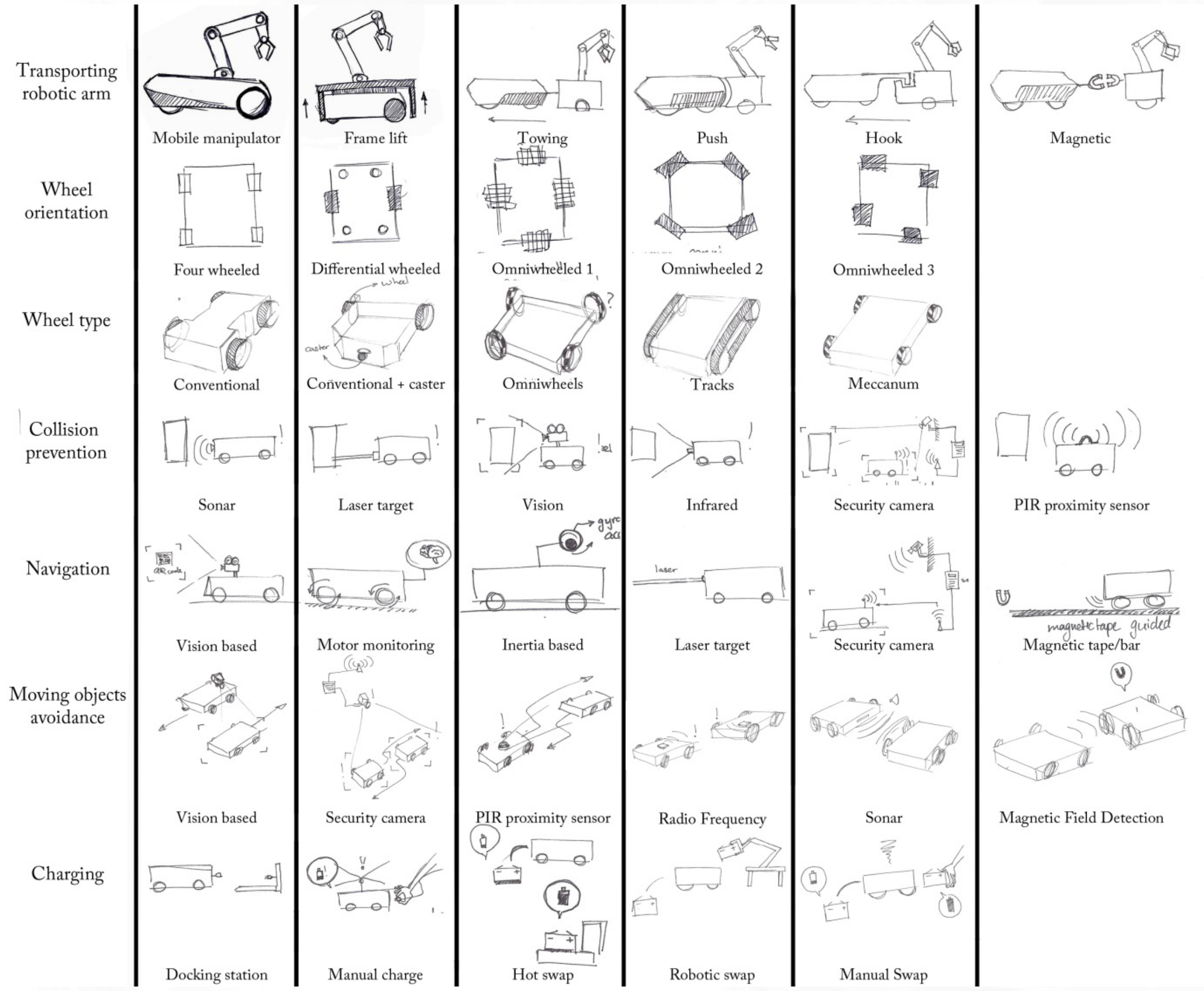


Figure 2.2: Morphologic diagram

Task	Concept 1	Concept 2	Concept 3
Transporting robotic arm	Mobile manipulator	Frame lift	Frame lift
Wheel orientation	Omniwheeled 1	Differential wheeled	Four wheeled
Wheel type	Omniwheels	Conventional + caster	Conventional
Collision prevention	Infrared	Sonar	Security camera
Navigation	Motor monitoring	Vision based	Security camera
Moving objects avoidance	PIR proximity sensor	Sonar	Security camera
Charging battery	Manual charge	Docking station	Hot swap

The first concept will manifest itself as a mobile manipulator, with a robot permanently situated on top. Omniwheels provide omnidirectional movement, while infrared sensors and tracking of motors provide environmental information. The passive infrared proximity sensor (PIR) provides information of nearby moving objects. Finally, the platform is charged manually by inserting a charging cable by an operator.

The second concept lifts a frame on which a robotic arm is situated. A differential wheeled setup provides increased mobility, albeit being less mobile than the omniwheeled design. Navigational features will be provided by means of sonar and optics to detect nearby objects. A docking station will be designed along with the concept for charging purposes.

Third, the last concept is a frame lifter, similar to the second concept. Two frame lifter concepts were selected due to the less accurate nature of dragging a robotic arm towards its destination. This concept incorporates security cameras in the environment to pinpoint the platform's location and objects around the platform. As the platform incorporates hot swapping batteries, the concept should be able to change batteries 'on the fly' and thus provide indefinite durations of operation.

The generation and rendering of the three concepts will occur according to the table above. The result is a collection of four differentiated concepts suitable to fulfill the relocation of the robotic arm. In the next phase, either one of the concepts is chosen for further development, or concept traits will be incorporated into a final concept.

2.3 Generating three concepts

Based on the table in the previous chapter, three concepts were generated through a further development process. Designs were sketched and reiterated upon, after which three concepts were established for further integration into a final workable concept. The images below and on the next page show the three concepts generated in the creative process.

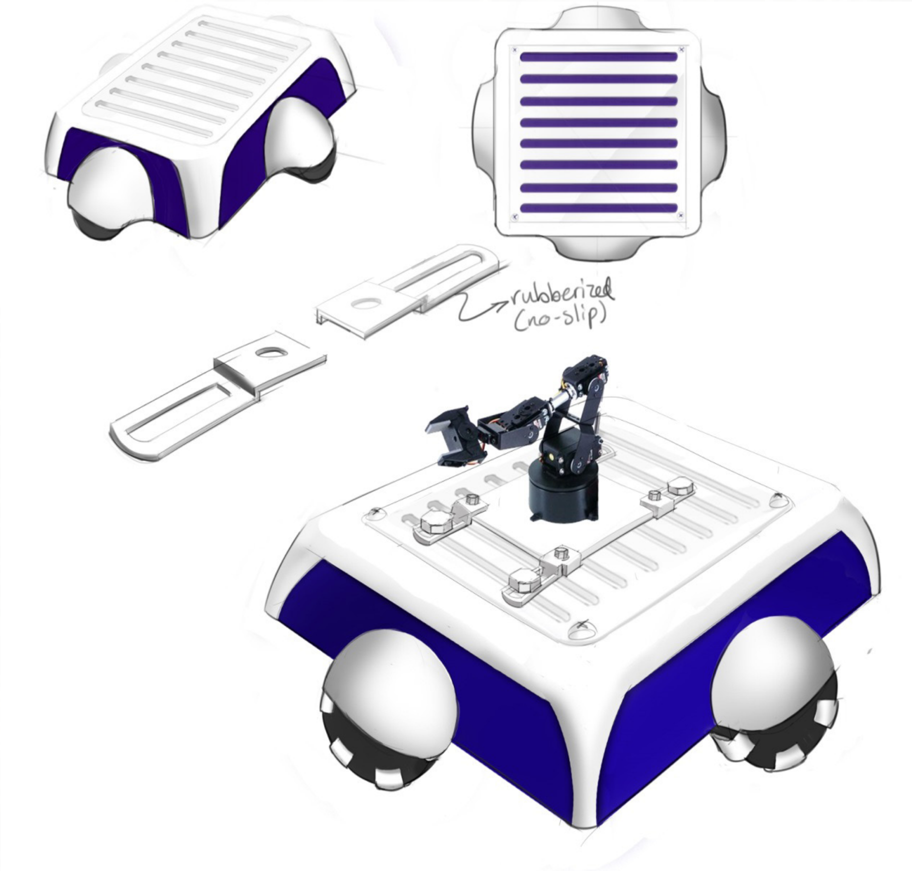


Figure 2.3: Concept 1

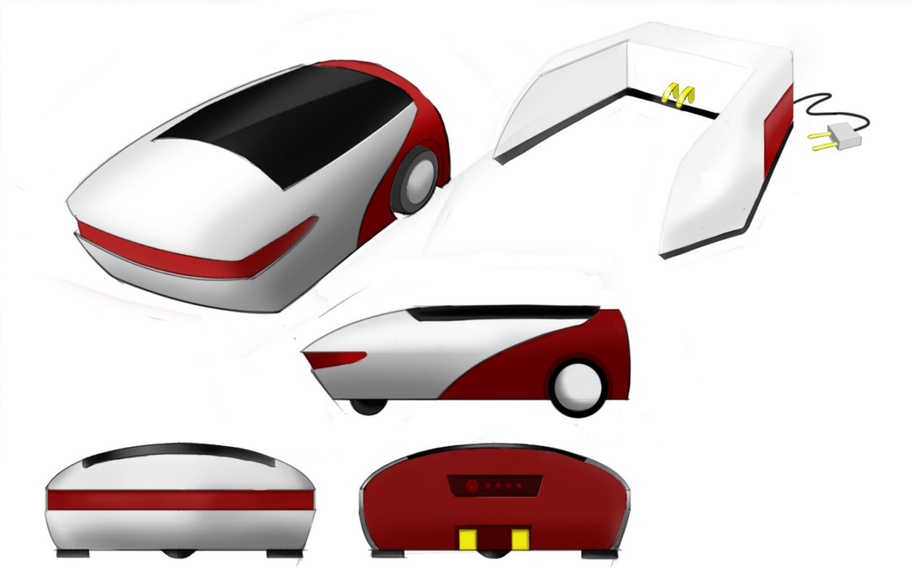


Figure 2.4: Concept 2

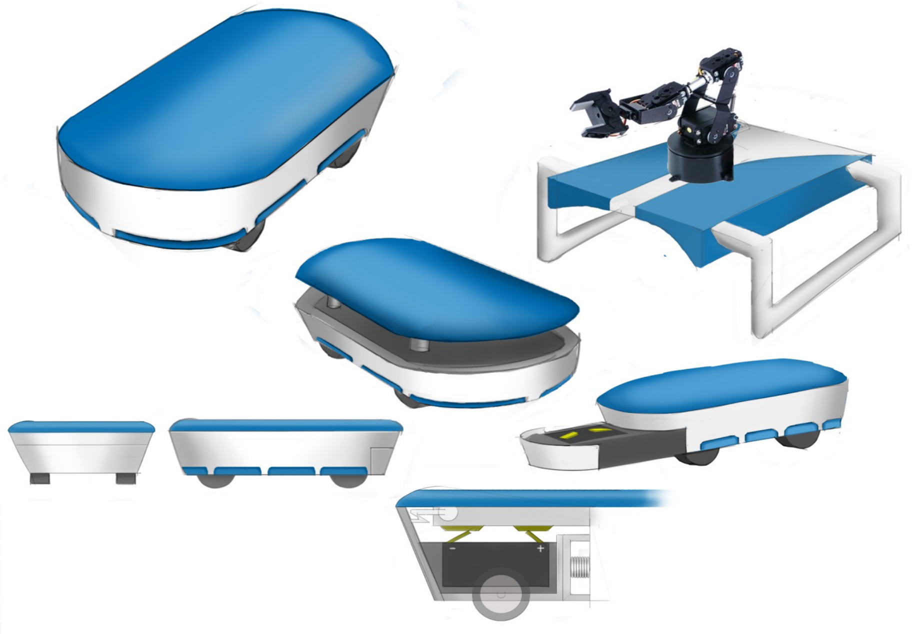


Figure 1.31: Concept 3

The three concepts were compared using a grade system, grading every concept based on its efficiency in fulfilling the intended tasks. The scale on which the concepts were judged varied from "--" to ""++", symbolizing 'not effective' to 'very effective' respectively. This process resulted into the table depicted below:

Aspect	Concept 1	Concept 2	Concept 3
Manufacture	-	++	+-
Cost	-	+	+-
Relocation efficiency	++	++	++
User Friendliness	+	++	++
Maneuverability	++	+	+-
Collission prevention	+	++	+-

Based on the table, concept 2 shows the greatest potential when compared to the other two concepts. However, when creating the final concept, value is provided by combining convenient or more effective aspects of the three concepts into one 'hybrid' system. This system should suit the working environment of a production facility, while executing its tasks efficiently. The final concept is described in the next section of this document.

2.4 The final concept

After the generation of three workable concepts, a hybrid concept was to be created, suiting the design requirements and able to execute its assigned tasks accordingly. The concepts were placed into another iterative creative process, and a final concept was created. By overviewing the earlier acquired knowledge, the concept could be viewed from a 'fresher' perspective, thus not inhibiting new inspiration and creativity. A render of the resulting concept is displayed on the next page (fig. 2.6).

Figure 2.1: Final concept render

Defining the final concept

The final concept is a ‘lifting’ platform system, able to lift a robotic arm by displacing a hatch situated on the top side of the platform. This mechanism was chosen due to its flexibility, as it implied that the platform needs not be situated in the vicinity of the robotic arm. Therefore, the batteries could be recharged or the platform could be assigned a task to relocate a second robotic arm on a frame.

The platform is equipped with a differential wheeled drive system, allowing for the platform to turn around an axis, coincident with the midpoint between the driving wheels. This type of drive will not surpass the mobility which omnidirectional wheels would provide; however, it provides decent mobility at a lower cost and power consumption – as only two motors are needed instead of four.

For the navigation and sensor system, the platform utilizes a sonar system, which detects objects in the vicinity using ultrasonic sensors. Navigation is done by the microprocessor, which monitors the revolutions, and thus the distance covered by the platform’s motors. This implementation should provide adequate navigation efficiency, while maintaining a low cost of the platform.

The charging system involves two contact points on the rear of the platform. These connect to two contact points on the docking station, which pivot into the docking station as the platform is pressed against the module. This ensures that enough contact is made between the contact points, thus charging the platform’s battery accordingly.

Conclusion

In this chapter, ideas and inspiration generated in the previous sections resulted in the creation of a workable concept. This concept will be further developed in upcoming chapters, in which the platform will be optimized for production and implementation. The dimensions, along with the components required to realize the various features assigned to the platform will be specified. The aim of this additional development process is to create a detailed concept and streamline the realization of said concept.

Chapter 3: Detailing Phase

At this stage, rough product specifications are defined in the form of a final concept. Sequential steps involve the definition of product dimensions and structure. In other words, the product is prepared for manufacture at the University of Twente's workshop. The following aspects are defined in this chapter.

- Definition of the system architecture by creating subsystems to accomodate each function
- Definition of the materials and components which make up the subsystems
- Definition of the electronic components which will sense and actuate for the platform
- Definition of the exact dimensions of the platform and its components
- Programming of the microcontroller to control the platform
- Manufacture of the platform
- Evaluation of the platform

The final result is a working prototype for testing purposes, along with a production plan for reproducing multiple platforms.

3.1 System architecture

This section expands on the development of functions into hardware to realize said functions. Dividing the total system into smaller subsystems helps organizing the construction of the prototype. Following the functional decomposition, the following set of systems was created:

- Relocation system
- Navigation system
- Lifting mechanism
- Power supply
- Sensor system
- Casing

The relocation system provides the components to drive the mobile platform. Therefore, when related towards the final concept, this would include the wheels and stepper motors transporting the robotic arm situated on the frame.

The navigation system represents the components which process environmental information into parameters for the relocation system. In other words, the system coordinates the movements which the relocation system executes. This system manifests itself within the microprocessor's software, as it exclusively processes and relays information towards the stepper motor drivers.

To lift the combination of frame and robotic arm, the mobile platform will include a lifting mechanism. This mechanism provides components to drive the upward lift of the upper hatch. As the upper hatch is lifted, the frame and robotic arm combination are lifted as such, thus allowing transportation of the frame.

The fourth system describes the power supply system, which provides electrical power to drive the different components. The system should provide enough power for at least 15 minutes of continuous operation without recharging.

The sensor system provides information concerning the mobile platform's environment. This information is collected by the sensors within the system and relayed towards the microcontroller for determining the platform's current position and nearby obstacles.

The casing of the system houses the mentioned systems and their components into one fully operational device. While ensuring the stability of the subsystems, the housing also protects these from external sources of damage and provides the aesthetics of the device.

Defining system interactions: N^2 diagram

The following page displays the N^2 diagram applicable to the robotic system (fig. 2.7). An N^2 diagram serves the purpose of providing an overview of the array of systems, and defining the interactions between these systems. When designing the different systems, the N^2 diagram is used as a checklist or 'heads-up' of the interactions which the systems must provide for. The six systems are placed in a diagonal line through the diagram, with interactions placed within their respective cells, adjacent to the systems. A system receives information through either the top or bottom side in the diagram, while outputting information on either the left or right side.

Relocation system	Motor information				
Steering directions	**Navigation system**	Cue to lift hatch			
	Servo status	**Lifting mechanism**			
Electrical power	Electrical power	Electrical power	**Power supply**	Electrical power	
	Nearby obstacles, position towards frame/ docking station			**Sensor system**	
					Casing

Figure 2.2: N^2 Diagram

As displayed in the diagram, the navigation system receives input from all other systems and uses the information to direct the platform's movements and activate the lifting mechanism. Therefore, the navigation system will serve as the core information processor in the device, while other systems activate actuators and provide feedback concerning component status. The N^2 diagram helps bringing structure in further developments of the system's architecture and its interactions between components.

Realizing systems: system architecture

Following the N^2 diagram, the components for the mobile platform can be placed in the array of subsystems. This method creates a rough image of the mobile platform's infrastructure, thus showing the connections within the system. The total array of subsystems is depicted on the next page. The lines represent bundles of wires, connecting sensors, actuators and power supplies to the microcontroller. The combination of the systems leads to a fully functional device, able to transport a robotic arm while conforming to the specifications presented in the design brief.

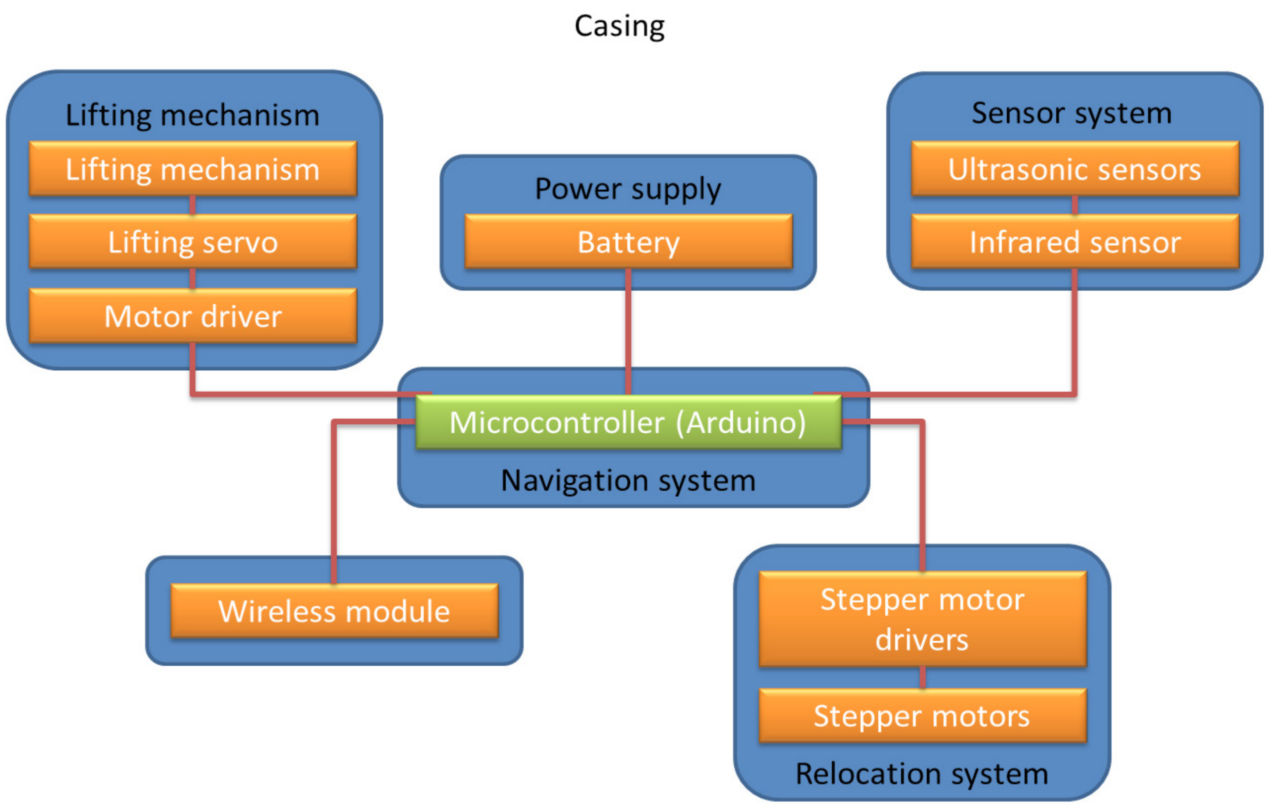


Figure 3.1: Array of subsystems and their connections

While developing and building the prototype, the architecture diagram will serve as an overview of the necessary connections between components. Also, this allows for structured realization of the prototype, in other words – building systems one by one. When one system is confirmed to be operational, both in hardware and software, the next system will be built. It should be noted that when systems are made operational, it requires the microcontroller's software to accommodate the system. The sequence in which the systems will be built is determined to be as follows:

1. Construction of the power supply

As all systems require electrical power to fulfill their assigned tasks, the power supply must first be installed in order to provide for this power requirement.

2. Construction of the relocation system

As movement of the platform is of the highest priority, the wheels and respective motors need to be installed. The system should be able to receive movement parameters and translate these into motor actuation.

3. Construction of the lifting mechanism

The second highest priority is enabling upward lift of the platform's hatch. The hatch utilizes a servo operating in an open loop fashion, thus requiring a servo capable of higher torque, as failure of the system will not be detected by the servo.

4. Construction of the sensor system

The sensor system provides environmental information used for pseudo-decision making. As the motors and lifting mechanism are activated when the parameters measured meet the requirements, this system will be installed after the relocation system and lifting mechanism.

5. Construction of the wireless module

When all subsystems are fully operational and controllable through the microcontroller's serial port, the wireless module will be installed. Inputs will then flow through the wireless module instead of the serial port, thus allowing for commands and inputs through wireless signals.

6. Finishing the coding and evaluation

When all systems are connected to the device, the software must be evaluated for operation efficiency. Only when the mobile platform meets the requirements of the design brief, the mobile platform will be finished by securing the casing onto the device.

7. Installing the casing

When the mobile platform's infrastructure is deemed fully operational and meets the design brief requirements, the casing will be installed. This casing provides for the platform's aesthetics and closes off the components from the environment.

3.2 Materials and components

Before the prototype is built, a bill of materials was required to inventorize the various materials and components to be integrated. Based on the system's architecture described in a previous chapter, the components and materials will be listed in an array for a quick overview.

Bill of materials

The table below displays the systems and their components which are to be produced in the workshop situated at the Horst building at the University of Twente. Components and materials are categorized under their respective systems. Components which are to be ordered at an external supplier are highlighted in italic font.

System	Required components	Required materials
Power supply	1x Lead acid battery Conrad Energy (12V, 3.2 Ah)	-
	1x Strip board	-
	Wires	-
Relocation system	2x Stepper motors (ROB-09238)	-
	2x Motor drivers	-
	2x Gearbox positioning bracket*	3D printer filament
	1x Caster wheel	-
	-	1x Steel rod (500 mm x 5 mm)**
Lifting mechanism	4x Compression springs	-
	1x Worm gear	-
	1x DC Motor (microHP100)	-
	1x Rack	3D printer filament
	-	1x Steel rod (500 mm x 10 mm)**
Sensor system	4x Ultrasonic sensors	-
Wireless module	1x Electric Imp	-
	1x Electric Imp Shield	-
Navigation system	1x Arduino Mega	-
Casing	Screws	-
	Bolts and nuts	-
	-	Wooden plank (500 mm x 400 mm x 4 mm)
	-	2x Metal plates (500 mm x 120 mm x 2 mm)

3.3 Preparing the prototype: Electronic components

Before the components are placed in the housing, the components must be connected to the microcontroller. The system is then tested and prepared for placement within the housing. This chapter expands upon the wiring of the components to the Arduino Mega. The coding will be covered second, which provides the interpretation and decision making based on the received signals of the sensors.

Navigation system: Microcontroller Arduino Mega 2560

The prototype will use an Arduino Mega to operate the sensors and actuators within the prototype. This microcontroller was chosen over the other Arduino types due to the larger array of analog pins and pins capable of Pulse Width Modeling (PWM). Also, the Arduino programming language is based on Java, thus providing a simple and understandable language. Because the Arduino is open source, a wide variety of tutorials and instructions created by hobbyists is available on the internet, resulting in a decrease in development time.

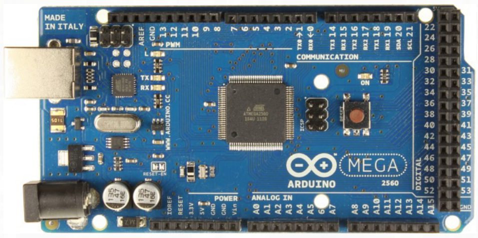


Figure 3.2: Arduino Mega 2560

The Arduino fulfills the role of coordinating the various components to navigate the platform through its surroundings. By means of interpreting incoming signals from sensors and its wireless connection, the Arduino microcontroller can steer the motors towards its intended destination while avoiding collisions autonomously.

Sensor system: Ultrasonic sensors hc-sr04

Four ultrasonic sensors are to be encorporated within the prototype, for interpretation purposes of the platform's surroundings. Ultrasonic sensors send out a sound wave, imperceptible to the human ear. The wave echoes upon reaching an obstacle, after which the echo is received by the sensor. The timing between the sent signal and the received signal is used by the microcontroller to determine its position in relation to the obstacle. For the prototype, four HC-SR04 sensors are incorporated.

Figure 3.3: HC-SR04

The HC-SR04 operates by the use of four pins: Vcc, Trig, Echo and Gnd. The 'Trig' – short for 'Trigger' – activates the 'ping' sensor upon receiving an electronic signal, resulting in the sending of a sound pulse. The Echo pin relays the signal towards the microcontroller, enabling the microcontroller to interpret the time difference between the ping and the echo. The Vcc and Gnd pins provide power for the transmission of the signals. The sensor needs 5 volts connected to the Vcc pin to operate. For better results, the 5V is supplied by the Arduino, as supplying this voltage from the battery seemed to create incor

Prototype implications

The Arduino will be connected to four ultrasonic sensors. Eight digital I/O pins will be used on the Arduino to operate the ultrasonic sensors. The Vcc and Gnd pins on each of the sensors will be accommodated by a self-manufactured circuit, connecting respective ultrasonic sensors' pins to the 5V and Gnd pins on the Arduino. Thus, the ultrasonic sensors are connected according to the following table:

Sensor	Trigger pin	Sensor pin
S1	22	23
S2	24	25
S3	26	27
S4	28	29

These pins will be used within the Arduino code (also referred to as 'sketch') to access the sensors. This table provides references when replicating the prototype.

Relocation system: Stepper motors SM-42BYG11-25 and EasyDrivers

As mentioned in previous chapters, the robotic platform will be driven by two stepper motors. Opposed to other motors, this type of motor provides more accuracy, which connects to the design requirements. Two stepper motors (type SM-42BYG011-25) were purchased. Stepper motors, unlike DC motors, exhibit discrete rotations and require a specific pulsed waveform to the motor's magnets in order to drive (Grant, 2005). Motor drivers are able to convert the Arduino's output signals to drive the stepper motors. For this purpose, two 'EasyDrivers' are connected between motor and Arduino, for easy connection and operation between the Arduino and the stepper motors.

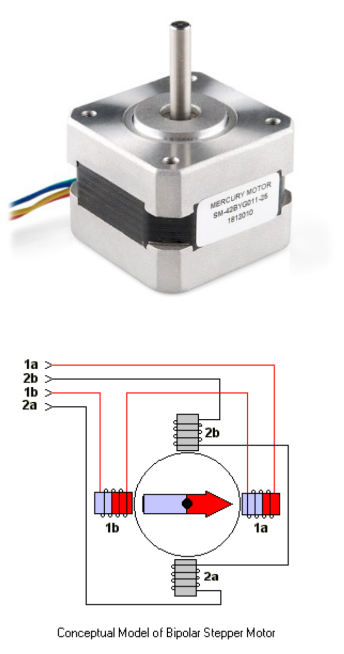


Figure 3.4: SM-42BYG11-25 and bipolar stepper diagram

The type of motor used in the prototype is specified as a bipolar motor, which signifies each phase of the motor driven by two opposing coils. The SM-42BYG011-25 is a four wire bipolar stepper motor with two phases, as displayed in the image on the right. For proper driving of the stepper motor using the Arduino stock library codes, the paired wires must be determined. As seen in the diagram, a four wire stepper will have two closed circuits. These circuits can be detected by using a multimeter, as not connected wire pairs will exhibit an infinite resistance. A more trivial solution would be to connect a pair of wires to two ends of an LED – twisting the motor shaft will light up the LED if the circuit is closed (National Instruments, 2001).

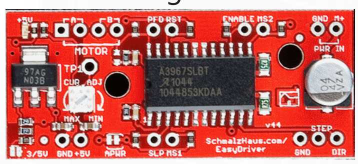


Figure 3.5: EasyDriver chip

After the paired wires have been determined, the stepper motor pairs have to be wired to the H bridge. The SN754410 can be used to drive two DC motors, or one stepper motor. Each pair of wires are to be connected to their respective pairs on the motor driver, represented as motor 1 and motor 2 on the image on the right.

The four PWM pins are to be connected to the Arduino's digital pins, as the PWM is only required for regulating DC motor speeds. Stepper motor speeds are controlled by the pacing of the waveforms sent by the Arduino. Two stepper motors are to be implemented – and thus two drivers are needed – resulting in the drivers to be connected to the Arduino according to the following table:

Driver 1 (left motor)	Arduino pin	Driver 2 (right motor)	Arduino pin
M1 Forward	4	M1 Forward	10
M1 Reverse	5	M1 Reverse	11
M2 Forward	6	M2 Forward	12
M2 Reverse	7	M2 Reverse	13

These pins will resurface in the Arduino's programming. In case of wrong wiring, the motors would either not drive, or drive in the wrong direction upon sending the respective signals.

Lifting mechanism: HP100 Gear Motor

As previously mentioned, the upward lift of the prototype's hatch involves a worm gear driving a rack and pinion system (see next page). Four compression springs were implemented to support the upward movement of the hatch and lower stress on the motor driving the worm gear. Inherently, the worm gear system holds the rack in place, even when pressure is placed on the hatch e.g. by means of the frame resting on top.

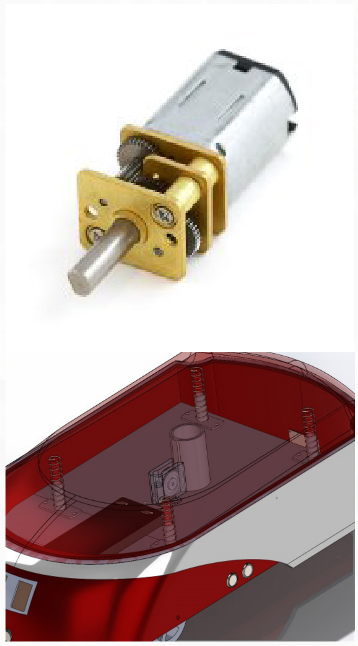


Figure 3.6: HP100 gear motor and it's location within the system

To drive the worm gear, a more powerful DC motor was selected, as the torque required to lift the hatch in such a fashion exceeds the torque available on conventional DC motors. A servo could provide the torque required, but as the worm gear system compromises the amount of rotations for torque, the servo would need to allow for continuous rotations – resulting in more expensive motors. The motor chosen for driving the worm gear system was the micro HP100 gearmotor (see right). The HP100 compromises on speed for torque due to the integrated gear box on the motor, while remaining low cost.

Figure 3.7: L298N Motor Driver

To drive this motor properly, another motor driver was added – the L298N dual H-bridge motor module (see right) . This component was readily available at the University’s electronics store, and allows for the Arduino to control the HP100 motor, as it has to provide for a maximum working current of 1.6 A. The L298N module can handle currents up to 4A and thus provides an adequate driving solution for the HP100.

Driver port	Arduino pin
IN1	30
IN2	31

The Vcc and Gnd ports represent the pins for powering the motors, and thus are to be connected to a self-manufactured circuit connected to the battery, to provide the correct voltage of 6V from the battery. This circuit involves using an lm317t voltage regulator with a pair of resistors to drop down the battery’s output voltage to 6V from 12V. Supplying this power from the Arduino could potentially damage the board due to resulting large currents flowing through.

Wireless Module: electric imp and imp shield

For the wireless connection, the Electric Imp module was chosen to be added to the prototype. Main benefits included a lower cost compared to the official Arduino WiFi modules and the ability to control the Arduino over the internet with greater ease of setup. The Electric Imp is a WiFi module in the form of an SD card, enabling establishment of an internet connection by the prototype (see right). The design of the Electric Imp allows for control of the device from any location, as no direct WiFi connection is needed between PC and Arduino.

Figure 3.8: Electric Imp and it’s shield

The Electric Imp is inserted to an Impee breakout board, designed to house the Imp and provide connection points to connect with the Arduino (see right). The Electric Imp will be set up in such fashion that received signals over its wireless connection are relayed towards the Arduino. To connect the imp to the Arduino Mega however, the ‘Serial1’ connection must be used (pins Rx1 and Tx1), as using the original Serial causes interference with the USB serial port. Pins 8 and 9 on the imp shield provide the UART connection and are to be connected according to the table below.

Imp shield	Arduino pin
8	Rx1 (19)
9	Tx1 (18)

After connecting both devices' respective ports, the Arduino can be programmed to transmit and receive signals through its UART pins. The Electric Imp is then programmed to transmit and receive signals in the same fashion, although through WiFi. Lastly it must be noted that while the Arduino uses 5V over its serial pins (Rx and Tx), the Imp shield is not 5V tolerant. This implies that a logic level converter must be connected to convert the 5V signals to 3.3V, indicated in the image as 'Level Shift'.

Power supply: Conrad energy sealed lead acid battery (CP1232)

To power the entire system, a lead acid battery is present within the prototype. With a capacity of 3.2 Ah, it should be able to power the system for a maximum of 70 minutes on full operation before requiring recharge. The battery will be wired to a stripboard circuit, which contains a selection of voltage regulators, resistors and capacitors in order to safely accommodate the external power requirements of various components.

Figure 3.9: CP1232 Lead Acid Battery

Conclusion

When adding all the wiring circuits into the system, the Arduino should be able to control all components accordingly. The assembly can then be placed and secured within the housing, so the platform can execute its program to relocate the frame through its environment. A graphical overview is placed on the next page, providing more insight when wiring the components together.

3.4 Detailing the concept: Dimensioning and new components

Before manufacturing the prototype, the dimensions of the various components need to be established. As the hardware components cannot be loosely implemented within the platform, mounting methods need to be devised and produced to fix the components in place. This chapter expands upon the various design decisions taken when converting the prototype concept to a producible platform.

Determining global dimensions

The platform's dimensions determine the available space for components and its capability to prevent toppling when carrying the frame with robotic arm. Also, dimensions of the docking station and frame must be specified in such a way that these match the platform's while providing room for errors in positioning. Dimensions should take into account the potential toppling situations when relocating the robot, expanded upon earlier in this document. The implicit requirements are as follows (retrieved from the toppling effects spreadsheet):

- The platform should allow for at least 117 mm in between the arm and nearest wheel.
- The placement of the robotic arm should be 553 mm at most.

The platform's dimensions and frame are specified as follows:

Platform maximum global dimension	Dimension in mm
Length	425
Width	302.1
Height	143.7
Frame maximum global dimension	**Dimension in mm**
Length	400
Width	400
Height	163

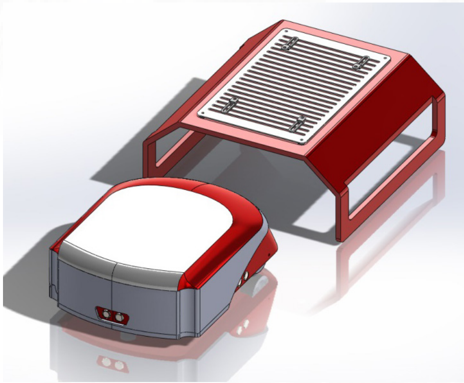


Figure 3.10: Platform and frame

All dimensions suffice to the design requirements, and therefore will likely not cause conflicts when the prototype is ready to be tested. The image below displays the platform along with its respective frame.

Adding new components for fastening

In order to enable the platform to keep its components in place, additional components were implemented to support the components in their operation. These components mainly consist of 3D printed brackets to mount to the casing with the use of bolt and nut fasteners. M5 sized bolts were selected to connect the different components, due to their availability and low cost. The image on the right shows the brackets implemented and fastened to the base of the casing.

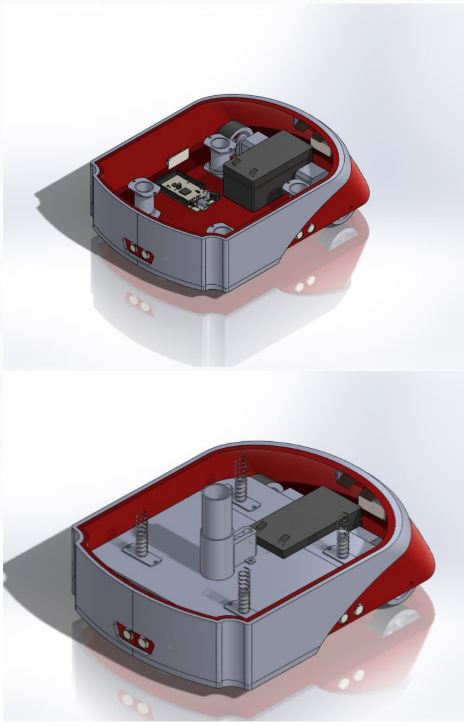


Figure 3.11: Platform with fastening plate exposed

The base plate will hold the pillars, which in turn hold a metal plate (see 3.11). The plate provides support for the lifting mechanism and shields the vulnerable components, such as the Arduino from any dirt in the platform's vicinity.

On top of the plate, four spring brackets are mounted, which hold the springs in place. The springs support the micro gear motor when it lifts the frame through the connected worm gear mechanism. This mechanism rests on top of the plate, held in place by the casing in the center of the platform. Adjacent to this casing, the pillar, which provides the upwards force is secured by the plate.

Lastly, the hatch is placed inside the spring brackets, finalizing the system's lifting mechanism.

Detailing the frame

The frame's shape is designed to fit the geometry of the hatch. When the platform is not positioned correctly beneath the frame, the frame's geometry will ensure proper positioning between the two assemblies. About 10 mm is left on each side for the platform to maneuver itself into (see fig. 3.13). Therefore, the movements of the robot should be correctly registered by the Arduino to achieve correct placement.

The components which make up the frame ensure that robotic arms of variable sizes can be mounted on top. The robotic arm is to be fixed on a plate with a thickness of 3 mm, so the plate can fit beneath the four brackets. In turn, the brackets are bolted to a roster, preventing the base plate of the arm from displacement. Beneath the plate, four spacers are present to make room for the bolts protruding beneath the roster. Finally, the plate is bolted down to the frame, finalizing a structure which can be moved by the robotic platform.

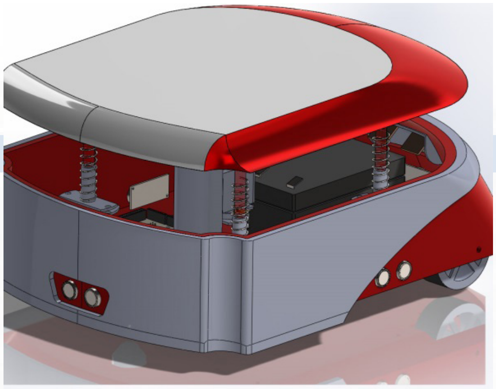


Figure 3.12: Platform with hatch opened

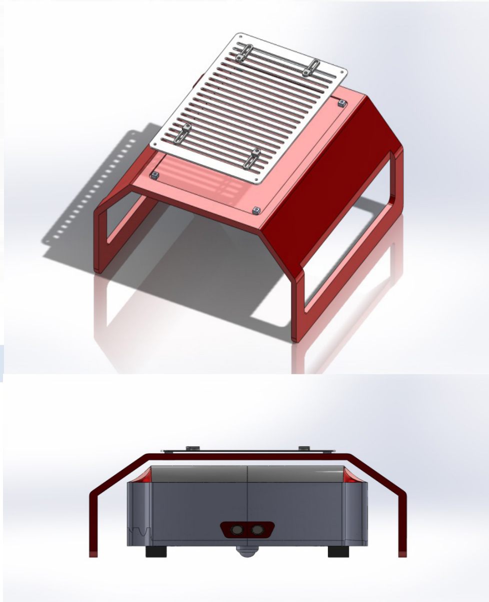


Figure 3.13: Frame and it's size in comparison

Docking station

The docking station, albeit a lesser part of the system, fulfills the function of keeping the battery topped up between operating cycles (fig 3.14). As such, it contains two metal extrusions which connect the metal plates on the rear of the platform to the battery charger.

Simply described, the two rods protrude from the docking station's casing, and pressure is applied by a spring. This causes the rods to veer into the casing when the platform drives against the rods, connecting the charge point on the platform with the two rods. The spring constantly applies pressure, preventing loss of contact between docking station and platform.

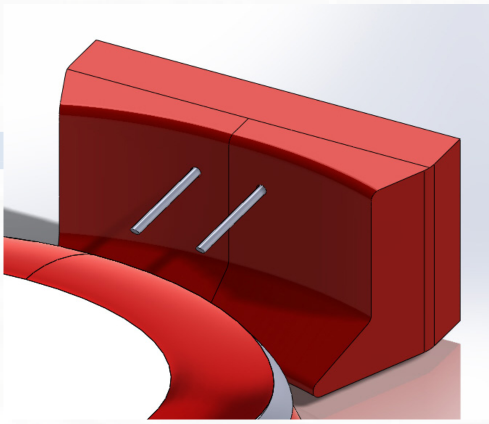


Figure 3.14: Docking station

Conclusion

This section introduces new components for the purpose of fastening hardware and supporting the platform in retaining its composure. The next chapters expand on further realization of these components, including choice of material and manufacture.

3.5 Choice of material and manufacture

After finalizing the concept and its components, a plan of execution was required for the manufacture of the prototype. This chapter expands on the subject of materials and tools used to produce the prototype. Materials and tools readily available in the workshop of the Horst building were preferred, due to greater ease in reproducing multiple platforms. Discussions with workshop manager N. Spikkert and project coordinator M. Essers helped steer procedures into the correct tracks. The table below summarizes the materials and tools used to fabricate the various components present in the prototype.

Component (Platform)	Materials	Tools	Notes
Casing	Glassfiber Epoxy resin Filler Polyester foam (rigid) Steel plate (2mm thick)	Paintbrush/ roller Sanding paper Spatula Laser cutting machine CNC milling machine Drill	Inner and outer shell are to be fabricated into one component.*
Hatch	MDF wood Filler Metal rods (9 mm dia.)	Sanding paper CNC milling machine Drill	Solid hatch is produced with holes for inserting.*
Pillar brackets (9x)	ABS filament	3D printer Drill	-
Spring brackets (4x)	ABS filament	3D printer Drill	-
Worm gear box	ABS filament	3D printer Drill	-
Wheel gear box (2x)	ABS filament	3D printer Drill	-
Wheel bracket (2x)	ABS filament	3D printer Drill	-
Charge point bracket	ABS filament	3D printer Drill	-
Charge point conductor (2x)	Aluminum plate	Plate bending tool Plate cutter tool	-
Caster wheel bracket	MDF (5mm thick)	Saw Drill	Positions the caster wheel to align with other wheels
Surface finish	Paint (Bordeaux) Paint (Light Gray)	Paintbrush Spraycan	-

* Advice originated from discussion with workshop coordinator N. Spikkert.

Additional comments: Casing

Due to the platform's complex form factor, its casing is the most labour intensive to craft. After a mold is produced by the CNC milling machine, the mold is to be separated in multiple connectible parts for easy disassembly. After the mold is finished, it is to be sealed with a coating, preventing any epoxy resin or fiberglass from sticking to the mold after drying.

The mold is then to be coated with four layers of fiberglass and resin, which gradually harden into the desired form. The mold is then removed from the fiberglass casing, after which the casing is to be finished with filler and a sanding process to smoothen the surface. After painting, the casing will be finished and the metal plate will be glued on for additional support. The whole process will take approximately three weeks. During the drying process, other components are to be produced, in anticipation for mounting these to the casing.

Component (Frame)	Materials	Tools	Notes
Supporting frame	MDF (10 mm thick) Wood screws	Milling machine Band saw machine	Produced in five parts: (top plate, two inclined parts and two supports)
Roster	Steel plate (2 mm thick)	Laser cutting machine	
Spacers (4x)	MDF (5 mm thick)	Band saw machine Drill	-
Mounting brackets (4x)	ABS filament	3D printer Drill	-

Component (Docking)	Materials	Tools	Notes
Metal charge rod (2x)	Aluminum rod (6 mm thick)	Hacksaw	
Mechanism bracket A	PVC tubing (32 mm)	Hacksaw File	
Mechanism bracket B	Wooden plate	Hacksaw/sawing machine Drilling machine	

Conclusion

The main components present in the platform prototype are laid out in this paragraph. These tables serve as a reference for the ordering of needed materials. Also, these tables are referenced during the manufacturing and assembly process, as machines can be prepared for the processing of the materials into the needed components. Further explanation of the procedures in the manufacturing process can be found in chapter 4.

3.6 Programming the platform and its behaviors

Merely adding the bought and manufactured components together does not make the platform operational. The core of the platform, the Arduino Mega 2560, needs to be programmed to interpret sensor data and direct its stepper motors into the right direction. The coding follows from the function decomposition, as it describes the platform's intended behavior. These behavioral types are to be split into small tasks, executed in sequence by the Arduino. This chapter describes the behaviors which follow from the function decomposition, and the method of implementing them into the Arduino's firmware.

Program structure

The structure of the program follows the diagram on figure 3.15. First, the kinematic part of the platform is to be programmed. This part directs the stepper and microgear motors and retrieves sensor information. The code generated in this phase cannot autonomously drive the platform towards its destination. It only directs motors and retrieves sensor information based on the parameters entered in the components' respective functions.

The pattern layer is a higher level and is based on the kinematic layer. This layer combines sensor and motor information into functions which, for example, steers the motors while checking the sensors. Also, functions will be written in this part in order to compare sensor information and provide parameters for further processing.

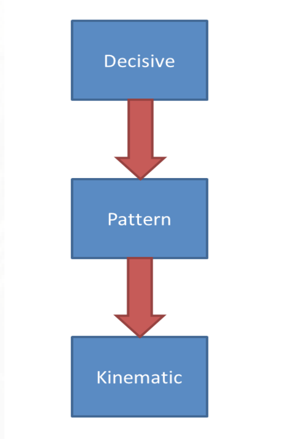


Figure 3.15: Program structure

The highest layer in the hierarchy is the decisive layer, which contains functions that make the device fully functional. Functions in this layer are developed in a fashion that allows the platform to move to its intended destination autonomously. All functions in the previous layers are combined to provide a single algorithm, allowing for autonomous navigation through the environment.

Before programming: defining platform axis system

Due to the early prototype lacking information or tools to retrieve information concerning the platform's environment, the most efficient axis for the prototype is centered on the prototype itself (see fig. 3.16). The platform's initial point is regarded as zero, or origin. The forward direction represents the Y axis, while reverse direction represents the negative area of Y. X and negative X are defined as right and left side respectively. This allows the platform to calculate the distance and direction it needs to travel in to reach its destination, based on the coordinates given.

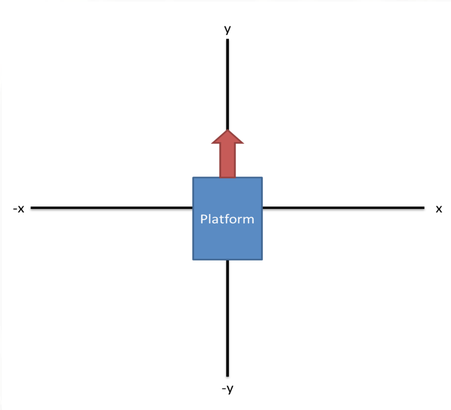


Figure 3.16: Diagram showing platform axis

For example, when a destination's coordinates are sent to the platform through its wireless signal, the platform will be able to calculate the angle it has to assume to travel towards its destination in a straight line, using a simple trigonometric function. Additional information will be shown in the program's comments.

How the platform must behave

Based on the functional decomposition, the platform must remain idle until it gets the coordinates through a user interface. Through the UI, coordinates are received by the platform's wireless module. These coordinates are used to move towards the platform's destination while traveling the shortest distance possible.

When approaching an object, the platform must detect the most efficient way to face before continuing its path. This is done with the use of the ultrasonic sensors on the platform's left and right hand side. It proceeds to travel alongside the object by turning a certain amount of degrees when the platform is closer to the object than a given limit. This provides an extra aspect to autonomous movement, as object perimeters need not be positioned parallel or perpendicular towards the platform as it tries to drive around mentioned objects. Figure 3.17 includes a flow diagram in which the behaviors of the platform are displayed.

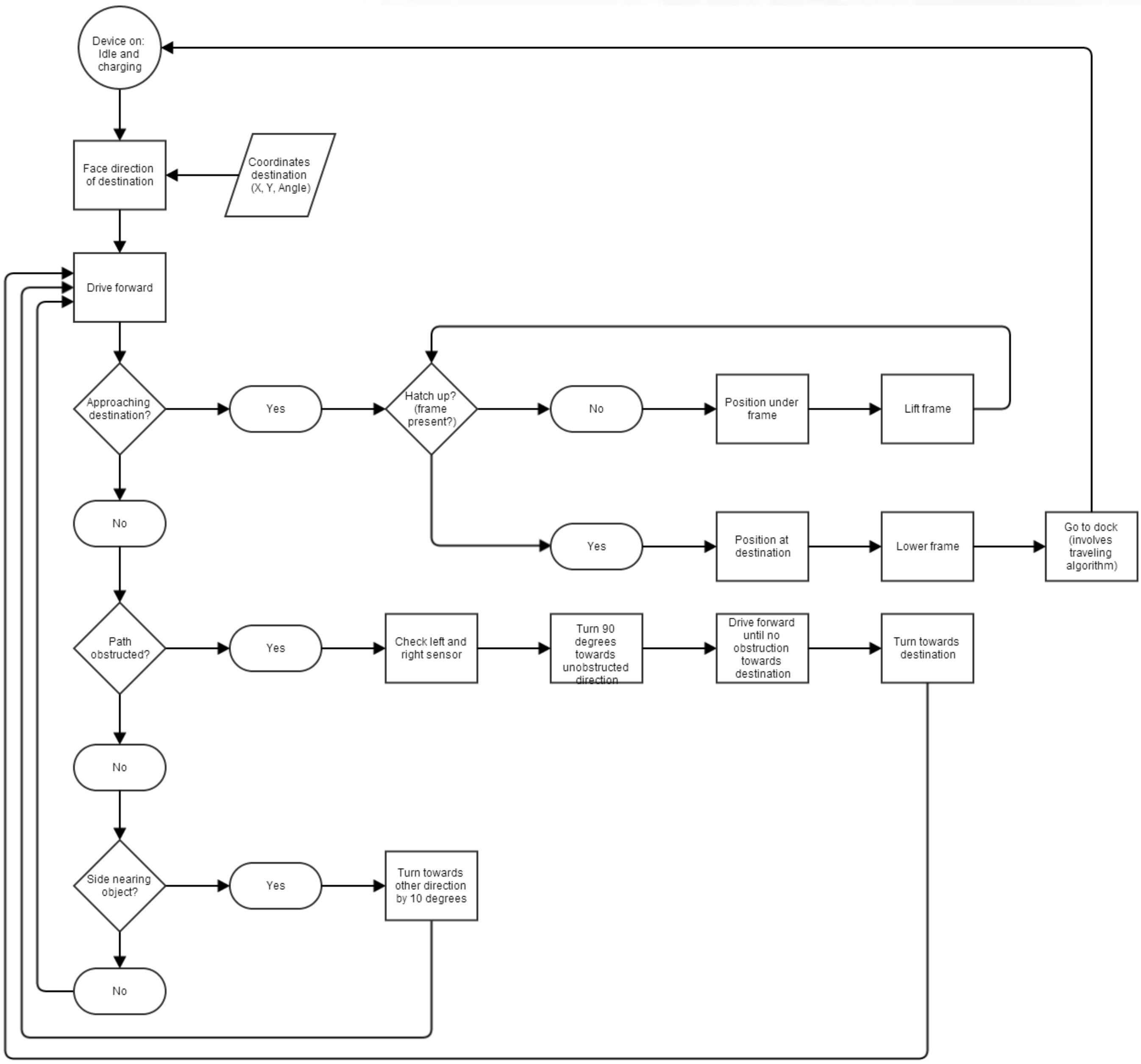


Figure 3.17: Platform flowchart

Platform behavior: allocating behaviors to functions

Before the code is to be written, the behaviors will be allocated to functions while following the program structure model. Functions from the function decomposition will be divided and allocated as shown in the table below:

Kinematic layer		
Behavior	**Function**	**Description**
Drive forward	void forward(int mm)	Drives forwards by 'mm' mm.
Drive backwards	void reverse(int mm)	Drives backwards by 'mm' mm.
Turn left	void left(int deg)	Rotate platform counterclockwise by 'deg' degrees .
Turn right	void right(int deg)	Rotate platform clockwise by 'deg' degrees.
Check front sensor	int checkFront()	Checks front sensor, returns the distance of detected objects in cm.
Check rear sensor	int checkRear()	Algorithm same as front sensor.
Check left sensor	int checkLeft()	Algorithm same as front sensor.
Check right sensor	int checkRight()	Algorithm same as front sensor.
Lift hatch	void lift()	Activates the microgear motor, lifting the hatch.
Lower hatch	void lower()	Reverses the microgear motor, lowering the hatch.
Pattern layer		
Behavior	**Function**	**Description**
Interpret wireless signal	int retrieveCommand()	Receives wireless signal from wireless module and uses it to update coordinates.
Compare left and right sensor	boolean compareLeftRight()	Compares left and right sensors, returns 'true' if left side is unobstructed and 'false' if right side is unobstructed.
Move to destination	void moveTo(int x, int y, int z)	Moves platform to given destination, using coordinates X, Y, angle Z. Combines functions above into one algorithm.
Decisive layer		
Behavior	**Function**	**Description**
Move and pick up hatch	void pickUp(int x, int y, int z)	Moves platform towards frame at given coordinates (X, Y, angle Z). Picks up hatch when destination isreached. Also sends location data to the Electric Imp for UI purposes.

Decisive layer		
Behavior	**Function**	**Description**
Move and lower hatch	void putDown(int x, int y, int z)	Moves platform towards frame at given coordinates (X, Y, angle Z). Lowers hatch when destination is reached. Also sends location data to the Electric Imp for UI purposes.
Move to docking station	void dock(int x, int y, int z)	Moves platform to docking station, standard coordinates are (0,0,0) or platform origin. Also sends location data to the Electric Imp for UI purposes.

Coding the arduino

The Arduino contains aforementioned functions to drive the actuators and relocate the platform to its intended destination. The coding process starts with the kinematic functions, working its way up to the decisive layer, where the functions are combined into movement algorithms. In short, the final result will be a single function accommodating movement to set destinations. The full code uploaded on the Arduino, along with instructions on how to install the code can be found in the appendix.

Travel towards platform destination

This section describes the intended method in which the platform will travel to its destination. This behavior must be present when observing whether the Arduino executes the code correctly. Graphical depictions of traveling situations are displayed on the next page (fig 3.18 - 3.20).

1. The Arduino sends out a command to the Imp, signaling that the system is ready for coordinates.
2. Upon receiving coordinates, the Arduino confirms this and proceeds to execute its algorithm.
3. The platform is to turn and face its frontal area towards the destination (monitored by updating its own angle's variable).*
4. The platform moves forward, monitoring its own position towards its final destination.
5. Upon approaching an object on the frontside (within 15 cm), the platform stops moving and compares data from its left and right sensor to determine the least obstructed direction.
6. The platform turns 90 degrees towards the determined direction and continues to move forward until the side towards the destination is unobstructed.
7. The platform drives another 10 cm, then turns and faces the destination of the destination. If another object is encountered, the same protocol is followed.
8. If the platform drives next to an object (a wall for example), the platform should adjust its route to drive along the wall in a near-parallel fashion.
9. Upon reaching the destination with a 20 cm offset, the platform drives under the frame and lifts up its hatch, thus lifting up the platform.
10. Upon receiving coordinates, the platform drives 20 cm backwards uses the same movement algorithms to transport the frame to its new destination and place the hatch on its new destination.
11. When the hatch is placed, the platform uses its movement algorithms to travel to its docking station for charging.

* Monitored variables are sent to the Electric Imp, which in turn sends a signal to the UI, signaling the current location status to the operating user.

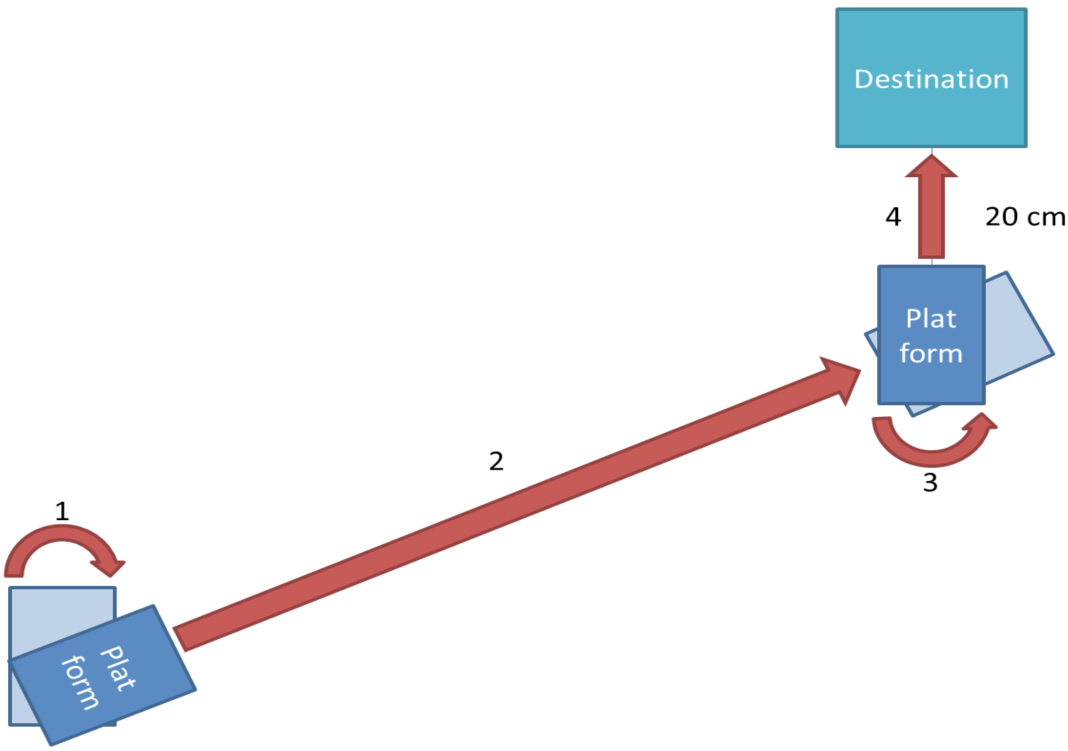


Figure 3.18: Normal behavior, traveling to destination in one line

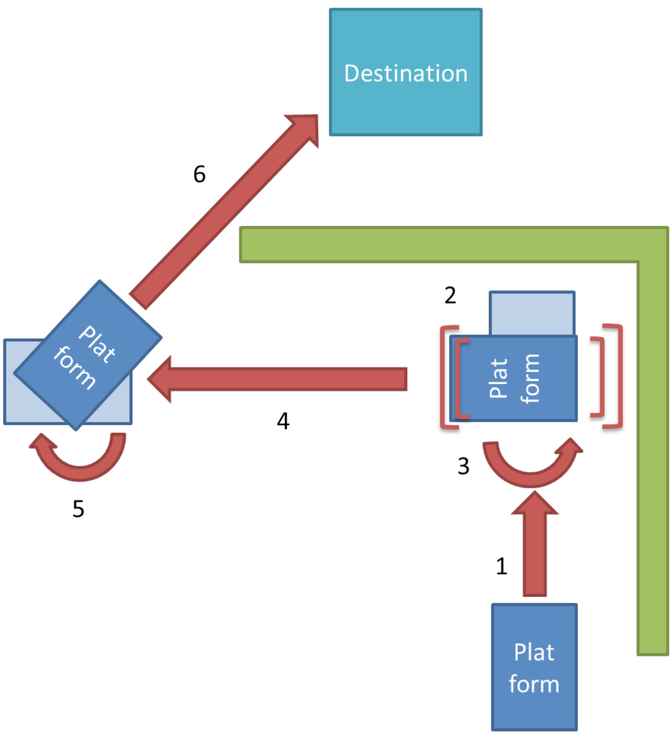


Figure 3.19: Choosing the correct direction for travel

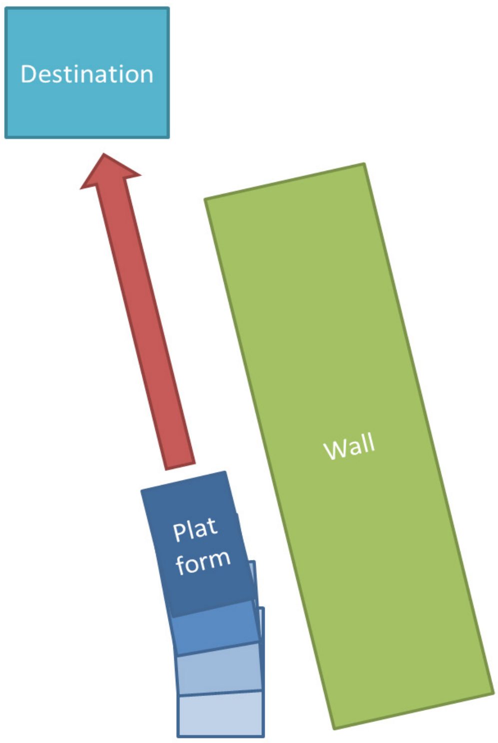


Figure 3.20: Traveling alongside obstacle

Coding the electric imp

The Electric Imp situated in its imp socket on top of the Arduino provides the wireless channel through which coordination commands are sent. The Imp allows data to be sent through a simple UI in the form of a website, allowing control over the platform from any situation where an internet connection is available. This is possible because of the Electric Imp's ecosystem, a cloud system where every Imp is connected to when powered on (Electric Imp, 2013). The Imp is essentially a second microcontroller – similar to the Arduino – able to actuate components or interpret sensors through its I/O ports. Therefore, a program or firmware must be written to interpret signals coming through the UI, and export these to the Arduino for further processing.

The Electric Imp runs on Squirrel code, a language similar to the C++ programming language. The microcontroller must be coded to accommodate the following tasks:

- Relaying commands sent through the user interface towards the Arduino for further interpretation and processing.
- Displaying the Arduino's current coordinates and operating status in the UI.

The Electric Imp can work with standard HTTP IN and HTTP REQUEST protocols to interact with one or more websites, providing a UI which can be adapted as desired. This aspect provides convenience when the platform needs to be reconfigured for greater accuracy or additional functions. The full code, along with the instructions on how to set up the Imp module can be found in the appendix.

Conclusion

This chapter has the purpose of expanding the understanding of the algorithms the platform will use to execute its tasks. The implemented code and instructions are displayed in the appendix of this document. In the code, comments have been placed for clarification of the functions. After setting and wiring up the prototype components, the codes can be easily uploaded to the Arduino and Electric Imp, resulting in easy production of additional prototypes. Further chapters will expand on the building and evaluation of the prototype.

Chapter 4: Manufacture, evaluation, and conclusions

This chapter describes the platform in it's final stages of development. The following aspects are present in this chapter:

- Manufacturing the components present in the platform prototype
- Assembling the prototype
- Testing the prototype's performances
- Recommendations for further development

The result of this chapter is a finished working prototype, capable of transporting a robotic arm between two given coordinates. For further development of features on the platform, the recommendations will provide an overview of aspects that may be improved.

4.1 Building the platform

The production and assembly of the platform components were mainly done in the workshop of the University of Twente. The various brackets and molds were to be produced, in order for these to be assembled to combine into a fully functional robotic platform. This paragraph describes the components which were manufactured before assembly took place. The technical drawings for all components are included within the appendix of this document.

Axes for rotating components

The platform includes three mechanisms converting rotational movement into movement in an axial direction. These movements are supported by metal rods that serve as the axis of rotation. A metal rod with a 6 mm thickness was purchased from the local home depot. The rod is split into smaller rods using a hacksaw and glued to its respective gears. After attaching the rods to their gears, they are inserted into their respective brackets for assembly.

Base plate and separation plate

To provide a sturdy base for the mounting of the components, a base plate and separation plate were produced out of steel plate (fig. 4.1). Using available lasercutting technologies, these two plates were cut out as finished products for assembly. In the third chapter, the base plate is abscent, as the idea for the base plate came from discussions with Norbert Spikkert from the University of Twente's workshop department.

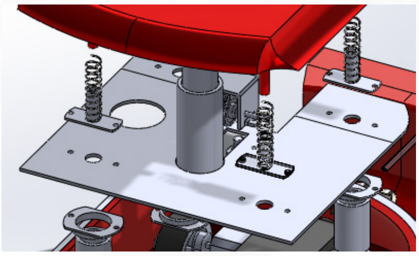


Figure 4.1: Separation plate

3D printed components

The 3D printed components, as described in chapter 3, are printed using available 3D print technologies on the University of Twente. Although the components were designed to fit, several modifications were to be made for a better fit. These modifications mainly included the widening of the holes which accomodate rotating components, as the axis was changed to have a thickness of 6 mm.

Casing and hatch

The casing which will provide protection from environmental damage to the components, is produced with glass fibre molding techniques. The mold is formed through CNC cutting technology available in the university's workshop. Through discussions with the workshop authorities, it was concluded that the current design of the casing had to be simplified due to the machine not being able to process a model containing undercut features. A second version reuses the front form features of the casing, while including a single curved rear, thus making the mold producable by the university's CNC machine. The material for the mold will be high density foam, providing a sturdy base for glass fibre molding.

The hatch will be made out of MDF plate material (Medium Density Fibre). This provides sturdiness at the top of the platform, and offers freedom for modification, as the material allows for manually drilling holes. Due to the complexity of the hatch's form factor, CNC milling is used to fabricate this component. The molds for both the casing and the hatch are depicted on figure 4.2. The transparency of the mold models allow for a clear view on their form factors.

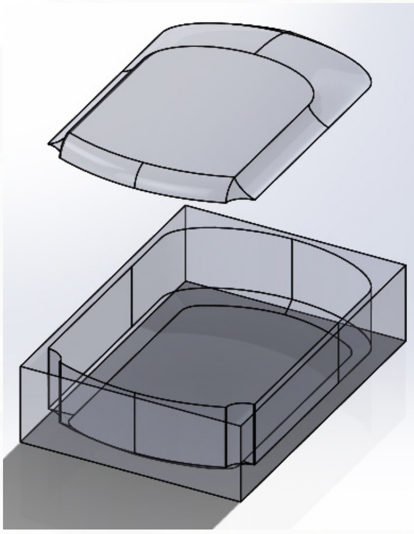


Figure 4.2: 3D models for hatch and casing

4.2 Installing the electronics

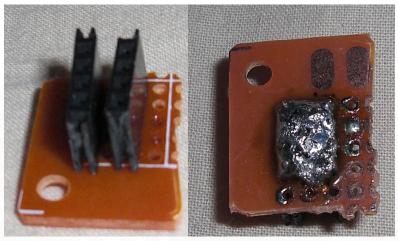


Figure 4.3: 5V circuit, top and bottom

The electronic components allow for automated movement of the platform and thus form a core part of the prototype. This paragraph briefly describes the circuits that accomodate the main components and aspects requiring extra attention when assembling the circuitry. Schematics depicting the circuits can be found in the appendix for further clarification.

Ultrasonic sensors

The ultrasonic sensors each have an ‘Echo’ and ‘Trigger’ pin, both used for the transmitting of ultrasonic signals towards the Arduino. Using the standard NewPing library created by a member of the Arduino community, multiple sensors can be implemented in the Arduino’s firmware with ease. Each sensor requires 5V on the Vcc port, and a simple circuit has been implemented to create multiple ports connecting to a 5V input (fig 4.3).

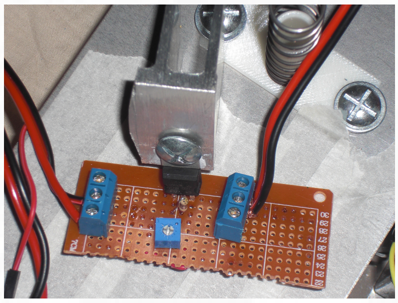


Figure 4.4: Circuit with lm317t

HP100 Motor and the L298N driver module

The HP100 Motor is a high power gearbox motor, able to deliver a large amount of torque for its size. At 6V and 1.6A, the motor can deliver 2.2 kg-cm of torque, when combined with the worm gear system can lift objects of up to 40 kg. To drive a motor with such specifications, the L298n module is used to convert low current 5V signals from the Arduino into high current 6V signals. Also, a lm317t circuit is used to convert the 12V from the battery to the HP100’s required voltage. It also should be noted that the L298N requires 5V on its respective port to power the module itself. This power requirement is provided the 5V input provided by the 7805c circuit, through the same circuit which accomodates the ultrasonic sensors. The image on the right hand side depicts the conversion module’s circuit. The left hand side of the image depicts the output pins towards the L298N motor driver, while the opposing side is connected to the lead acid battery. The heat sink is required as dropping 12V down to 6V leads to a large amount of heat dissipated from the lm317t semiconductor.

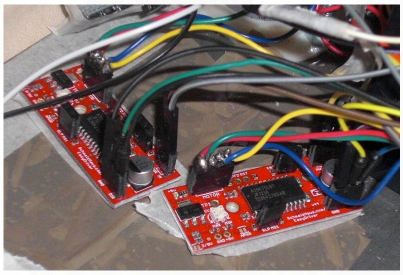


Figure 4.5: EasyDrivers

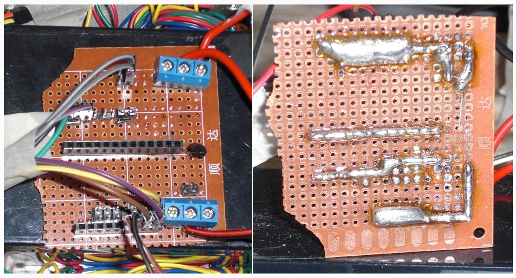


Figure 4.6: Power circuit, top and bottom

Mercury Motors and the EasyDrivers

Like the HP100 motor, the mercury stepper motors require a driver to supply the correct power for motor movement. As the stepper motors are specified to work at 12V, no additional circuit was required to adjust the voltage.
The EasyDrivers were connected to the battery, stepper motors and Arduino. Using signals from the Arduino, the EasyDrivers relay the power coming in from the battery and drive the motors (fig. 4.5).

Main power supply

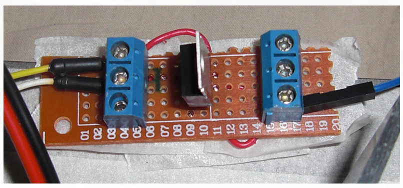


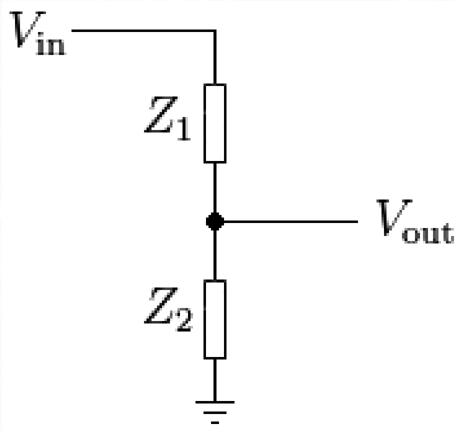
Figure 4.7: 7805c circuit

All power requirements are fulfilled with the use of the mentioned lead acid battery. To maximize compatibility with the other components, a circuit was created which allows for connection of the components using regular jumper wires (see fig. 4.6). It should be noted that while this setup allows for quick assembly of the components, jumper wires may come loose if assembled incorrectly, resulting in malfunction or even damage to the system. Therefore, components must be wired with care, with emphasis on the stress applied to the wires.

5V circuit - 7805c voltage regulator

Due to an event of shorted circuit within the Arduino, the 5V pinout became dysfunctional on the board. Therefore, an extra circuit was added to convert the 6V into the 5V voltage required by the ultrasonic sensors and L298n motor driver module (see fig. 4.7). This circuit utilizes a 7805c voltage regulator, without a heat sink as the voltage is dropped by 1V and thus generates only a small amount of heat.

Voltage resistor divider - Measuring battery levels



A quick adjustment to the platform's design was made in order to allow the platform to read its own battery level. This was done using a voltage resistor divider. This divider is wired to the lead acid battery, leading the current to an analog pin and the Gnd pin on the Arduino as seen on the image on the right. In this case, Z1 represents a 140k ohm resistor, while Z2 represents a 100k ohm resistor.

The voltage divider essentially scales down the voltage from the battery to a voltage between 0 and 5 Vdc. This voltage can then be read by one of the Arduino's analog pins (as applying more than 5V would damage the pin. The voltage read from this pin is proportional to the battery level. The lead acid battery level varies between 12.5 V and 10.8 V (Conrad Electronics, 2003). When the battery reaches 10.8V, the analog pin will receive an input of 4.5 V, and the Arduino will initiate a docking procedure. The full circuit of this system is displayed in the appendix.

Additional notes

During the assembly of the platform, some issues have occurred regarding the electronics. This paragraph describes the aspects which can cause failure within the device, and thus should be taken into account.

- Shortcircuiting: Because the plate on which the electronic components rest is made of aluminum and thus conductive, the aspect of shortcircuiting the pins on the circuit boards may occur. It is advised to isolate these components from the metal plate. Simple masking tape is applied on the bottom of the circuit boards and on the aluminum plate to prevent shorted circuits. Also, soldered circuits must be checked for any faulty or shorted connections, preferably with a multimeter. Improper connection of components could lead to irrepairable damage.
- Displacement of electronic components: Due to the components not being fastened to the plate, it is possible for the components to shift or wires to disconnect during transport or due to improper handling of the device. It is advised to either fasten jumper wires to their respective pins, or fasten the components to the base plate with adhesive tape or bolts.
- Handling of wires: Due to the amount of required connections between the components, the wires establishing these connections may block one's view or hands during assembly. It is advised to bundle and fasten wires traveling in the same direction for an optimum overview of the wire connections..

The three points given are the main points of attention during the assembly of the electronic circuit. Handling the electronics properly results in a fully operational circuit, only requiring the firmware to be uploaded to the Arduino.

4.3 Building the frame

After the platform prototype has been finished, the robot mounting frame and the charging station are to be manufactured. This system requires no electronics, and thus requires less steps in the manufacture and assembly process. This paragraph describes the main process in which the components are manufactured and assembled. As in the previous paragraph, technical drawings are included in the appendix for each part.

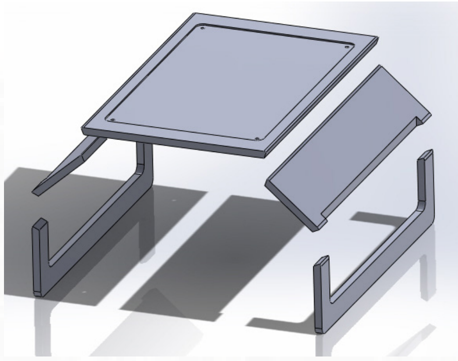


Figure 4.8: Exploded view of the frame

The frame is the main part of the structure, on which the robot is mounted through small 3D printed components (fig. 4.10). The whole structure is lifted by the platform, and transported to its new location. The structure is made of MDF wood material, in separate parts which are then fastened through the use of screws and wood glue (see fig. 4.8).

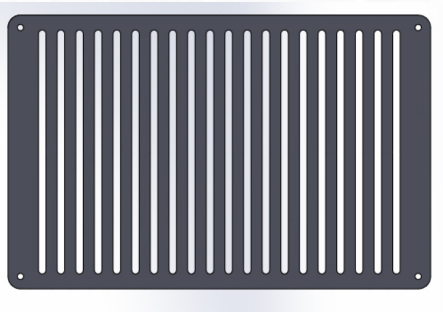


Figure 4.9: Base plate frontal view

The base plate requires little labor and involves cutting the design out of aluminum plate (see fig. 4.9). After cutting, it was mounted onto the top part of the frame through bolt fasteners.

Also, four brackets were created to fasten the AL-5D to the base plate. These were 3D printed and required little labor to fabricate (see fig. 4.10).

4.4 Building the docking station

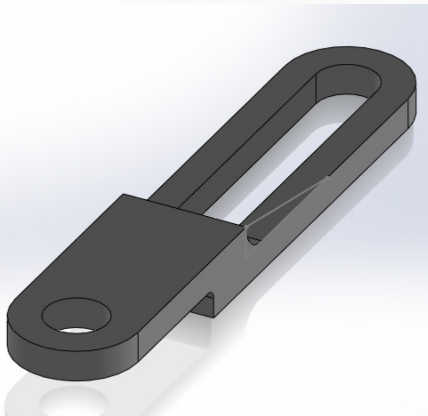


Figure 4.10: fastening bracket

The docking station was decided to be simplified during the manufacturing of the system. The system fulfills a lesser function in between cycles of operation, basically keeping the battery level at maximum when the robotic platform is not in use. This is done by connecting the standard battery charger to the platform's lead acid battery through metal rods (see fig. 4.11). The result is an easy manufacturable charging station which will relay the power from the battery charger to the lead acid battery.

The battery charger is a standard lead acid battery charger ordered from Conrad internet store. The charger can be simply connected to the metal rods through the clamps. The charger is internally protected from short circuiting and switching of the polarities.

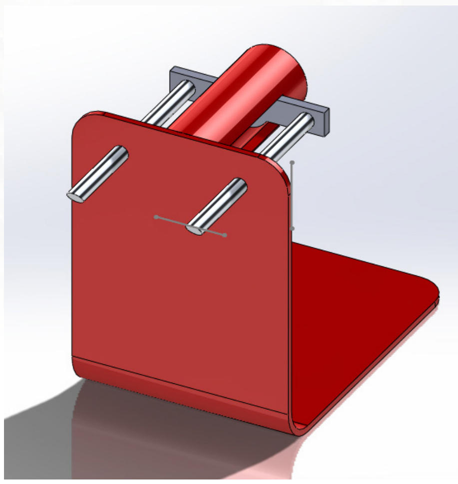


Figure 4.11: Renewed docking station model

Due to most of the technology being delivered by the charger itself, the docking station is mainly a bracket to connect the charge clamps to the lead acid battery. The main plate (fig 4.11) is lasercutted from sheet metal and bent in a 90 degree angle. The bracket holding the two rods (gray) is produced out of a wooden plate material (MDF), as it is easily millable using either machine or hand. The red cylinder guiding the rods is produced from an off-market PVC tubing, using a hacksaw to saw the indents. Finally, the rods are produced from a 6mm aluminum rod, the same material as the axes in paragraph 4.1.

4.5 Evaluating the platform

The evaluation of the platform is divided in two phases: software testing and hardware testing. The platform's components are tested for functionality. Hardware evaluation includes testing the following aspects:

- The readings of the ultrasonic sensor
- The driving of the wheels by the stepper motors
- The opening of the hatch by the microgear motor (HP100)
- Response by the Arduino on cue given through UI

After the hardware is deemed fully functional, the actual behavior resulting from the Arduino's firmware should be tested. This includes evaluation of the following aspects:

- Correct travel towards given coordinates
- Opening of hatch when it is below the platform
- Correct transport of the frame structure and robotic arm combination towards given coordinates
- Correct relocation towards docking station for charging
- Performance of the platform and how it measures up to the requirements established in the design brief, as discussed in paragraph 1.9
- Overall behavior according to the flowchart in fig. 3.17

When all the aspects are thoroughly tested, any faults in the program code are to be corrected. If the platform passes the points, it can be deemed fully functional and ready for usage.

Figure 4.12: Conrad lead acid battery charger

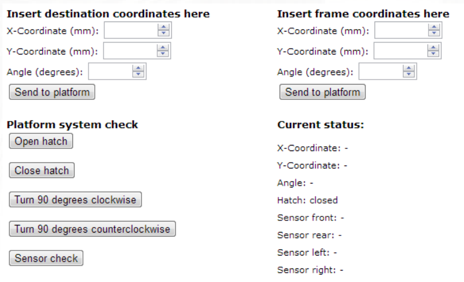


Figure 4.13: Robot user interface

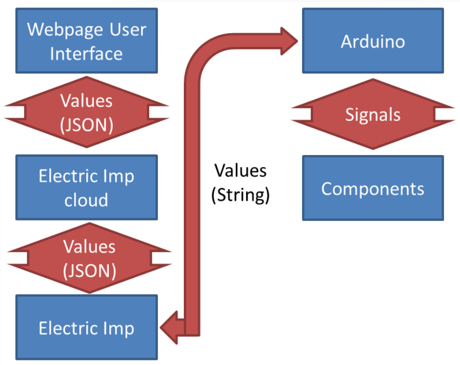


Figure 4.14: Overview of data flow

4.6 Controlling the platform

The platform is controlled through an online webpage, sending HTTP 'post' requests towards the electric imp wireless module, after which the firmware on the imp converts these requests into signals for the Arduino to interpret. The webpage possesses two forms, each with three input forms, representing the x and y coordinates, and the angle respectively (see fig 4.13). The destination coordinates and overall orientation of the frame are entered in the top section, after which these coordinates are used for the navigation of the platform.

On the bottom left, a set of buttons allow for the testing of systems. Clicking the buttons makes the platform perform the tasks described on the mentioned buttons, thus allowing for the checking of the actuators within the platform.

The bottom right of the webpage shows a set of feedback lines, each representing an aspect of the platform's status. This allows for the monitoring of the platform while it is operational within its working environment.

The communication channel is set up as follows:

- The operator sets the desired values using the webpage UI. This results in a batch of values being sent to the Electric Imp cloud in the form of a JSON string.
- The JSON string is relayed towards the Electric Imp from the cloud.
- The Electric Imp converts the received values into a standard string and relays the string to the Arduino through it's UART serial.
- The Arduino receives the string and processes these in order to drive its respective components.

For further clarification, values sent from the webpage would contain values such as the X, Y coordinates and angle of both the final destination and the location of the frame. Submitting the values in the UI would result in the data being sent in the format similar to the example below:

"x": 200 ", "y": " 400 ", "z": " 260"

With X and Y representing their respective coordinates, while z represents the angle. The variables, for example "x:" are required for a JSON string, as JSON strings carry over a variable along with an assigned value. The standard string sent to the Arduino would look as follows:

"200, 400, 260"

After receiving this data, the Arduino parses and converts the data into component movement.

The full webcode, along with the Arduino and Electric Imp code are available in the appendix.

7 Manufacturing costs, -plan and evaluation plan

For the production of multiple platforms, a complete bill of materials along with the cost of the components is placed within the appendix. Using these two documents as a guideline for the production of platforms decreases total expenses, as no experimentation with components is needed after the completion of this project. Also, technical drawings have been adapted to fit the components purchased from local home depots.

For evaluation of the platform, a system testing procedure has been produced and placed within the appendix of the document. Following this procedure ensures that the platform meets the set requirements at the start of this project. The system is checked for full operationality and its performance regarding mentioned requirements.

4.8 Recommendatons for further development

As the platform was designed and built within a time span of six months - including the experimentation and testing with components - development of platform features has been limited to a certain degree. For the further development of a new version of the platform, the following aspects are deemed to be worthwhile to implement:

- Although not necessary, the platform as designed, relays information gained from its components to the webpage UI, controlled by the operator. Research in the implementation of feedback LEDs could prove to be worthwhile to add to the user experience. Analysis should be conducted on the most intuitive of relaying information towards the user through the use of colored lights.
- Further research into the dampening of the forces applied to the 3D printed components - mainly the gearbox - could lead to an improvement in the lifespan of the platform's components. Implementing ball bearings and creating slots for such bearings within the 3D printed components could decrease the amount of friction and wear on the ABS material.
- As the material was too costly to rapid prototype in masses, only one layout could be designed and tested for the platform. Therefore, a new layout could be designed based on the experiences with the current layout. This could lead to a cleaner arrangement of the wiring, thus improving the overall overview in case the wires need inspection.
- As the Electric Imp cannot communicate over the WPA-Enterprise protocol, it can only be

operated within the range of a wireless access point which utilizes regular WPA-PSK (or WPA2) protocols. Currently, the Arduino possesses no pheriperals able to communicate over aforementioned protocol. Therefore, it might prove beneficial to look into wireless possibilities, should a wireless module capable of handling WPA-Enterprise surface on the market.

- For the adjusting of the firmware, only the USB serial can be used on the Arduino. The Electric Imp's code can be adjusted wirelessly through the Electric Imp website, as long as it's connected to the internet. An admin on the Electric Imp forums has stated that loading code on the Arduino through the Electric Imp is possible, although the code was fabricated by one of Electric Imp's business clients, and thus could not be distributed. Attaining such a code would allow for wirelessly programming and testing of the platform.

  The mentioned discussion can be found on: http://forums.electricimp.com/discussion/1373/uploading-new-sketch-to-arduino-via-imp.
- The usage of a laser range finder would improve the overall navigation capabilities of the platform. Accurate readings of the distance between the platform and an obstacle could allow for improvements in the avoidance of obstacles.
- The usage of an external source of information regarding the platform's position within the operating environment would allow for further improvement in navigation. Using cameras to monitor the platform's position and those of obstacles would allow for early planning of the traveling route, thus allowing for shorter operating cycles.
- Although not a primary, developing an iOS or Android app should be possible in combination with the Electric Imp technologies. Due to most people having a smartphone these days, wireless communication using everyday devices could improve on the user experience and satisfaction when using the platforms. The interface could resemble the webpage UI to allow for more intuitive controlling of the platform.

These are currently the points on which the electric imp can improve. Considering the list above for implementation could lead to the platform approaching the status of more professional and industrial hardware.

Closing words

After the reading of this document, you - the reader - should be able to replicate the prototype built from this project. Also, the basic technologies - both considered for and implemented within the platform - have been described and clarified upon. This allows for a basic understanding of how an autonomous device, such as the produced prototype operates.

I do believe some aspects within this project could have been improved upon. For example, if an additional student could have participated as a group assignment, it would have lead to the sharing of knowledge and research regarding technologies and design. This could have allowed for further progress in the development of features and details implemented in the platform. Although it has been suggested that I cooperated with other students within the SInBot project, I felt that information arrived at the wrong time, due to us working on different projects - thus resulting in asynchronous - or sometimes irrelevant to my project - research procedures.

Nevertheless, this project has proven to be both a learning process and a test to hone my knowledge about analytics, design methods, electronics and manufacturing methods. Analyzing, designing and building a piece of 'pseudo-intelligent' hardware greatly helped in my understanding of the inner workings of electronic devices. Building and testing the prototype has been a fulfilling task to myself, and I can only hope that this has shown my passion and effort placed in this project from this document.

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Building a robotic platform – Appendix A

University of Twente

This appendix contains the analysis part of the project and is relevant for further understanding the choices in the first half of the document. Manufacturing instructions, drawings and schematics are to be found in Appendix B.

CK

8-10-2013

TABLE OF CONTENTS

CALCULATIONS ON TOPPLING BEHAVIOUR

This section of the appendix expands on the calculations of the toppling behaviour in various situations. The images below display the situations, as seen in the chapter in the main document.

CALCULATING THE TOPPLING EFFECTS

To simplify this calculation, a simplified model of the robot arm situation was made. The models are displayed below. Four relevant situations have been identified in which the platform could be toppled – robotic arm system. These 'Free Body Diagrams' are displayed on the following page and include:

A. The robot arm gripper is holding a mass, while the shoulder is fully inclined and the elbow and wrist straightened. Thus, the arm is perpendicular to the floor.
B. The robot arm is on a slope, taking on the same position as the previous situation
C. The robot arm makes a quick swinging motion around the shoulder, generating an impulse and thus, a change in momentum within the system.
D. The platform's motor generates enough torque for the system to topple. This will be calculated for all aforementioned situations.

Using the data from the AL5D robotic arm specifications and the physics models supplied on the next page, rough estimations can be made on when the platform – robot combination may topple. Calculations may aid in defining the specifications of the mobile platform and prevention of dysfunctionality. These are displayed after the illustrations. Because the results from the calculations consist of large equations, these were directly implemented in a spreadsheet instead of depicting it in a table at the end of the section.

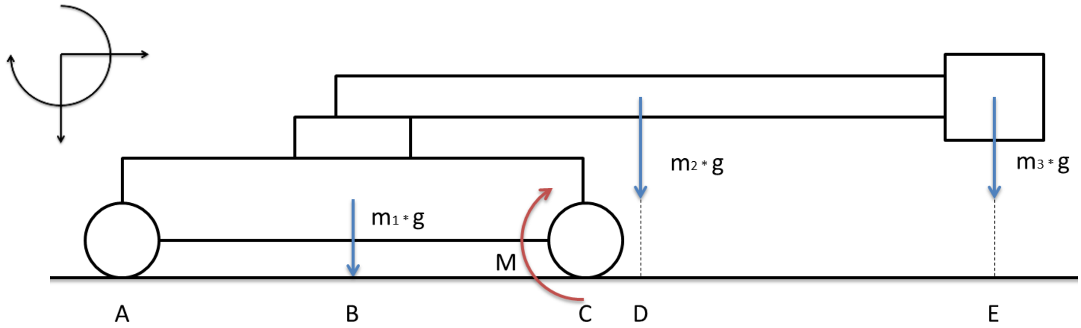


Figure 1: Free body diagram: situation A

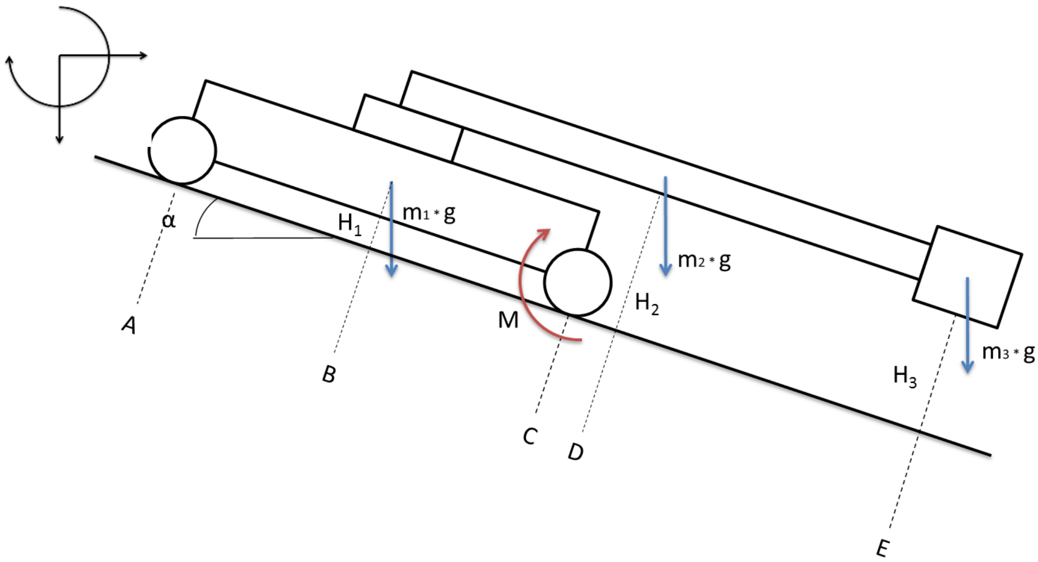


Figure 3: Free body diagram: situation B

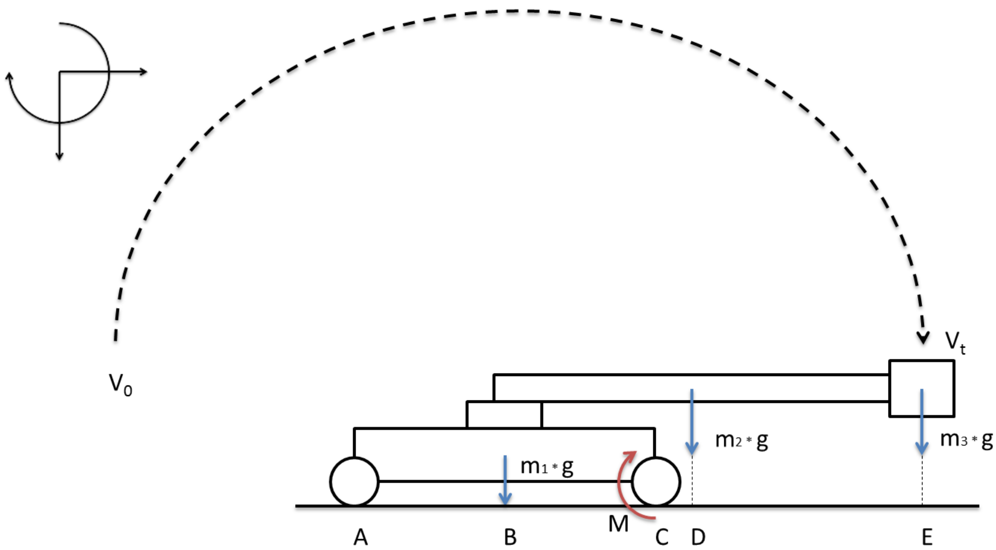


Figure 4: Free body diagram: situation C

DEFINING PARAMETERS

Before calculation, a few parameters need to be defined to prevent confusion, with unknown parameters displayed in bold:

- **m_1** The mass of the platform supporting the robot arm
- m_2 The mass of the robot arm
- m_3 The mass of the maximum weight the robot arm can grip
- **BC** The ground distance between the toppling axis and the platform center of gravity
- **CD** The ground distance between the wheel and the robot arm center of gravity
- **CE** The ground distance between the wheel and the gripped mass.
- **M** The momentum delivered by powering the motor
- V_0 The starting speed of the swing (assumed to be zero)
- **V_t** The ending speed of the swing
- **H_1** The height between the center of m_1 and the floor
- **H_2** The height between the center of m_2 and the floor
- **H_3** The height between the center of m_3 and the floor
- **α** The angle of the slope

BC; CD and CE are parameters used to define the dimensions of the platform, while m_1 will be used to determine whether counterweight is needed.

CALCULATIONS SITUATION A

In order to calculate the toppling effects on the system in situation A, all forces delivering a rotational momentum on the system need to be inventoried. Collecting these in a static equation provides an algorithm with which the minimum dimensions of the platform can be calculated to prevent toppling effects. Note that the first calculation does not incorporate the momentum delivered by motor torque. The section is separated in two calculations: the first omits the motor momentum, and the second includes the effects of this momentum.

The collected momentums result in the equation:

$$\sum M = -m_1 * g * B + m_2 * g * CD + m_3 * g * CE = 0 \ (1.1)$$

Note that when the sum of momentums exceeds zero, the system will result in a net momentum in the positive direction and thus result in toppling.

$$\sum M = -m_1 * g * BC + m_2 * g * CD + m_3 * g * CE > 0 \ (1.2)$$

Because CD and CE are dependent on BC – as they all are dependent on the chosen dimensions of the platform – one can relate these three parameters together with the length of the robot arm "L_{arm}":

$$CD = \frac{1}{2} L_{arm} - BC; CE = L_{arm} - BC \ (1.2)$$

Substituting CD and CE results in:

$$\sum M = -m_1 * g * BC + m_2 * g * (\frac{1}{2} L_{arm} - BC + m_3 * g * (L_{arm} - BC) > 0 \ (1.3)$$

Simplify the equation down to create an algorithm for the right dimensions of BC:

$$-BC(m_1 * g + m_2 * g + m_3 * g) + L_{arm}\left(\frac{1}{2}m_2 * g + m_3 * g\right) > 0 \; (1.4)$$

Further simplifications results in a relation between BC and m_1, where toppling occurs:

$$BC < \frac{L_{arm}\left(\frac{1}{2}m_2 * g + m_3 * g\right)}{m_1 * g + m_2 * g + m_3 * g} \; (1.5)$$

Thus BC needs to be larger than the result the equation provides in order to prevent toppling over in this particular situation.

SITUATION A: ADDING THE ENGINE

Because the torque delivered by the engine may result in toppling, an extra momentum is added to the aforementioned calculation. This momentum is also displayed in the Free Body Diagrams as a red curved arrow. Because the other parameters are exactly the same, only the M variable needs to be added to equation 1.3:

$$\sum M = M - m_1 * g * BC + m_2 * g * (\frac{1}{2}L_{arm} - BC + m_3 * g * (L_{arm} - BC) > 0 \; (2.1)$$

Simplifying this equation down results in:

$$M - BC(m_1 * g + m_2 * g + m_3 * g) + L_{arm}\left(\frac{1}{2}m_2 * g + m_3 * g\right) > 0 \; (2.2)$$

Thus resulting in the equation:

$$M > BC(m_1 * g + m_2 * g + m_3 * g) - L_{arm}\left(\frac{1}{2}m_2 * g + m_3 * g\right) (2.3)$$

Or otherwise:

$$BC < \frac{M + L_{arm}\left(\frac{1}{2}m_2 * g + m_3 * g\right)}{m_1 * g + m_2 * g + m_3 * g} \; (2.4)$$

If M is greater than the result of the equation, the system will topple. This is a logical deduction when considering that if the motor's torque is too great, the system will topple over if the mass and dimensions of the platform do not provide sufficient contramomentum to prevent this. For the design it means that the motor's torque needs to be chosen based on the parameters of the platform self.

CALCULATIONS SITUATION B

In this situation, the system is situated on a sloped surface. Basically this means that the distance in between toppling axis (point C) and the three masses change depending on the height of these masses. This situation depicts the event where the system is most likely to topple over (when on a slope). The momentums bear resemblance to those in situation A, with a few changes to BC, CD and CE:

$$BC \rightarrow (BC - H_1 * tan \propto) * cos \propto (3.1)$$

$$CD \rightarrow (CD + H_2 * tan \propto) * cos \propto (3.2)$$

$$CE \rightarrow (CE + H_3 * tan \propto) * cos \propto (3.3)$$

Substituting these in equation 1.2 results in the following equation:

$$\sum M = -m_1 * g * (BC - H_1 * tan \propto) * cos \propto + m_2 * g * (CD + H_2 * tan \propto) * cos \propto + m_3 * g * (CE + H_3 * tan \propto) * cos \propto > 0 \ (3.4)$$

Substituting CD and CE as done in equation 1.3 results in:

$$\sum M = -m_1 * g * (BC - H_1 * tan \propto) * cos \propto + m_2 * g * \left(\frac{1}{2} L_{arm} - BC + H_2 * tan \propto\right) * cos \propto + m_3 * g * (L_{arm} - BC + H_3 * tan \propto) * cos \propto > 0 \ (3.5)$$

Note that because the height is measured as a line perpendicular to the ground, and the arm is fully extended as the free body diagram describes, H_2 and H_3 are equal. Also, H_2 is a parameter dependent on H_1, as the height of the platform defines the height of the robotic arm. We assume that H_2 is equal to twice the height H_1, so that the robot arm is situated flush on top of the platform. When summarizing these factors, the following set of equations is achieved:

$$H_2 = H_3 \ (3.6)$$

$$H_2 = 2 * H_1 \ (3.7)$$

Substituting the parameters in 3.5, while simplifying the equation by removing brackets and omitting cos α results in:

$$\sum M = BC(-m_1 g - m_2 g - m_3 g) + H_1(m_1 g + 2m_2 g + 2m_3 g) tan \propto + L_{arm}(\frac{1}{2} * m_2 g + m_3 g) > 0 \ (3.8)$$

This equation can be used to relate the height with the platform's dimensions, therefore the equation will be concluded as:

$$H_1 > \left| \frac{BC(m_1 g + m_2 g + m_3 g) - L_{arm}\left(\frac{1}{2} * m_2 g + m_3 g\right)}{(m_1 g + 2m_2 g + 2m_3 g) tan \propto} \right| \ (3.9)$$

Basically, the height must not exceed the parameter on the right side of the equation, as to prevent toppling effects from occurring. The result is an absolute value because the numerator results in a negative number (as the slope angle can be specified as an either positive or negative value).

SITUATION B: ADDING THE ENGINE

Again, similar to the aforementioned situation, when the motor is added a momentum M is added to the equation in 3.8:

$$\sum M = M + BC(-m_1 g - m_2 g - m_3 g) + H_1(m_1 g + 2m_2 g + 2m_3 g) tan \propto + L_{arm}\left(\frac{1}{2} * m_2 g + m_3 g\right) > 0 \ (4.1)$$

Moving the momentum to the right side of the equation results in:

$$M > BC(m_1 g + m_2 g + m_3 g) - H_1(m_1 g + 2m_2 g + 2m_3 g)tan \propto - \left(\frac{1}{2} * m_2 g + m_3 g\right) \quad (4.2)$$

CALCULATIONS SITUATION C

Situation C occurs when a full swing is executed of the robot arm, while keeping the elbow straight. This delivers an impulse on the system, potentially toppling over the robot. The principle of impulse is as follows:

$$J = F * \Delta t \; (impulse) \; = m * \Delta v \; (change \; in \; momentum) \quad (5.1)$$

To calculate the extra force generated by this impulse, the speed of the robotic arm is required. Because this section covers toppling effects, the platform should account for the most extreme situation in which toppling would occur. Therefore, the robot's maximum speed will be used as the initial velocity, and zero as the velocity after collision with the platform (fully parallel to the floor). As the Lynxmotion AL5D's most powerful motor is the HS-805BB servo (Lynxmotion, 2013a), the 60-degree time is 0.14 seconds at least (Hitec, 2013). Assuming that the servo needs 10 degrees to slow down before impact, Δt will be approximately 0.023 seconds. The mass delivering impulse is the payload, or equal to m_3.

The length of the arm determines the radius of the circular path of the payload. This is crucial for the calculating the change in velocity. By using the radius to calculate the circumference of the path, one can relate this value to the 60 degree time and attain the distance s for calculating the velocity. This results in the following equation:

$$\Delta v = \frac{\Delta s}{\Delta t} \rightarrow \frac{2\pi * Larm * \frac{1}{6}}{0.14} \quad (5.2)$$

The bracket '1/6' relates the denominator to the 60 degree time, as without this bracket the denominator would represent a full 360 degree path. Substituting the change in velocity into 5.1 results in:

$$F = \frac{m_3 * \frac{2\pi * Larm * \frac{1}{6}}{0.14}}{0.023} \quad (5.3)$$

Simplifying this equation results in:

$$F = \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322} \quad (5.4)$$

F is a force vector resulting from the impulse delivered by the sudden stop in velocity when swinging the robotic arm. The origin of this vector is positioned on the center of the payload mass, and thus delivers an additional momentum in equation 1.4, thus resulting in:

$$-BC(m_1 * g + m_2 * g + m_3 * g) + L_{arm}\left(\frac{1}{2}m_2 * g + m_3 * g + \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322}\right) > 0 \quad (5.5)$$

Simplifying this equation delivers the final algorithm:

$$BC < \frac{M + L_{arm}\left(\frac{1}{2}m_2 * g + m_3 * g + \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322}\right)}{m_1 * g + m_2 * g + m_3 * g} \quad (5.6)$$

Using the same method, the equation can be obtained for the situation in which an active engine is present:

$$BC < \frac{M + L_{arm}\left(\frac{1}{2}m_2 * g + m_3 * g + \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322}\right)}{m_1 * g + m_2 * g + m_3 * g} \quad (5.7)$$

SITUATION C: APPLYING TO SLOPED SITUATIONS

The same can be done with situation B, delivering a more accurate algorithm for height parameters. Starting from equation 3.5, one can add the force vector resulting from impulse to the total collection of momentums:

$$\sum M = -m_1 * g * (BC - H_1 * tan \propto) * cos \propto + m_2 * g * \left(\frac{1}{2}L_{arm} - BC + H_2 * tan \propto\right) * cos \propto + m_3 * g * (L_{arm} - BC + H_3 * tan \propto) * cos \propto + \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322} * (L_{arm} - BC + H_3 * tan \propto) > 0 \quad (6.1)$$

Simplification and substitution following the steps in between 3.5 and 3.8 results in the following equation:

$$\sum M = BC\left(-m_1 g - m_2 g - m_3 g - \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322}\right) + H_1\left(m_1 g + 2m_2 g + 2m_3 g + 2 * \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322}\right) tan \propto + L_{arm}\left(\frac{1}{2} * m_2 g + m_3 g + \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322}\right) > 0 \quad (6.2)$$

Further simplification delivers the final algorithm:

$$H_1 > \left| \frac{BC\left(m_1 g + m_2 g + m_3 g + \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322}\right) - L_{arm}\left(\frac{1}{2} * m_2 g + m_3 g + \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322}\right)}{\left(m_1 g + 2m_2 g + 2m_3 g + 2 * \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322}\right) tan \propto} \right| \quad (6.3)$$

Adding the engine results in:

$$M > BC\left(m_1g + m_2g + m_3g + \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322}\right) - H_1\left(m_1g + 2m_2g + 2m_3g + 2 * \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322}\right) tan \propto - \left(\frac{1}{2} * m_2g + m_3g + \frac{m_3 * 2\pi * Larm * \frac{1}{6}}{0.00322}\right) \quad (6.4)$$

CONCLUSION

After this analysis, a spreadsheet was compiled using the different algorithms set up in this section. The spreadsheet uses predefined equations and values to calculate required dimensions. It is important to note that most values in the grey defined boxes are defined for the Lynxmotion AL5D, but these can be used to calculate platform dimensions for any similar robot manipulator. The dimensions resulting from these values will be utilized when detailing the design. An image of the

Toppling effects formula spreadsheet

Green fields highlight editable cells, while gray cells are values defined for the Lynxmotion AL5D. The blue cell indicates the final requirement.

Parameter	Variable	Value		
Mass platform	m1	10.000	kg	
Mass robotic arm	m2	0.879	kg	
Mass payload	m3	0.369	kg	
Length robotic arm	Larm	0.419	m	
Gravitation	g	9.810	m/s²	
Motor Torque	M	2.420	Nm	
Slope angle	α	2.000	degrees	
Motor 60 degree time	t_60	0.140	s	
Time to slow down on impulse	Δt	0.023	s	
Angle of travel distance during impulse slowdown	Δs	10.000	degrees	
Force resulting from impulse	F	50.282	N	
Minimum distance platform/tipping point (static)	**Min. BC**	3.012	cm	(Situation A)
Minimum distance, motor torque added	**Min. BC (inc. M)**	**5.205**	cm	(Situation A, with engine)
Maximum height platform (static)	**Max. H1**	122.828	cm	(Situation B)
Maximum height, motor torque added	**Max. H1 (inc. M)**	**121.925**	cm	(Situation B, with engine)
Minimum distance platform/tipping point (static, on impulse)	**Min. BC (inc. Impulse)**	22.105	cm	(Situation A, with impulse)
Minimum distance, motor torque added (on impulse)	**Min. BC (inc. M + Impulse)**	**24.298**	cm	(Situation A, with engine + impulse)
Maximum height platform (static, on impulse)	**Max. H1 (inc. Impulse)**	94.212	cm	(Situation B, with impulse)
Maximum height, motor torque added (on impulse)	**Max. H1 (inc. M + Impulse)**	**93.716**	cm	(Situation B, with engine + impulse)

Figure 5: Platform dimension spreadsheet

MARKET RESEARCH: WHEELS

In order to gain insight into viable wheel designs, analysis of existing competing products is made. As accuracy is of high priority, the focus is laid upon slippage resistance of wheels. The second priority is the agility of the platform, and thus comparison of wheel types is necessary in order to choose the most efficient components. This section displays the research results and a comparison in which the most promising wheel type is selected.

CONVENTIONAL WHEEL

Conventional wheels are common wheels used to propel consumer and industrial products such as cars, bicycles, toys and aeroplanes. Frequently produced using alloy and rubber (heavy duty) or plastic and rubber (lighter duty), this type of wheel can produce movement in both forward and backward directions. By angling one or a set of wheels, the vehicle can be steered into another direction. Movement perpendicular to the hub axis is inherently not possible with this type of wheel. The wheels commonly consist of a hub, rim, tire and, depending on the type of wheel, spokes or wires. Tires are usually pneumatic (filled with air or gas) or non-pneumatic and textured, depending on the requirements assigned to the wheel to either improve ground friction or reduce hydroplaning. Hydroplaning is a phenomenon where the wheel no longer rests on the surface, but on a layer of water, thereby losing surface friction entirely.

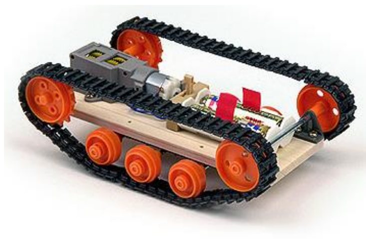
Pros (Institute of Technology and Engineering - Massey University, 2002):

- Cost effective, easily replacable
- Ease of meeting requirements due to great variety available
- High load capacity
- High tolerance to work surface irregularities

Cons:

- One-dimensional movement

CONTINUOUS TRACK



Tracks are a continuous band of threads spanned and driven by two or more wheels. These are commonly found in tanks and heavy duty utility vehicles, such as for snow clearing. Compared to conventional wheels, a tracked vehicle displays a larger contact with the ground surface and thus attains more surface friction. However it is also subject to slippage, especially when turning, as the orientation and structure is similar to the conventional wheel, and steering is only possible by differing the driving force between tracks.

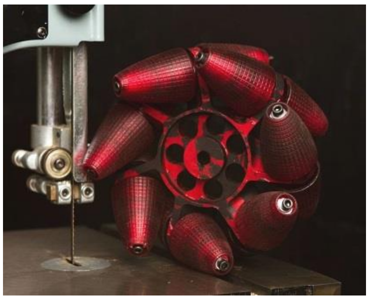
Pros:

- Greater ground to vehicle contact → greater ground surface friction
- Retains traction on soft surfaces

Cons:

- Slippage when steering and turning

MECANUM WHEEL



A wheel design invented by the Swedish inventor Bengt Ilon, allows the vehicle to move in any desired direction. The mecanum wheel is a conventional wheel with a number of rollers fixed in the rim at a roughly 45 degree angle. This allows the vehicle to not only move forward or backwards, but also sideways and diagonally. An opposing factor to the wheel is the high cost which comes with it. Lower quality and less expensive mecanum wheels commonly produce slippage, thereby hindering accuracy of the vehicle. Although omnidirectional movement is possible, the mecanum wheel should only be incorporated with the design if accuracy loss and costs are limited.

Pros:

- Allows for omnidirectional movement
- Wheel orientation similar to conventional wheels

Cons:

- High in cost
- Lower cost and quality results in lower accuracy

OMNIWHEEL

Similar to the mecanum wheel, the omniwheel allows for twodimensional movement. Bearing resemblance to the conventional wheel, it houses rollers on an axis tangential to the rim, and perpendicular to the hub axis. Therefore, twodimensional movement is only possible when the wheels are angled at a 45 degree angle to the driving axis. This implies that, for a four wheel vehicle to move omnidirectionally, its wheels are required to be perpendicular to the vehicle's center point. The image on the right hand side demonstrates such a vehicle. Omniwheels, while limiting the wheel orientation, are lower in cost when compared to the mecanum wheels. Accuracy of these wheels is arguable, however, Rojas and Förster show in their research that if motor torque is kept to a limit, wheel slippage is kept to a minimum (Rojas & Förster, 2005). The design would benefit from testing their allegations, as enabling omnidirectional movement would decrease the need for a large workspace.

Pros:

- Allows for omnidirectional movement
- Lower in cost compared to mecanum wheel

Cons:

- Limited integration within system
- Slippage (may be kept to minimum)

SPHERICAL WHEEL

A spherical wheel is a sphere bearing situated inside a fixture, similar to those in a ball computer mouse, and allows for omnidirectional movement. Although commonly used in conveyor systems with the ball side up, these may be used for vehicles when the main problems are overcome. These problems manifest in the load bearing fixture: as the fixture rests on the sphere, the stresses result in larger wear on the restraining fixture. As this type of wheel cannot be driven by an engine, it only may fulfill a passive role if it is incorporated in the design.

Pros

- Allows for omnidirectional movement
- Low profile, allows for 'floating' designs

Cons

- Does not allow for actuation
- Ball-down position results in greater wear on the fixture, requires heavy duty specimen

CONCLUSION

After the analysis, the omniwheels represent one of the more prominent choices. Allowing for movement in two directions, it would decrease the need for workspace in the environment. The omniwheel would be more applicable for the design compared to the mecanum wheel due to their price differences. Also, little research has been found concluding a higher achieved accuracy of mecanum wheels compared to omniwheels. Due to the occurrence of slippage while driven by omniwheels, it would be wise to further investigate options which retain accuracy during these movements. This should be done through testing the theories provided by Rojas and Förster, and analyzing and documenting the results – provided that the decision is made to include this principle in the final design.

Two other configurations are determined to be suitable for the mobile platform: differential wheeled and conventional four wheeled vehicle. In a differential wheel setup, two driven wheels facilitate movement of the vehicle, while spherical wheels or caster wheels provide balance. This setup allows for turning around the vertical axis with a small turning radius. Due to this set up requiring only two motors instead of four, it is also the most cost effective.

The third configuration is the four wheeled robot, providing the most traction of the three configurations. Cheaper than the omniwheel set up due to the cost effectiveness of conventional wheels allow for a cheaper device with more traction than an omniwheel device. Steering would occur by changing the rotational movement of the wheels, also called 'skid steering' (four motors required), or changing the angle of one of the pairs of wheels (three motors required). This configuration, although providing the most traction, is costlier than the differential wheeled configuration and reduces mobility compared to both aforementioned configurations. In further analysis and concept development this issue is reflected upon, to prevent limitations to creativity.

MARKET RESEARCH: ROBOTIC MANIPULATORS

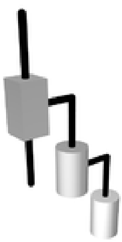
The platform accommodating the robotic arms, or robotic manipulators could account for a variety of manipulator designs, thereby improving compatibility and usability. In this section, a number of robotic arm types will be discussed and analyzed to provide arguments for future design decisions in this project. This also delivers the benefit of learning the methods in which robot manipulators operate. It is important to note that the current platform will be designed to accommodate the available Lynxmotion AL5D robotic manipulators, but compatibility with other types is desired. According to RobotWorx, six categories of robots are available on the market, which include cartesian, SCARA, cylindrical, delta, polar and vertically articulated types. Each type offers a different joint or axis configuration (RobotWorx, 2013c). This section will cover examples from four robot types, and the data will be used to determine the most suitable dimensions of robotic arms the platform has to account for.

VERTICALLY ARTICULATED: FANUC ARCMATE 100I

Vertically articulated robots commonly vary between four and six axes and are most common in the automobile industry. An example of a robot manipulator articulated in six axes is the Arcmate 100i, which houses six servos, enabling rotation with six degrees of freedom (RobotWorx, 2013d). Its reach is specified at 1368 mm, with a payload of 6 kilograms. Weighing at 290 kilograms, it has a specified repeatability of approximately 0.1 mm (RobotWorx, 2013a). Repeatability specifies the accuracy with which the manipulator can position itself, with respect to the initially 'taught' point.

To program the 'algorithms' for the robot to execute, a teach pendant is used to register and program the robot's motions. When programming, the manipulator is repositioned manually, and its position is stored by the teach pendant. After every step and their respective position is recorded, the robot can repeat these steps with the aforementioned repeatability of approximately 0.1 mm. Joint speeds are set between 120 and 450 degrees per second.

SCARA: ADEPT COBRA SCARA ROBOT S800 4 AXIS ROBOT



A robot manipulator manufactured by Adept Technologies, an American company active in industries requiring high speed precision part handling. SCARA is an acronym for Selective Compliant Assembly Robot Arm, indicating the two parallel axes present in the robot. The tip of the robot enables vertical positioning of the gripper for the execution of tasks. The reach of this model covers a distance of 800 mm, with a maximum payload of 5.5 kilograms.

Cobra SCARA robots possess a higher level of accuracy compared to the standard 6 axis robots, with an XY plane repeatability of 0.017 mm and 0.003 mm in the Z axis (Adept Technologies, 2013). Specifications of this product indicate joint speeds between 386 and 1200 degrees per second, thus allowing for faster execution of tasks compared to the 6 axis robots.

CARTESIAN: ADEPT PYTHON LINEAR MODULE

Cartesian robots operate by moving in a straight line, instead of rotating axes. These axes are configured perpendicular to each other, thus are simple in operation compared to the articulated or SCARA robots. Performance wise, the Cartesian robot bears similarity to the SCARA robots. Cartesian robots are commonly sold in hanging variants, situated on a grid, resulting in more floor space, at the cost of decreased mobility. SCARA robots on the contrary, can be built on a smaller scale at the cost of floor space (RobotWorx, 2013e).

The Adept Python linear module's 'reach' varies between 100 mm and 2000 mm, depending on the requirements. Supporting a maximum payload of 160 kilograms, it is able to reach speeds up to 1450 mm per second. Due to the static nature of Cartesian robots, this type of robotics is not considered efficient to account for in the design.

DELTA ARTICULATED: FANUC M-1IA

Delta articulated robots sport a spiderlike appearance and provide a compact solution for automated lightweight material handling tasks. This compact type of robot can move light materials at a joint speed of 1440 degrees per second. Weighing 17 kilograms, it can relocate materials of a maximum of 1 kilogram, justifying its usage in lightweight material handling. The M-1iA has a repeatability of 0.02 mm, placing it between the Arcmate 100i and the Cobra s800 accuracy-wise, but surpassing these models on speed of task execution.

However, not all delta articulated models are compact and mobile, as some models are attached on a grid similar to those found in Cartesian robots. Therefore, the platform will provide accommodation for compact 'floored' robots.

CYLINDRICAL AND POLAR ARTICULATED

Cylindrical and polar articulated robots work from a rotating base, with the gripper moving vertically to execute its tasks. Due to their structure, one can transport these robots in a similar fashion as the vertically articulated robots. Also, market research showed decreased availability of these kind of robots compared to the former, and thus the assumption was made that these are similar in size and mounting as the vertically articulated models.

AVERAGE SPECIFICATIONS

To derive dimensions for the platform, a small scale research of robot sizes has been conducted. The footprints, heights and arm lengths of a range of robots were collected from datasheets, and specifications have been acquired and documented. As already mentioned, cylindrical and polar articulated robots are treated as vertically articulated robots, and thus not mentioned. The table on the next page shows the results of this research. It is also important to note that this project focusses on light duty robots. However, it is possible to derive specifications of the platform for heavy duty robots by upscaling the platform's dimensions.

Type	Weight	Footprint	Arm length/ reach	Maximum payload	Maximum shoulder speed
Vertically articulated					
AAB IRB 120	25 kg	250 x 250 mm*	580 mm	3 kg	250 °/s
KUKA KR 3	53 kg	250 x 250 mm*	635 mm	3 kg	240 °/s
KUKA KR 5	127 kg	210 x 210 mm*	650 mm	5 kg	375 °/s
FANUC Arcmate 50iL	41 kg	220 x 220 mm*	856 mm	3 kg	90 °/s
FANUC Arcmate 100i	290 kg	500 x 500 mm*	1368 mm	6 kg	120 °/s
SCARA					
Adept Cobra SCARA s800	43 kg	338 x 200 mm*	800 mm	5.5	1200 °/s**
Motoman HS-5-450	20 kg	120 x 120 mm*	450 mm	5 kg	Unknown
Motoman YS650L	20 kg	120 x 120 mm*	650 mm	5 kg	1870 °/s**
Yamaha YK400XG	19.5 kg	140 x 140 mm*	400 mm	5 kg	1020 °/s**
Stäubli TS40	46 kg	270 x 150 mm*	400 mm	8 kg	2020 °/s**
Delta articulated					
Arcmate 100i	17 kg	370 x 120 mm*	280 mm	1 kg	1440 °/s**
Codian Robotics D4-500	25 kg	N.a.***	500 mm	2 kg	Unknown
Adept Quattro s650H	117 kg	N.a.***	1300 mm	3 kg	Unknown
ABB IRB 360-1/800	120 kg	N.a.***	800 mm	1 kg	Unknown

* Estimated number, (RobotWorx, 2013b)

** SCARA and delta robots deliver impulse only in the horizontal range

*** Not applicable, as most delta robots are mounted on a ceiling or a frame, so dependent on environment design.

CONCLUSION

After collecting data on a variety of industrial robots, estimations for an 'archetype' can be made. This archetype will represent the range of robotic manipulators which the platform will account for. It is important to note that the mobile platform will be designed solely for usage by the University of Twente, and thus must accommodate mainly for the Lynxmotion AL5D, a vertically articulated robotic manipulator. It is desired that the platform supports a range of robotic arm types, and thus a range of theoretical robotic arm specifications have been derived as follows:

Weight	Footprint	Arm length/ reach	Maximum payload	Maximum shoulder speed
30	200 x 200 mm	800 mm	5 kg	400 °/s

The values in the list are meant for larger industrial robotic manipulators, and not for the Lynxmotion AL5D. The theoretical design, which will not be prototyped, would account for these values. The prototype to be built in this project will not reflect on these values as these would make the platform too large, thereby impairing the Lynxmotion AL5D's. Notable is that this issue only arises when the robotic arm is fixed to the platform, whereas relocating a separate robotic arm (situated on a frame) will not be affected by the platform's size.

MARKET RESEARCH: WIRELESS COMMUNICATION SYSTEMS

Requirements specified for the mobile platform, included the need for wireless control. In order to determine the most efficient communication method between user and platform, an analysis of current industrial uses of wireless communication systems has been conducted. Much of the specifications were derived from data sheets on automated guided vehicles (AGVs), due to the large similarity with the mobile platform. Also, current mobile manipulators have been analyzed for further insight regarding this issue.

WI-FI WIRELESS COMMUNICATION

Wi-Fi refers to any wireless device which uses protocols based on the Insititute of Electrical and Electronics Engineers (IEEE) 802.11 standards (Webopedia, 2013). Wi-Fi is currently used to establish communication canals between AGVs and their industrial environment, utilizing a signal frequency of 2.4 GHz. Because this form of communication is widely used in industrial, office and consumer environments, companies do not need to adapt their already deployed networks to control purchased AGVs. Also, WiFi provides a wide compatibility to a variety of wireless devices aside from AGVs, such as programmable logic controllers (PLCs), measuring devices and sensor devices. The technology enables devices to 'roam,' signifying the ability to seamlessly switch between access points, thus data connection is not lost even when moving out of range (Moxa Technologies, 2013). Lastly, current mobile manipulators use the protocol to communicate with their operating server, an example would be the 'Little Helper' developed by Mads Hvilshøj and Simon Bøgh at Aalborg University.

SPREAD SPECTRUM COMMUNICATION

Spread spectrum wireless communication is a technique often used in WiFi connections and to a lesser degree, cellular networks (Mitchell, 2013). The frequency on which the signal is communicated at varies according to a defined algorithm. Receivers scan the range of frequencies according to a predefined algorithm, and combine the signal parts together to recreate the intended signal (Rouse, 2006). The technology is present in AGVs designed by Hitachi Technologies (Hitachi Technologies, 2013).

BLUETOOTH

Bluetooth, or is a wireless technology used in a variety of handheld devices. Similar to WiFi, it operates on a frequency of 2.4 GHz. Compared to the former, it is used to a lesser degree in industrial environments – due to wide availability of WiFi networks and superior data speeds – resulting in WiFi being more practical overall. However, Bluetooth devices are applied in industrial uses when certain requirements, such as a lower power consumption, are present.

The main difference is present in the capacity of the networks, as the most utilized version (2.0) can connect to a maximum of seven wireless devices (Sena Technologies, 2007). Also, Bluetooth requires a lower energy input to establish its connections, down to three percent of the power required by WiFi for certain tasks. The lower power consumption compromises on range, as WiFi's range of operation may be ten times greater than that of Bluetooth (Vogler, 2013). As already mentioned, WiFi's data transfer speeds and range are greater compared to Bluetooth's, respectively 54 Mb/s compared to 1 Mb/s, and 10 – 100 meters compared to 50 – 100 meters for range (Lee, Su, & Shen, 2007).

OPTICAL DATA TRANSMISSION

Optical Data Transmission is a principle with which devices can communicate through the use of infrared light. Already utilized in automated vehicles, it establishes a wireless connection between two devices while eliminating interference present in radio frequency methods such as WiFi or Bluetooth. Also, recalibration is not needed with the usage of ODT, according to Sentek (Sentek Solutions, 2013). It should be noted that ODT devices require a direct line of sight to establish the connection, thus requiring a certain structure to the workspace for proper operation. The power consumed by ODT is only a fraction of the power requirements of previously mentioned radio frequency methods. Due to the line of sight required by the devices, ODT should be considered for the design's data transmission during docking or operating down a linear path.

ZIGBEE

ZigBee, or the IEEE 802.15.4 protocol, is a configuration of a wireless communication method, similar to WiFi and Bluetooth. Targeted at applications requiring a lower data rate, long battery life and secure networking, it is used in the industry for control of actuators and monitoring by utilization of wireless sensor networks.

ZigBee's design goal was the creation of a low power wireless communication method, emphasizing low power consumption. As a result, ZigBee can go into 'sleep mode' within 15 milliseconds, making the ZigBee protocol highly responsive, lower in power consumption compared to WiFi and Bluetooth, with a significantly longer battery life (Sena Technologies, 2010). However, this compromises on data transmission speeds, as the maximum data speed is 250 Kb/s with a range of 30 meters. ZigBee is best used and targeted for applications not requiring a constant data stream to operate.

ZigBee®
Control your world

CONCLUSION

This section reflects on mobile manipulators and AGVs to determine the wireless protocols most suitable for the mobile platform. WiFi, due to its superior range and wide availability seems most efficient when the decision is made to produce multiple robots. Bluetooth presents itself as a promising competitor to WiFi, but for the current project, the latter would be more suitable to control the robot, as the project must be able to reflect on industrial usage. Optical data transmission could be chosen to include for situations in which direct line of sight is available and radio interference is present. Lastly, the ZigBee protocol is deemed unsuitable due to its focus on low power consumption, thereby compromising on data stream.

It is predicted that the mobile platform will require a constant data stream, therefore WiFi (with spread spectrum protocol) and ODT are deemed most suitable to be included within the design.

ANALYSIS: BATTERY REQUIREMENTS

One of the requirements specified for the project is for the design platform prototype to operate at least 15 minutes without charging the battery. For this purpose, the energy consumption should be collected from the sensors and actuators present within the mobile platform. Analysis of current batteries in similar products, such as AGVs or mobile manipulators should provide further insight into the choice of battery for the mobile platform.

MOBILE MANIPULATORS AND AGVS

This section reflects on current mobile manipulators and AGVs, focusing on the batteries used within respective devices. By analyzing current technologies, specifications for the mobile platform can be derived. For this section, three current similar technologies are described and analyzed.

LITTLE HELPER – AALBORG UNIVERSITY

The Little Helper – previously mentioned in this document – is a mobile manipulator developed by students at the Aalborg University, situated in Denmark. Able to detect loads by the use of QR codes and lift these towards their respective destinations, it presents itself as a mobile manipulator suitable for industrial use.

The little helper is powered by a battery pack, consisting of eight 12 VDC (Volt Direct Current) lead acid batteries, generating a total of 24 VDC. To power the robotic arm, which requires 230 VAC, a DC/AC inverter is used to invert the 24 VDC from the battery pack to the required 230 VAC. The Little Helper's power supply provides sufficient power to drive the 230 kg machine – with a payload of 20 kg – for a total of 8 hours at a speed of 1 m/s. However, it is able to charge automatically during operation (Hvilshøj & Bøgh, 2011).

MOBILE PLATFORM MP-500 – NEOBOTIX

The MPO-500 mobile platform created by Neobotix GmbH is a compact industrial mobile robot suited for industrial use. Prepared for easy modification, the robot can be deployed for use in various applications. Both its hardware and software may be modified in order to fully adapt the robot to the client's needs.

Able to carry loads up to 50 kilograms, the MP-500 is powered by battery which enables an operating time of up to 10 hours before requiring a recharge. The battery is able to provide a voltage of 24 V, paired with a capacity of 38 Ah. The MP-500 itself weighs approximately 70 kilograms and is capable of driving at speeds up to 1.5 m/s (Neobotix, 2012).

SPH-2200 – ADEPT TECHNOLOGIES

The SPH-2200 is a mobile manipulator created by Adept Technologies. Sporting a polar articulated robotic manipulator, the platform is able to autonomously navigate through a crowded environment based on the operator's requests. Used for handling 150 or 200 mm SMIF pods – semiconductor wafers, commonly used in integrated circuits – it can transport these objects without any changes required to the infrastructure.

The mobile manipulator includes a 28-30 VDC Lithium-Iron battery, which is similar to Lithium-Ion, with a longer cycle life and less pollution through omittance of cobalt present in Lithium-Ion batteries (Electropaedia, 2005). Battery life of the SPH-2200 is specified at up to 8 hours, after which the device requires a recharge of 3.5 hours. Lastly, the device is able to run at speeds of 1.8 m/s (Adept Technologies, 2012).

TYPES OF BATTERIES

Aside from insight to battery specifications from current product datasheets, a comparison of battery chemical principles provides further understanding when selecting a suitable battery. The table below summarizes the benefits and limitations of various battery chemistries.

Battery type	Benefits	Limitations
Nickel Cadmium (NiCd)	• Fast and simple charge' • Simple storage (no requirements) • High number of charge/ discharge cycles (> 1000) • Charging at low temperatures possible • Long shelf life • Low temperature performance • Economical pricing • Wide range of sizes and performances	• Relatively lower energy density • Must be periodically exercised (memory effect) • Environmentally unfriendly • Relatively high self-discharge
Nickel-Metal Hydride (NiMH)	• 30 – 40% higher capacity over standard NiCd • Periodical exercise needed to lesser extent (lesser memory effect) • Simple storage (no regulatory control) • Environmentally friendly (only mild toxins)	• Deep discharging/ charging lowers service life (amount of cycles) • High discharge currents reduce service life • Generates more heat and requires longer charges • High self-discharge (50% higher than NiCd) • Performance degrades at higher temperatures • Requires high maintenance (full discharge to prevent crystallization) • About 20 percent more expensive than NiCd
Lead Acid	• Inexpensive and simple in manufacture (lowest cost per Wh) • Reliable and well understood technology • Low self-discharge (among	• Must be stored in charged condition • Low energy density – poor weight-to-energy ratio • Limited number of deep discharge cycles

	the lowest) • Low maintenance (no memory effect) • Capable of high discharge rates	• Environmentally unfriendly • Transportation restrictions (flooded lead acid) • Thermal runaway may prevent proper charging
Lithium-Ion (Li-ion)	• High energy density • Relatively low self-discharge (less than 50% of NiCd and NiMH) • Low maintenance (no periodic discharge, no memory effect)	• Requires protection circuit to limit voltage and current • Subject to aging • Moderate discharge current • Subject to transportation regulations (in larger quantities) • Expensive to manufacture (40% higher in cost than NiCd) • Not fully mature technology, battery tests might not be accurate
Lithium-Ion Polymer (Li-ion polymer)	• Low profile (credit card profiles feasible) • Flexible form factor • Light weight • Improved safety (resistant to overcharge, less prone to leakage)	• Low energy density and decreased cycle count compared to Li-ion • Currently expensive to manufacture

Source: (Battery University, 2010)

REFLECTING ON THE MOBILE PLATFORM

Based on the analysis, a lead-acid battery would seem most suitable for the mobile platform when brought into an industrial environment. However, the prototype will have its dimensions scaled down to suit the Lynxmotion AL5D, and thus requires a lesser weight capacity compared to its theoretical industrial variant. To select a battery with suitable specifications, calculations were needed to specify requirements on battery capacity.

The specifications of the Lynxmotion AL5D state that the servos that drive the robotic arm require a voltage of 6 VDC to operate. This is relevant when the design decision is made to permanently situate the robot on the platform. To calculate the power for driving the platform towards its destination, an assumption should be made regarding the power drawn by motors. These assumptions are based on the servos present in the AL5D.

As the position on which the platform arrives should be within 1.0 cm of its intended destination, stepper motors serve as the most suitable solution for driving the platform. The specifications of a general stepper motor on the market will be used for the calculation: the ROB-09238, commonly used for realizing features in robotic projects. The ROB-09238 stepper motor requires a voltage rated at 12 V at 0.33 A to operate. During the calculating process, one should note that most probably four of these motors will be implemented within the platform's design. The sensors included within the platform will draw power to a far lesser degree compared to actuators – in this case – the motors and, if included, the robotic arm. Therefore, these are obsoleted from the calculation and replaced by an assumed value. In order to calculate the right ampere-hours for finding the right battery, all parameters need to be converted into ampere. The next section will cover this calculation.

ESTIMATION FOR THE SELECTION OF A SUITABLE BATTERY

To calculate the required specifications assigned to the battery, the components drawing power need to be defined. Through assumptions, omission, anticipation and datasheets, the following parameters are acquired:

Component	Amount	Voltage	Amperage
Stepper motor	4	12 V	0.330 A
Ultrasonic sensor	1	5 V	0.002 A
Infrared sensor	1	1.7 V	0.100 A
LED indicators	10	2.5 V	0.030 A
Wi-Fi Module	1	3.3 V	0.154 A
Microcontroller	1	12 V	0.050 A
Optional: Servo motor**	1	6 V	0.164 A
Optional: Lyxmotion AL5D	1	6 V	0.500 A***

* Voltages and amperages are displayed per module.
** Servo motor applicable when choosing to lift a frame of 20 kg in 10 seconds using a Hitec HS-805BB servo.
*** Assumption based on usage of 4 servos present in the Lynxmotion AL5D

Sources: (Sparkfun, 2013); (Tradeflair - Ebay, 2013); (Emarket4un - Ebay, 2013); (Texas Instruments, 1995); (Maplin Outlet - Ebay, 2013); (Arduino, 2013); (Hitec, 2013); (Lynxmotion, 2013).

As parameters are defined, a spreadsheet using cell equations was created to provide a quick specification for the battery. As components change within the process, battery capacity requirements and maximum operating times can be easily retrieved by adjusting parameters within the spreadsheet.

Component	Amount	Voltage (V)	Amperage (A)
Stepper motor	4	12	0.330
Ultrasonic sensor	1	5	0.002
Infrared sensor	1	1.7	0.100
LED indicators	10	2.5	0.030
Wi-Fi Module	1	3.3	0.154
Microcontroller	1	12	0.050
Optional: Servo motor**	1	6	0.164
Optional: Lyxmotion AL5D	1	6	0.500
Total Amperage			**2.59**
Minimum battery voltage	12	V	
Operating time	0.25	hours	
Minimum battery capacity	**0.6475**	Ah	
Selected battery capacity	7	Ah	
Operating time	**2.7**	hours	

SELECTING A SUITABLE BATTERY FOR PROTOTYPE INTEGRATION

Based on analysis on battery types and batteries used in current products, the most prominent battery is either a NiMH or lead acid battery. Mainly their availability and properties regarding frequent recharge/discharge makes these battery types most suitable for the prototype, as the prototype will most probably perform a short task, then relocate to its charging station. Maintenance issues can be resolved by writing 'battery exercising' tasks within the software, depending on which battery is used.

MOST COST EFFICIENT BATTERY

To define the most cost efficient battery for prototyping use, further research was conducted on battery pricing. The batteries selected needed to qualify conforming the following requirements derived from the spreadsheet:

- Either NiMH or Lead cell battery
- Solution must provide for at least 12 V of voltage
- Solution must provide for at least 1.2 Ah of capacity
- Solution should not exceed € 30 in cost (assumption)

Based on these requirements, the battery with the highest Ah to price ratio will be considered. The table below displays the battery solutions found, after which a conclusion might be drawn.

Lead acid battery	Amount	Voltage	Capacity	Price
DAS12-2.2	1	12 V	2.2 Ah	€ 14,95
BP1.2-12BB	1	12 V	1.2 Ah	€ 10,49
GP1245	1	12 V	4.5 Ah	€ 15,45
NiMH battery	**Amount**	**Voltage**	**Capacity**	**Price**
SANYO HR4/3AU	1	12 V	4.0 Ah	€ 9,95
Tenergy 12V 2000mAh NiMH Battery Pack	1	12 V	2.0 Ah	€ 22,25
AT: Rectangular Nimh 12V 4200mAh High Drain Battery Pack	1	12 V	4.2 Ah	€ 24,99

Sources: (Replace Direct, 2013a); (Conrad, 2013b); (Replace Direct, 2013b);(Zbattery, 2013b);(Zbattery, 2013a);(All-Battery, 2013b);(All-Battery, 2013a)

Also, considerations regarding the use of batteries from existing products were present, such as a power drill or laptop battery. Analysis of market prices of these products proved this method to be less cost efficient compared to a standalone battery. Options to include multiple rechargeable standard batteries were also considered, but ultimately turned out more expensive compared to compounded battery packs. The options were placed into a spreadsheet to select the battery with the highest Ah to price ratio. This spreadsheet is displayed on the next page.

Component	Amount	Voltage (V)	Amperage (A)
Stepper motor	4	12	0.330
Ultrasonic sensor	1	5	0.002
Infrared sensor	1	1.7	0.100
LED indicators	10	2.5	0.030
Wi-Fi Module	1	3.3	0.154
Microcontroller	1	12	0.050
Optional: Servo motor**	1	6	0.164
Optional: Lyxmotion AL5D	1	6	0.500
Total Amperage			**2.59**
Minimum battery voltage	12	V	
Operating time	0.25	hours	
Minimum battery capacity	0.6475	Ah	
Recommended capacity	**1.2**	Ah	
Selected battery capacity	3.2	Ah	
Operating time	1.24	hours	
Uptime in minutes	**74**	minutes	

Lead acid battery	Amount	Voltage (V)	Capacity (Ah)	Price (€)	Ah-Price ratio
DAS12-2.2	1	12 V	2.2	14.95	0.15
BP1.2-12BB	1	12 V	1.2	10.49	0.11
GP1245	1	12 V	4.5	15.45	0.29
NiMH battery	**Amount**	**Voltage (V)**	**Capacity (Ah)**	**Price (€)**	**Ah-Price ratio**
SANYO HR4/3AU	10	1.2 V	4	99.5	0.04
Tenergy 12V 2000mAh NiMH Battery Pack	1	12 V	2	22.25	0.09
AT: Rectangular Nimh 12V 4200mAh High Drain Battery Pack	1	12 V	4.2	24.99	0.17
Highest value:	0.29				

The spreadsheet indicates that the GP1245 is the most cost efficient battery for the prototype. Providing 4.5 Ah of battery capacity, it would enable the prototype an operating duration of 104 minutes, greatly exceeding the specified requirement of 15 minutes. It should be noted that as the GP1245 is a lead acid battery, caution must be exerted regarding the following factors:

- Should not be left uncharged
- Should not operate too long without charging to increase amount of duty cycles
- Should exert caution at disposal, as the battery is environmentally unfriendly

CHARGING THE BATTERIES

Off the shelf lead acid batteries can be recharged with the use of a universal lead acid battery charger. Chargers are cost effective, down to € 8 for a universal lead acid battery charger (Conrad, 2013a). It is desirable for the prototype to charge autonomously, and a docking station would provide a suitable solution. This docking station will have to be developed in parallel with the concept. Purchasing a ready-to-use docking station would prove to be expensive, limit the concept's form factor and is therefore not desirable.

CONCLUSION

Analysis concluded that the GP1245 provides the most prominent solution to powering the prototype. Enabling the prototype to operate for a maximum duration of 104 minutes, it exceeds requirements and allows for more flexibility when using the mobile platform. The frequent use of this type of battery confirms this decision, and further analysis into battery types points towards the cost effectiveness of this particular solution.

To accommodate the battery, the prototype's software should include battery maintenance tasks. The prototype may not be left uncharged or operate too long in order to maximize battery cycle life. After the GP1245 has become unusable, it should be disposed properly and be replaced with a new battery of the same type. However, as the battery can operate up to 5 years in standby service or more than 260 cycles at 100% discharge rate (as an extremity), replacement should not be too much of an issue. The prototype should allow for easy replacement of the battery should the need arise.

Charging the battery will ensue autonomously at a docking station. The docking station will have an off the shelf lead acid battery charger integrated to reduce production costs.

MARKET RESEARCH: STRUCTURE OF MOBILE PLATFORMS

This section expands on the general structure of mobile platforms. Analysis on this subject generates further understanding on working principles of autonomously operating vehicles and benefits the overall design process of the mobile platform concept. Analyzed vehicles will include mobile research robots, as these robots bear most resemblance to the platform concept. Due to the versatility these robots provide, the hardware for the platform design can be derived in order to build an adaptable platform. Research will be conducted by selecting current vehicles and decomposing their structure within the following categories:

- Processing hardware
- Driving principles: wheel configuration, steering
- Principles that prevent collision: sensors, software
- Principles that establish communication canals
- Principles providing power to components

All of these categories will be described in brief for a total of three autonomously operating robots, after which the data will be summarized and result in a checklist for the prototype.

KOALA II – K-TEAM MOBILE ROBOTICS

The Koala II is a robotic platform for the usage in real-world experiments and demonstrations. Designed and manufactured by K-Team mobile robotics, it is intended for usage by researchers and hobbyists. The Koala platform, along with the Khepara platform – also produced by K-Team – is currently a standard for academic research on robotics (K-Team Mobile Robotics, 2002a).

KOALA II – HARDWARE STRUCTURE

The Koala II sports the following hardware to enable its functionality in research environments:

- Motorola 68331 processor @ 22 MHz
- 1 MB RAM memory
- 1 MB ROM memory (for running the software)
- Extra Input/Output ports for expansion (I/O ports)
  - 12 digital inputs
  - 4 CMOS/TTL digital inputs
  - 8 power (open collector) digital outputs
  - 6 analog inputs

(K-Team Mobile Robotics, 2002b)

KOALA II – DRIVING

The Koala II is supported by six wheels driven by two DC brushed servo motors with integrated incremental encoders.

KOALA II – COLLISION PREVENTION

To prevent the robot from colliding into walls or other objects within the environment, the Koala II includes the following sensors:

- 16 infra-red proximity and ambient light sensors
- 4 optional triangulation longer-range infrared sensors
- Up to 6 optional ultrasonic sonar sensors

By modifying the software to accommodate the sensors, the Koala II detects objects in its path and can execute tasks based on sensor information.

KOALA II – COMMUNICATION CANALS

The Koala II interfaces through a standard RS232 port, and allows any software capable of RS232 communication to control the robot. Wireless connection is also possible by equipping the device with a Wi-Fi wireless communication card.

KOALA II – POWER SUPPLY

The battery of the Koala II is a Nickel Metal Hydride battery with charge level memory, preventing the occurrence of battery memory effects. The battery pack has a capacity of 4Ah and can be replaced. Its capacity allows the six wheeled robot to drive for a time span between 4 and 6 hours, depending on the load moved.

PIONEER 3-DX – ADEPT TECHNOLOGIES

The Pioneer 3-DX is a compact, lightweight robot for use in laboratories and classrooms for research purposes. According to Adept, the Pioneer robot series are the world's most popular intelligent mobile robots for education and research. Its sturdiness and reliability resulted in some of the robots being used for over 15 years (Adept Technologies, 2011).

PIONEER 3-DX – HARDWARE STRUCTURE

The Pioneer is built using the following hardware for computation:

- Renesas SH microcontroller with ARCOS firmware
- 8 KB RAM memory
- 128 KB ROM memory for software purposes
- I/O pins ports for expansion
    - 32 digital inputs
    - 8 digital outputs
    - 7 analog inputs
    - 3 serial expansion ports

PIONEER 3-DX – DRIVING

The Pioneer 3-DX is supported by two wheels driven by servo motors equipped with 500-tick encoders with a swiveling caster on the rear. This allows the robot to turn around its axis and drive at a maximum speed of 1.2 m/s.

PIONEER 3-DX – COLLISION PREVENTION

The Pioneer 3-DX is equipped with 8 forward facing ultrasonic sensors, and can be extended with 8 rear facing sonars. Software can be programmed as such that the values retrieved from the sensors are incorporated within the driving behavior of the robot, for the purpose of preventing collision with walls or other objects (Webots, 2013). Optional accessories can extend the robot's interpretation of the environment through video cameras, wireless connections and laser range finders.

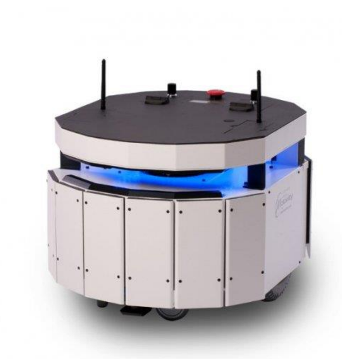
PIONEER 3-DX – COMMUNICATION CANALS

Similar to the Koala II, the Pioneer 3-DX can interface with a computer through the use of the RS-232 standard or USB standard. Pioneer SDK software developed by Adept Technologies can be used to write programs for the robot to execute. Optional accessories expand on communication possibilities, such as a Wi-Fi module for wireless communication (Adept Mobile Robots, 2013).

PIONEER 3-DX – POWER SUPPLY

The power supply of the Pioneer 3-DX consists of sealed lead-acid battery with a 9 Ah capacity. Three batteries may be inserted into the robot, extending the capacity to 27 Ah. This allows the device to drive for 30 hours continuously, provided that no laser or computer modules are attached.

MT 400 – ADEPT TECHNOLOGIES



The MT 400 is a small robot platform developed by Adept Technologies. The robot is a self-driving platform, allowing developers to customize the robot to suit their own applications. Adept has equipped the robot with her own software for self-navigation in crowded environments and tight hallways.

MT 400 – HARDWARE STRUCTURE

The MT 400 sports the following hardware for running programs:

- Integrated microcontroller with µARCS™ firmware
- Integrated Single Board Computer running Advanced Robotics Automation Management (ARAM™) software
- Flash drive for storage, 3 GB space left for mapping and configuration data
- I/O ports for expansion:
    - 8 Digital input ports
    - 8 Digital output ports
    - 6 Analog input ports
    - Auxiliary bumper ports
    - 2 serial ports in RS 232 standard

Source: (Adept Mobile Robots, 2012a)

MT 400 – DRIVING

The MT 400 is supported by two larger wheels driven by servo motors, with two pairs of caster wheels on the front and rear side for maintaining balance. Adept's robot can reach speeds up to 1.8 m/s using this set up, depending on the load.

MT 400 – COLLISION PREVENTION

To prevent collisions with other objects, the MT 400 can sense its surroundings with the use of a laser range finder on the front and 5 sonar sensors on the rear. Extra I/O ports allow for expansion of the device, further increasing its interaction with the surroundings. Collision chances are further diminished by Adept's self-proprietary software, focused at navigating while avoiding obstructions.

MT 400 – COMMUNICATION CANALS

Adept's MT 400 can interface with its operator through a wireless Ethernet (WiFi) module integrated with the device). Also, Ethernet ports are available for wired communication through a computer network. For uploading programs, maintenance and testing, a COM port is available for interface between PC and the MT 400. This is also possible through the integrated RS 232 ports, similar to the aforementioned robots (Adept Mobile Robots, 2012b).

MT 400 – POWER SUPPLY

The MT 400 is powered by two 24 VDC NiMH batteries wired in parallel, or two 12 VDC lead-acid batteries wired in series. Battery type can be selected per order, as the two battery types are more efficient in different applications:

- Lead-acid batteries suit a 1:1 run-to-recharge, thus two hours runtime followed by two hours of charging.
- NiMH batteries suit microcycling typically of about 16 minutes runtime on a 4 minute recharge.

Source: (Adept Mobile Robots, 2012a, 2012b)

KUKA OMNIMOVE – KUKA ROBOTER GMBH

The KUKA omniMove is marketed as a mobile platform solution, capable of holonomic movement due to it being equipped with omnidirectional mecanum wheels. It is designed for trans bulky loads with a high placement accuracy. The omniMove is capable of lifting pay tonnes, and ten different variants are available, depending on size and payload requ Robotics, 2013c).

KUKA OMNIMOVE – HARDWARE STRUCTURE

Details regarding the KUKA omniMove's exact hardware are unknown, as these were not released to the public domain. KUKA Roboter GmbH presents operator instructions in the form of seminars on order, where safety procedures and operator instructions are presented to companies (KUKA Robotics, 2013a).

KUKA OMNIMOVE – DRIVING

The KUKA omniMove is equipped with four or more mecanum wheels, depending on size or payload capacity. Using this system allows the omniMove to travel holonomously at speeds between 0.1 and 3.0 km/h (KUKA Robotics, 2013b).

KUKA OMNIMOVE – COLLISION PREVENTION

The omniMove can be controlled using two methods, the first being manual control using a joystick or similar controller. The second control method involves either inductive or optical guidance systems. Both systems are complemented by optical guidance systems and positioning assistance, resulting in positioning accuracies of up to approximately 5 mm. Additional accuracy and navigational features can be added by optional laser scanners (KUKA Robotics, 2013b).

KUKA OMNIMOVE – COMMUNICATION CANALS

KUKA's omnidirectional robot is equipped with radio communication channels for operator control (KUKA Robotics, 2013b). This allows for wireless communication between operator and platform. Additional information regarding this aspect is unavailable in the public domain.

KUKA OMNIMOVE – POWER SUPPLY

The KUKA omniMove is equipped with three 400V batteries, capable of powering the device at 32 amperes. This ultimately results in the platform being able to drive and relocate components with 20 to 40 kW of power, depending on size and payload (KUKA Robotics, 2013b).

REFLECTING ONTO THE PROTOTYPE

Reflecting the structures of intelligent logistics products on the platform prototype provides a rough image of components required to allow for proper operation. After the analysis, the following table was constructed, containing required hardware and respective anticipated technologies – along with their specifications – for inclusion within the platform.

Hardware	Practical technology and specification
Microcontroller	Arduino Mega • 54 digital I/O pins (15 capable of Pulse Width Modeling) • 16 analog input pins • 128 KB Flash memory • 8 KB SRAM • 4 KB EEPROM
Driving	2 – 4 stepper motors • Appropriate stepper motor drivers • Desired maximum speed of 1.0 m/s Wheel configuration: • Differential steered (2 wheeled + caster) • 3 wheeled • 4 wheeled • 6 wheeled
Collision prevention	1 – 4 ultrasonic sensors 1 – 4 infrared range sensor Navigation protocols in software
Communication canals	Wi-Fi module USB (Standard Arduino Port)
Power supply	Lead-acid battery, model GP1245

The specifications in this table will be used for the main internal architecture of the mobile platform. The exact amount of required stepper motors and sensors will be defined in a later stage of the project, as to prevent limitations during the design process.

CONCLUSION

This section has expanded onto the internal structure of currently available mobile robot platforms, from which parameters for the mobile platform design were derived. Specifications in this section define the core functionality of the mobile platform – to navigate itself through an environment while preventing collision with obstacles.

Features such as transporting a robotic arm are not specified in this section, as the technical aspects of such features must be defined after a definitive concept has been selected for construction. Questions regarding the method of transportation and other features will be explained later in this report, as defining of such questions will occur in the concept phase. This results in a wide variation of generated concepts while reducing the chance of omitting viable ideas.

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Building a robotic platform – Appendix B

University of Twente

This appendix contains the manufacturing instructions for the project and is relevant for further understanding the manufacturing methods in the second half of the document.

CK

10/14/2013

Contents

INSTALLING THE ARDUINO AND ELECTRIC IMP AND UPLOADING THE SOFTWARE

This section expands on the set up of the Electric Imp and its connection to the Arduino. Following these instructions will enable the Arduino to communicate wirelessly with the UI. For the physical implementation, the following materials are needed:

Components needed	Tools needed
• Arduino Mega 2560 • Electric Imp Shield • Electric Imp • Female headers • Male headers • Connector wires (or solder wire)	• Soldering iron • Soldering tin

The following steps should be executed to finish the physical implementation:

1. Solder the male headers onto the outer row of pins on the Electric Imp. The short side of the headers should be facing up, and the long side must face down and be able to connect to the Arduino.
   Note: The SCL and SDA pins must not be soldered. Also, the two unmarked pins adjacent to the RST pin must not be soldered. Soldering pins on these inputs will interfere physically when placing the shield on the Arduino.
2. Solder the female headers onto the inner row of pins on the Electric Imp. The input side must be facing upwards. The shield will look like the images on the right.
3. Place the shield on top of the Arduino, aligning its pins with the ones on the Arduino. The socket in which the Imp will be placed must face away from the USB connection port.
4. Wire pin 8 on the Imp shield to pin 19 on the Arduino (Rx1) and pin 9 on the shield to pin 18 on the Arduino (Tx1).
5. Place the Imp (SD card) into the imp socket. A light click confirms correct placement of the imp.
6. Finished.

SOFTWARE SETUP

To set the Imp up and immediately start receiving signals, the following steps should be followed. Note that these steps only need to be executed once, or when the imp is to be moved to another network.

Tools required:

- An internet connection
- A computer
- A smartphone, preferably an iOS device such as an iPhone or iPad (iOS devices give the least problems when configuring the imp, Android support is limited).

1. Browse to http://www.electricimp.com and create an account.
2. Download the Electric Imp app on the Android or iOS device.

3. Follow the app instructions and enter the SSID and security key.
4. The account credentials should be entered in the app, allowing for a direct association to be made between the Imp's cloud based environment and the Imp itself. The credentials can be found on the next page.
5. Power the Arduino with a barrel plug jack or through the Vin port, either through the battery or wall socket, USB may work. The Imp SD card should blink yellow.
6. Start the 'blink-up' procedure and immediately hold the electric imp's receiver (situated on one of the imp's sides, resembles a small rectangle) against the Android/iOS device's screen. Note: look away from the screen if one is sensitive to epileptic seizures.
7. The Electric Imp should blink LEDs in variable colors, and start blinking a green LED eventually.
8. If the Electric Imp does not blink green, when using an Android device, switch to an iOS device. If already using an iOS device, clear the wireless configuration on the Imp using the Imp app, and retry step 5. Also, shade the Imp from ambient light to improve transmission of the blink signal.

If the Imp blinks a green LED, it signifies that the Imp has been connected to the Imp cloud service, and is ready for program setup.

UPLOADING THE PROGRAM TO THE IMP

The Electric Imp code is readily available on www.electricimp.com. The software is stored on the account associated with the imp and can be accessed by using the 'sign in' option at the top right of the webpage. As of the 8th of October 2013, the account credentials are as follows:

Username: c.k.yong@student.utwente.nl
Password: eiutwente4991

The username is set to CKToxin, and cannot be changed. However, the e-mail address and password can be changed as desired. If the Electric Imp is powered on and connection is established (green blinking LED) by following the instructions on the previous page, the Imp's ID (currently "2314593643fc42ee") will show up within the electric imp webpage interface (Blueprint > Impees). The software used for the platform is called 'RobotWireless' and should be accessible from the same webpage named Code. By clicking "Build and Run," the webpage will send the code directly to the Electric Imp, and ready to be used for the platform.

From this webpage, further adjustments on the Electric Imp side of the platform processor can be made.

UPLOADING THE PROGRAM TO THE ARDUINO

To upload the code to the Arduino, one will need to install the Arduino software and the following libraries:

- NewPing library: http://playground.arduino.cc/Code/NewPing
- Accelstepper library: http://www.airspayce.com/mikem/arduino/AccelStepper/

The arduino software can be retrieved from http://www.arduino.cc. A tutorial for setting up the program for the Arduino Mega 2560 ADK is available on the same website. The libraries can be downloaded and imported by selecting Sketch > Import Library > Add Library within the Arduino programming environment. The zip file can be selected directly and needs not to be extracted in order to function properly.

Uploading the code from the Arduino programming environment requires a USB cable to be connected between PC and the Arduino. The code is uploaded by opening the .ino file included with this project's files. The code is then uploaded by clicking the right arrow button (top left of the screen, second button from the left). The Arduino is then ready to be connected to its other components.

PLAN OF MANUFACTURE

The following contains a step by step manufacturing plan for the purpose of recreating additional prototypes. The plan is divided into three parts: Platform, Frame and Docking Station. As the platform comprises the most procedures to produce, this part is elaborated in certain steps. The steps require the Bill of Materials, as the ID codes used within the procedures refer to their respective CAD filenames and components within the bill of materials. It is assumed that the 3D printed components are available when the components are to be assembled. Specifications on required materials can be found within the bill of materials in this appendix. Components are to be produced once per platform unless specified.

PLATFORM

01 – Casing

Materials:
- Carnaubawax or other kind of carnauba based solid wax
- Glass fiber sheet
- Epoxy resin
- Supplied mold

Note: The mold used for the prototype is to be reused for the manufacture of this part.

1. The MDF plug must be waxed/rubbed using carnaubawax until the mold is glossy. Applying at least 10 coats of wax is recommended.
2. Apply a piece of tape over the bottom hole (in the hollow area).
3. Place a layer of glass fiber sheet onto the plug.
4. Use a paint roller or brush to coat the sheet with the epoxy resin. The glass fiber sheet should be covered in resin thoroughly.
5. Apply another sheet of glass fiber until the entire plug is covered, while applying epoxy resin thoroughly.
6. After four layers of glass fiber are applied onto the plug, allow the plug to dry for 24 hours.
7. After the casing has dried, use an air compressor to blow air into the hole from the flat side to separate the casing from the plug.
8. Cut off the excess glass fiber on the top of the casing.
9. Drill the holes as displayed in the manufacturing schematics.
10. Using the spray paint, paint the surface of the casing.

02 – Hatch

The hatch is manufactured through CNC milling of the supplied CAD file from MDF material. Four holes of an 8 mm diameter must be drilled according to the schematics.

04 – Separation Plate and 05 – Base Plate
These two components are manufactured through the laser cutting machine from steel plate material.

06 – Pillar A (4x) and 09 – Pillar C
Cut the PVC tubes according to size, and sand down the edges for a smoother finish.

08 – Pillar B
This component is cut according to size from the 44 mm – 40 mm PVC tube. Sand down the edges of the tube. Using a bandsaw machine or hacksaw, cut two straight lines according to the schematics.

07 – Hatchbracket (4x)
The hatchbracket is cut from the wooden profile and needs no further adjustments, other than the sanding of the edges.

10 – Axis A (2x) and 11 - Axis B
The axes must be cut according to size and the edges need to be sanded down to prevent any possible injuries.

12 – Chargeplate (2x)
Two chargeplates are cut using the lasercutting machine in the workshop, similar to the plates with ID 04 and 05. The plates are bent into a 90 degree angle according to the schematics.

Required 3D printed components
P5 – SpringBracket (4x)
P6 – Platebracket (8x)
P7 – Gearbox A (2x)
P8 – Gearbox B (2x)
P9 – Chargebracket
P10 – Rack
P11 – Gear (4x)
P12 – GearHousing
P13 – GearB

Assembly

Note: It is assumed that the 3D printed components (see the bill of materials) are available before the assembly process begins.

Requirements:
- M5 bolts (18x)
- Double sided fastening tape
- Epoxy resin glue

1 – Apply fastening tape on the bottom of the electronic components. Do not remove the layer protecting the other side of the tape.

2 – Bolt four plate brackets (P4) to the base plate on the top side. Use the same bolts to bolt the casing (01) to the bottom of this plate.

3 – Glue two of the gears (P11) to two Axis B (10), one axis each.

4 – Place both gearbox A's (P7) onto the mercury steppers (B3).

5 – Glue the other two gears (P11) to the mercury steppers (B3).

6 – Place the assembly acquired from step 3 into the gearbox A's (P7) along with the assembly acquired in step 5.

7 – Place the ball bearings (B24) onto the gearbox B's (P8).

8 – Glue the wheels (B1) to both axis B's.

9 – Close off the gearbox assemblies using the assemblies from step 7.

10 – Place four pillar A's (06) in the plate brackets and fasten using epoxy resin glue.

11 – Place the electronic components on top of the base plate, removing the protective layer on the tape to adhere the components to the base plate.

12 – Wire the components as described in the electronic schematics in this appendix. Leave the HP100 motor (B22) separated from the L298n module (B21).

13 – Bolt four plate brackets (P4) to bottom of the separation plate (04), with four springbrackets (P5) on the other side of the plate.

14 – Attach the springs on top of the springbrackets (P5).

15 – Insert axis A (10) into the GearHousing (P12), while holding the worm gear (B6) and gear B (P13) in place as the axis is run through. Glue the gears onto the axis. This will inherently prevent the axis from falling out of the housing.

16 – Insert the HP100 motor (B22) into the motorbracket (P15) and wire it to the L298n according to the schematics. Glue the motoraxis (14) to the worm (B6) and glue the assembly to the HP100 motor. Check whether the glue is holding the components properly, as these should not be able to rotate unless driven by the HP100 motor. The worm should connect to its respective gear after this step.

17 – Tidy up the component wires by bundling wires traveling in the same direction.

18 – Place the separation plate on top of the pillar A's. Check whether the space beneath the center hole is devoid of any wires.

19 – Place the pillar bracket (P14) onto the separation plate and fasten it with glue.

20 – Glue the rack (P10) to pillar B (08) and insert it into pillar C (09).

21 – Insert and glue the four wooden profiles into the hatch's (03) holes.

22 – Insert pillar C (09) through the pillar bracket (P14). Glue the bottom of pillar C (09) to the base plate.

23 – Using pillar C (09) as guidance, glue pillar B (08) to the bottom of the hatch (03). Make sure the long non-dented side of pillar B is glued to the bottom of the hatch.

24 – Place the hatch (03) along with pillar B (08) on the casing (01), while pillar B is inserted into pillar C (09). Make sure the teeth on pillar B (08) are aligned with the teeth on gear B (P13).

FRAME

16/17/18/19/20 – FrameTop and FramesupportA1/A2/B1/B2
The frame components are fabricated by lasercutting respective MDF plates. The indent of FrameTop (16) is created using CNC milling. After the plates are cut and milled, the incline parts (see schematics) are to be sanded onto each part.

21 – Roster
The roster is lasercutted from steel plate and assembled onto the frame.

22 – Spacer (4x)
The spacer is fabricated using lasercutting components from an MDF plate with thickness 10 mm.

Requirements:
- Wood glue
- Screws
- M5 bolts

Required 3D printed components
P4 – PlateLock (4x)

Assembly

Assemble the frame components using wood glue and clamp the components together. In order to prevent the structure from breaking down, it is recommended to drill 8 screws into the structure, two for each binding. The screws are entered as follows:

- Four vertically aligned screws between the four joints on FrameSupportA1/A2 and FrameSupportB1/B2.
- Four horizontally aligned screws between the four joints on FrameSupportB1/B2 and FrameTop.

Place the spacers (22) on top of FrameTop, inside the indented part, aligned with the holes. Use the plate locks (P4) to fasten the robotic arm (situated on a plank of wood) to the roster (21) using four M5 bolts (use additional screws to fasten to the plank itself if necessary). At last, fasten the roster to Frametop (16) using M5 bolts.

DOCKING STATION

13 – Docking plate
This component is lasercutted from a plate of sheet metal and bent 90 degrees according to the schematics.

15 – ChargeRod (2x)
This component is cut from a standard aluminum rod (5 mm diameter).

Required 3D printed components
P1 – DockingCylinder
P3 – Rodbracket

Assembly

Start by inserting a spring (B5) into the dockingcylinder (P1). Insert the rodbracket (P3) into the cylinder by pulling the spring towards the longer non-cut side. The rodbracket must be turned sideways to be inserted, and then rotated towards its intended position. Pull the chargerods (15) through the rodbrackets and fasten these with glue. Next, glue the dockingcylinder (short non-cut side is glued) to the dockingplate (13). Make sure the chargerods (15) are running through the docking plate (14). Lastly, connect the lead acid battery chargers on the other end of the chargerods (15). Make sure the red clamp connects to the red pole of the lead acid battery when charging, while the black clamp connects to the black pole.

Note: Make sure the chargerods are sealed from any contact with the docking plate, as this will lead to shorted circuits. The chargerods may be covered with tape or a non-conductive coating.

BILL OF MATERIALS AND COST

Note: The names for the components are the same as their sldprt and stl files included with the deliverables of this project. An attempt was made to match the list as close to the SolidWorks files as possible.

ID	Amount	Component	Materials	Dimensions/Type	Cost	Availability	Notes
01	1	Casing	1. Glass fiber 2. Epoxy resin	1. 5m² 2. 1kg	1. € 18,76 2. € 17,91	1. http://polyservice.nl/Glasmat-450--p-16374.html 2. http://polyservice.nl/Poly-Pox-THV-500----1-kg-epoxyhars-p-16177.html	Usage of “MoldCasing” in order to manufacture. Surface finish using white and red spray paint
02	1	MoldCasing	MDF	1220 x 2440 x 12	€14,29	Local home depot (Praxis)	Mold for Casing glass fiber molding. MDF plates are stacked to achieve a block for the mold.
03	1	MoldHatch	MDF	-	-	See 03	The actual hatch which will end up assembled onto the platform. Fabricated from same material as 02. MDF plates are stacked to achieve required height. Surface finish using white and red spray paint
04	1	Separation Plate	Steel Plate	450 x 300 x 2 (mm)	€3*	Supplied by University of Twente	
05	1	Base Plate	Steel Plate	450 x 300 x 2 (mm)	€3*	See 05	
06	4	Pillar A	PVC Tubing	50 X 32 ∅ (outer) x 26 ∅ (inner) (mm)	€2*	Local home depot (Praxis)	
07	4	Hatchbracket	Wood (round profile)	90 x 8 ∅	€2*	Local home depot (Praxis)	

08	1	Pillar B	PVC Tubing	113 x 44 ∅ (outer) x 40 ∅ (inner) (mm)	€2*	Local home depot (Praxis)	
09	1	Pillar C	PVC Tubing	113 X 32 ∅ (outer) x 26 ∅ (inner) (mm)	-	Local home depot (Praxis)	Fabricated from same material as 06
10	1	Axis A	Aluminum	40 x 6 ∅ (mm)	€ 2*	Local home depot (Praxis)	One profile is used for all axes
11	2	Axis B	Aluminum	60 x 6 ∅ (mm)	-	See 11	Fabricated from same material as 10
12	2	Chargeplate	Aluminum	51 x 20 x 1 (mm)	€ 1*	Supplied by University of Twente	
13	1	DockingPlate	Aluminum		€ 1*	Supplied by University of Twente	
14	1	MotorAxis	Aluminum	30 x 6 ∅ (mm)	-	Local home depot (Praxis)	Fabricated from same material as 10
15	2	ChargeRod	Aluminum	50 x 6 ∅ (mm)	-	Local home depot (Praxis)	
16	1	FrameTop	MDF	1220 x 2440 x 8 (mm)	€ 10,49	Local home depot (Praxis)	
17	1	FrameSupportA1	MDF	-	-	Local home depot (Praxis)	Fabricated from same material as 16
18	1	FrameSupportB1	MDF	-	-	Local home depot (Praxis)	Fabricated from same material as 16
19	1	FrameSupportA2	MDF	-	-	Local home depot (Praxis)	Fabricated from same material as 16
20	1	FrameSupportB2	MDF	-	-	Local home depot (Praxis)	Fabricated from same material as 16
21	1	Roster	Steel Plate	450 x 300 x 2 (mm)	€2*	Supplied by University of Twente	

22	1	Spacer	MDF	-	-	Local home depot (Praxis)	Fabricated from same material as 16

*Price may vary depending on distributor, described price is a rough value of the expense made.

3D PRINTED COMPONENTS

These components are to be printed using the University of Twente's own printing modules. These components are fabricated with ABS plastic filaments. Some holes may need to be adjusted as this allows for a smoother finish as opposed to directly printing larger holes. As these components are to be fabricated using rapid prototyping, the components are not included within the schematics.

ID	Amount	Component
P1	1	DockingCylinder
P2	1	ChargeBracket
P3	1	RodBracket
P4	4	PlateLock
P5	4	SpringBracket
P6	8	PlateBracket
P7	2	GearboxA
P8	2	GearboxB
P9	1	ChargeBracket
P10	1	Rack
P11	4	Gear
P12	1	GearHousing
P13	1	GearB

ELECTRONIC COMPONENTS

ID	Amount	Component	Dimensions/Type	Cost (per piece)	Availability	Notes
B1	2	Wheel	No. 10237565	€ 3,95	iPrototype.nl	
B2	1	Caster wheel	No. 55247008	€ 1,70	iPrototype.nl	
B3	2	Stepper motor	No. 87578688	€ 14,95	iPrototype.nl	
B4	1	Servo motor	No. 85424570	€ 6,95	iPrototype.nl	
B5	4	Spring	No. 889243 - 89	€ 2,76	Conrad.nl	
B6	1	Worm Gear	No. 236950 - 89	€ 9,99	Conrad.nl	
B7	1	Lead acid battery	No. 250189 - 89	€ 24,99	Conrad.nl	
B8	1	Electric Imp WiFi module	No. 66789124	€ 29,95	iPrototype.nl	
B9	1	Electric Imp Host shield	No. 66789125	€ 19,95	iPrototype.nl	
B10	4	Ultrasonic Sensors	SKU - 133696	$ 3,10	DealExtreme.com	Purchasing spare components is recommended as some may be dysfunctional
B11	1	Lead acid battery charger	No. 200060 - 89	€ 8,49	Conrad.nl	
B12	2	EasyDrivers	No. 49875225	€ 10,95	iPrototype.nl	
B13	2	Jumper wire set	SKU - 55454	$ 3,10	DealExtreme.com	
B14	1	Arduino Mega ADK 2650	SKU - 215579	$ 22,10	DealExtreme.com	See B10

B15	1	Circuit boards (10x)	SKU - 136887	$ 6,20	DealExtreme.com
B16	2	Lm317t voltage regulator	-	€ 0.25	Stores (UT waaier)
B17	2	Male headers (1x40)	-	€ 0,13	Stores (UT waaier)
B18	2	Female headers (1x40)	-	€ 0,15	Stores (UT waaier)
B19	10	Circuit screw terminals (3 terminals)	-	€ 0,26	Stores (UT waaier)
B20	-	Set of resistors	-	-	Stores (UT waaier)
B21	1	L298n motor driver module	-	€2,45	Stores (UT waaier)
B22	1	HP100 motor	No. 73339100		iPrototype.nl
B23	4	Ball bearings	No. 214469	€2,29	Conrad.nl

This list may vary regarding the costs as the University of Twente may offer less expensive solutions.

PLATFORM TESTING

The following checklist includes the procedures through which the platform is to be tested for functionality and performance. These are deviated from the design brief mentioned within the main document. The left column displays the action required to test a certain aspect, while the second column describes the result if the platform passes. If the platform fails in a certain aspect, the third column provides directions on how to fix the broken aspect.

Also, general solutions for faulty behavior may be fixed by:

- Resetting the platform
- Checking whether the firmware is uploaded to the Arduino correctly
- Checking the wiring of the components
- Checking whether the Electric Imp is communicating properly with the wireless router

It is recommended to check the points above when any faulty behavior is exhibited.

Action	Result if passed	If not passed	Passed?
Direct the platform towards a destination with given coordinates.	Platform drives towards destination with a maximum offset of 15 mm (soft flooring) and 10 mm (hard flooring), all while avoiding obstacles.	- Check the connection between the small gears within the gearbox assembly - Check the assembly of the wheels - Check whether the sensors are functioning correctly.	
Click 'open hatch' in the user interface	Top of the platform opens	- Check the connection between the worm gear and the racked pillar. - Check whether the gears on top of the separation plate are mounted properly.	
Click 'close hatch' in the user interface	Top of the platform closes	- See above.	
Click 'sensor check'	UI displays the correct distances on all sides of the prototype	- Check whether the sensors are not obstructed when no obstacle is placed near the platform.	

Click 'Turn 90 degrees CW' and 'Turn 90 degrees CCW.'	Platform turns in the respective directions	- Check wheel alignment and assembly. - Check roller wheel for any dirt on the inside
Direct the platform through it's routine of picking up and putting down the frame	Platform performs the full routine while avoiding obstacles	- Reset or start doing other tests to indicate the problem - Check whether the frame is positioned at the indicated coordinates.
Direct the platform to check whether it's position is monitored.	Correct data is displayed in the UI	- Check for any errors within the firmware or the wireless communication between Imp and the UI.
Activate the platform's docking mechanism by clicking 'Dock platform'	Platform travels towards it's docking station and starts charging	- Check for any errors with the wiring of the voltage divider. - Check whether the docking station is situated at the (0,0,0) position (platform uses these coordinates as a reference point). - Check whether the charger is connected to the charge rods with the correct polarities.

MANUFACTURING SCHEMATICS

This section includes the schematics of the components which are to be produced within the UT workshop by non-3D-printing techniques. These components have no prefix in their ID and thus require schematics in order to be produced properly, with exception of the laser cutted components. In combination with the bill of materials and the manufacturing plan, the entire platform can be recreated using mentioned aspects. The schematics can be found starting at the next page.

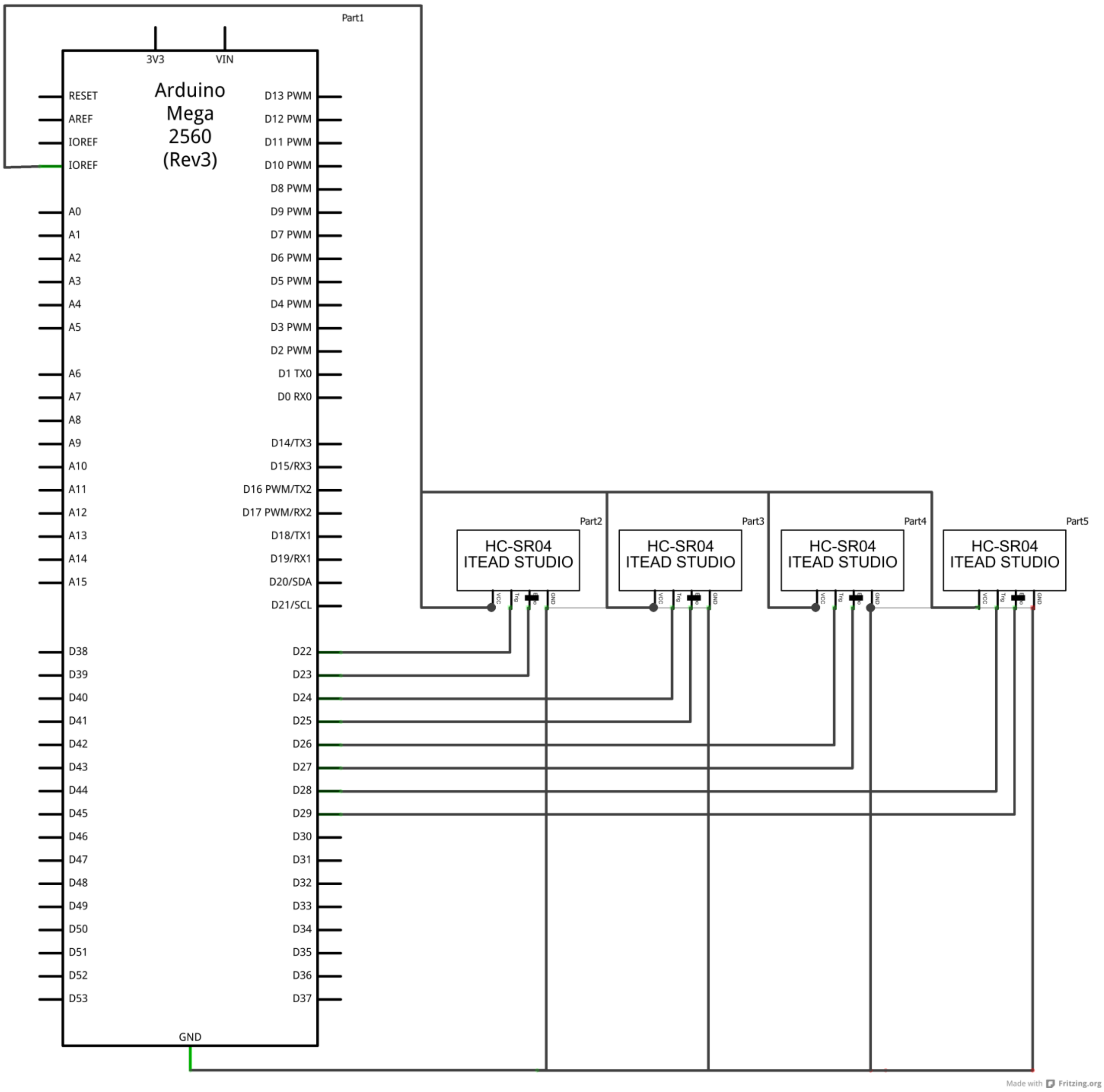
ELECTRONIC CIRCUITS

This section includes the electronic circuits present within the platform. The circuits should be used one by one in order to connect the microcontroller with all of the components. The recommended sequence of component wiring is as follows:

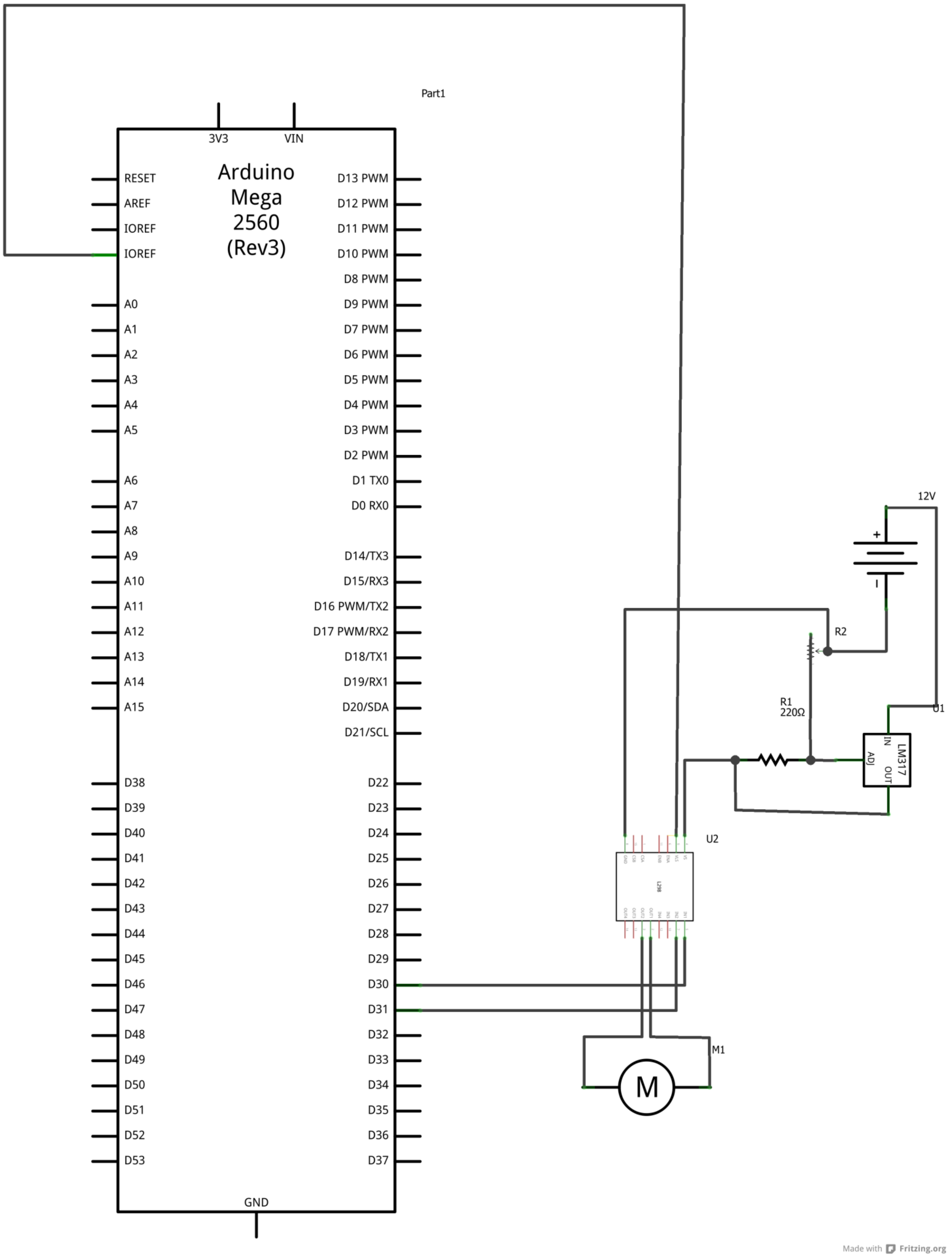
- Wire power circuit to the battery. This circuit should provide for the following output voltages and should have a way to cut off the battery power from the rest of the device:
    - 5V (for the ultrasonic sensors and L298n module)
    - 12V (for the stepper motors)
    - 7V (for the Arduino's power supply
    - 6V (for the hp100 motor)
- Wire the Arduino to the 7V outlet of the power circuit.
- Wire the ultrasonic sensors according to the circuit schematics
- Wire the L298n and HP100 according to the circuit schematics
- Wire the EasyDrivers and stepper motors according to the circuit schematics

The schematics of the circuits can be found after this page.

Ultrasonic sensors



L298n and HP100 motor



EasyDrivers and Mercury Stepper Motors