Developing a Rapid Prototyping Kit for Interactive Sports and Movement Design within Creative Technology

Graduation Project Report

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0.1 Abstract

People are becoming more and more physically inactive, which leads to a less healthy society. To combat this, the Human Media Interaction (HMI) group at the University of Twente is using interactive technologies to get people moving again. Many of their projects find their origin in Student projects. However, during these projects, students often spend too much time getting the functional aspects of their prototype to work. This leads to them lacking time to develop the user experience of their prototypes. The goal of this graduation project was to develop a system that helps the students develop their prototypes more quickly. During this project, the Creative Technology design process was used (Mader & Eggink, 2014 [1]). This project started with a literature review and a thematic analysis of anonymised student reports to get an understanding of what technologies are currently used. After which the project scope and definition were determined and the first low-fidelity prototypes were made. These prototypes were further developed into medium and high-fidelity prototypes, on which use evaluations were performed. These use evaluations consisted of the participants designing the functional side of a design task given to them. The end result is a toolkit with components chosen based on the literature review and thematic analysis. For all of the components, a documentation page was made to aid the implementation. To aid the selection of components, three systems were designed: A filter system with accompanying questions to make setting the filters easier, quick reference cards and an item graph that showed which other components were needed to make certain components work together. While this system was not perfect, it showed much promise during the use evaluations. It was able to help students pick the components they needed and explain to them how to implement them. Especially participants with less experience in electronics appreciated the system. The main issue with the system was the user interface. At times, parts of the system were not used or completely missed which caused the participants to not complete the set design task in full. The main strengths of the system were the fact that all the information to make a component work was in one place and that students no longer need to find the connection between components themselves. Some of which, the participants of the evaluations considered impossible due to the fact they ran on different coding languages.

0.2 Acknowledgements

First and foremost I need to thank Ysbrand Burgstede, with whom this project was done in partial collaboration. While Ysbrand and I both focused on different parts of the toolkit, I could not have made the documentation so nice without having Ysbrands website to host it on. Much of the ideation for what the end result would look like was also done together with him, so we could create two parts that would come together as one system. I would also like to thank Dees Postma and Richard Bults, my supervisors, for their help and advice on the project. As well as their patience when it took a while for physical prototypes to be presented. Finally I would like to thank my friends and classmates Door Kolkman and mette laros. Often we would work together on our own projects, which allowed me to bounce ideas off of them and get another perspective on whatever I had thought up for my own project.

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1 Introduction

1.1 Context

More and more people are growing physically inactive, leading to a less healthy society. According to the World Health organisation [2]: ”81% of adolescents and 27.5% of adults currently do not meet WHO’s recommended levels of physical activity”. Guthold et al. [3] explain that a lack of physical activity can lead to an increased risk of hypertension, cardiovascular disease, diabetes and even certain cancers. The Human media interaction (HMI) research group at the University of Twente is researching ways in which technology and interaction can help people to participate and improve in sports. Examples of these can include interactive playgrounds or immersive home trainers, but also simpler devices that remind the user to be active. In these devices, its important to have a good user experience so they actively engage the users to sport more. The last thing you want as a designer is that the users avoid sporting more because they did not enjoy the sport because of a product that was meant to encourage the users. The HMI groups research tries to analyse these relation and interactions between people and technology, combining computer science with social science. A large number of the projects regarding sport and health find their roots in student projects within the study of Creative Technology. In their project ‘Research and Design of User Experience’ (ResDesUX) they are tasked to develop a product prototype that can be used to improve sport or health related activities within a target group of their choosing. The goal of the ResDesUX project is to teach students different forms of prototyping as well as user testing, all with a focus on the user experience of the product. However, the step from low-fidelity (paper or cardboard) prototypes to high-fidelity (electronics and a working system) has proven to be difficult for some students. This is mainly because the implementation of the functions of the prototype when building the high-fidelity prototype can be rather challenging. This means that during the project, the students focus shifts away from the user experience and towards finding and fixing issues they are experiencing with the implementation of their functionality. The HMI group wants to develop a toolkit that these students and possibly the professionals at the HMI group can use during the development of their project(s), to make sure that the focus can stay on the development of the user experience.

1.2 Problem statement

Students following the Creative Technology project ’Research and Design of User Experience’ currently spend too much time finding and developing the functionality of their high-fidelity prototype. This leads to a shift of focus towards the functional requirements of the prototype, while the goal of the course is to teach students how to develop for user experience. The goal of this project is to develop a first version of a toolkit, that enables these students to more quickly and efficiently design prototypes within the field of interactive sports and movements, so more time can be spent on the user experience. This toolkit would consist of components, both physical and digital. The components would be accompanied by short instructions explaining what the block can do, in what range or context, and a short explanation on how to implement it. The instructions would not explain on what physical principles the sensor is based or how it works, unless this is vital information for making the decision on what part to use. Because of the large scope of this project, the background research as well as the ideation phase were done in collaboration with Ysbrand Burgstede [4]. Our project focus split during the Specification phase, where we both worked on separate parts of the toolkit.

1.3 Research questions

The main research question of this project is: *How can students following the ResDesUX project, that struggle with the implementation of their hardware, best be aided in the development of their high-fidelity prototype?*

Sub-questions for this project are:

- *What (interactive) technologies are currently already used in sports research?*
- *What functions did the previous students want to achieve in their projects?*
- *What sensing, actuating and support systems should be supported by our toolkit?*
- *What information should the students be provided about these systems?*
- *What is the best way to present this information to the students?*
- *How do you support the students in finding the components they need?*

1.4 Structure

This thesis is structured as follows: Chapter 2 contains background research on relevant topics. Chapter 3 contains explanations of the methods used during this thesis. Chapter 4 covers the ideation phase of the project. Chapter 5 covers the specification phase. Chapter 6 covers the realisation phase. Chapter 7 covers the evaluation. Chapter 8 is the discussion as well as possible future recommendations. Chapter 9 is the conclusion. The references and appendices can be found at the end of this thesis.

2 Background research

This chapter summarizes the background research done to get a base understanding of all fields covered by the toolkit. This consists of a literature review to determine what (interactive) technology is used in sports research as well as a state of the art analysis into relevant systems.

2.1 Sport and technology

2.1.1 Finding papers

To determine what technology is currently used in sport research, a literature review was conducted. IEEE Explore was used to find relevant papers. Search terms used were:

- Sports AND design, 2014-2024, public access, filters: Internet Of Things, Wearable Devices, Wireless Sensor Networks, Actuator (59 results)
- Moving AND design, 2014-2024, public access, filters: Internet Of Things, Actuator (106 results)
- Movement AND design, 2014-2024, public access, filters: Inertial Measurement Unit, Actuator, Internet Of Things, EEG Signals, Wearable Devices (224 results)

These results were further manually filtered on relevance based on research title and abstract. This resulted in 17 papers to be analysed.

2.1.2 Common measurement techniques

In the literature, four techniques for measuring on sport were mentioned. The most common of these was movement monitoring through inertial measurement units (IMUs). These sensors have a wide variety of usages. They were used to measure limb movement by Zhang et al. [5], Kos and Kramberger [6], Huang et al. [7], Fu et al. [8] and Demrozi et al. [9]. Schiatti et al. [10] and Shenoy et al. [11] used IMUs to measure hand movement. Gait cycle was analised using IMUs by Asif et al. [12]. And Song et al. [13] validated different methods to estimate the angle between IMUs. There are two types of IMU mentioned in the papers, 6 degrees of freedom (6DOF) and 9 degrees of freedom (9DOF). The 6DOF IMUs use accelerometers and gyroscopes in 3 dimensions, the 9DOF IMUs add magnetometers in the three dimensions. While most papers do not explain the reason why they chose their respective type of IMU, Song et al. [13] explain that a 9DOF IMU will give more accurate results in controlled environments due to their capability to measure absolute heading. However they are more susceptible to interference from electrical devices and ferrous objects then their 6DOF counterparts. This means that for different applications, either type of IMU can be the preferred sensor.

The second type of measurements are electromyography (EMG) signals. Zhao et al. [14] and Crepaldi et al. [15] used EMG to measure muscle impulses. Shen et al. [16] used EMG to measure athlete performance. EMGs were also used to perform analysis of how muscles respond to brain impulses (corticomuscular coherence analysis) by Cerone et al. [17]. There are two versions of EMG measurements: Needle

EMG (nEMG) and surface EMG (sEMG). nEMG sensing is better suited for measuring on specific muscle fibres, while sEMG senses more general activity and is much less intrusive. This makes sEMG better suited for sports according to Shen et al. [16]. They also propose the use of textile electrodes to perform these sEMG measurements. Cerone et al.[17], Zhao et al. [14] and Crepaldi et al. [15] use more conventional electrodes.

Temperature sensors were used by Shen et al.[16], Guembe et al. [18] Kos and Kramberger [**kos**] and Huang et al.[7]. However none of the papers elaborate on why they use temperature sensors, nor what insight measuring temperature gives. To acquire insight into this, the paper of Engeroff et al. [19] was found. They state heat to be an important factor in sport not only because any energy turned into heat is not used for movement, but also because the body core does not handle a temperature rise of 5 °C well. So in order to sustain high levels of exercises, the body temperature needs to be well regulated.

For the measurements of heart rate and heart rate variability, two methods were mentioned. Photoplethysmographic (PPG) sensing uses a light emitting diode (LED) and a photo-diode to determine the live blood volume under the sensor. This can be used to determine heart rate, heart rate variability, oxygen saturation of the blood and respiratory rate. Demrozi et al. [9] and Huang et al. [7] both integrated them in wireless body area networks. However, these sensors do not need to be placed over the entire body as Kong and Chong [20] and Kos and Kramberger [6] used forehead or wrist worn devices. In contrast to the other papers, Shen et al. [16] use Electrocardiography (ECG) sensing to determine the electrical activity of the heart. With this method they are able to detect heart rate, heart rhythm, identify emotions and recognize heart abnormalities. This method is partially supported by Kong and Chong [20]. They explain that ECG is generally considered the golden standard and they use ECG measurement as their reference in researching PPG sensing. However they explain that the usability of ECG measurements is limited in devices that require constant monitoring and is generally more intrusive then PPG. Because of this, PPG measuring is much more common in consumer products.

2.1.3 Golden standards

Three other papers explicitly stated the golden standards in their measurement. Demrozi et al. [9] specifically mentions products like BioSension, Shimmer, Vicon Nexus or G-Walk as golden standards within the field of wireless body area networks. Kim et al. [21] stated that visual analysis of motion tracking or video by an expert, or analysis using a pressure plate are the golden standard within the study of flat feet. Asif et al. [22] state "Both IMUs (inertial measurement unit) and rule-based methods are the optimal choices for gait analysis". Other papers share the opinion that IMUs are the best option for their experiment, but do not state it as the best option for a more general field of study.

2.1.4 Kinematics in sport

Kinematics in relation to sport is not much different from Kinematics in robotics, where joints and links are drawn to create a schematic representation of the possible movements. The forces on and movement of these joints can then be calculated using kinematics theory. However, in sports, these links might not always represent the limbs of the human body. Zhao et al. [14] use the model of a single spring to represent a leg, including feet but excluding the hip joint. The way certain movements are classified is also not always consistent. Kim et al. [21] propose a 4 step cycle to characterise walking stride, while Asif et al. [12] further divide the cycle into 7 steps. Both papers do use the stance phase and swing phase as groupings of these steps. To determine the position or rotation of the limbs, IMUs were the most common sensor. Based on the acceleration and rotation of the IMUs, the movement can be determined. The position or rotation of the limbs and joins can then be extrapolated from this. Song et al. [13] validated 6 different methods of determining the angle between two IMUs that move relative to each other.

2.1.5 User feedback

While most papers were focused on measurement only, two forms of feedback were mentioned in more than one paper. The first was visual feedback. Shen et al. [16] and Demrozi et al. [9] utilise a display screen for this. Ding et al. [23] use VR as an information environment rather than feedback. However this does show the possibility of using a VR system as a form of feedback. Kos et al. [6] and Sciatti et al. [10] use RGB programmable LEDs. Sciatti et al. [10] and Demrozi et al. [9] also use tactile feedback through vibrations. What kind of feedback was used was mostly determined by what devices had to give the feedback. Visual feedback was more common because they could rely on already existing devices for this.

2.1.6 Data processing

There are two types of data preprocessing that make multiple appearances in the literature. The more common of these are various forms of Butterworth filters. Zhao et al. [14] and Song et al. [13] use both high and low pass filters, while Kong and Chon [20] use high and band pass filters for their measurements. These filters pass almost all frequencies within their pass region unattenuated. At the cutoff frequency, the attenuation has already started but for most applications not significantly enough for the signal to become unusable. This attenuation then increases to a final slope with a set rate of attenuation per decade dependent on the order of the filter. Another filter that was used was a moving average or mean filter. This filter was used by Zhang et al. [8]. Shen et al. [16] explain that it can be used to smooth out incoming signals. This filter works by taking a small window of the time around a point in the signal and setting the average of this window as the output signal of the filter at this point.

2.2 State of the Art

Continuing on from the literature review, the paper by Shen et al. [16] contains a State of the Art about wearables. In this they discuss multiple articles of clothing like the Xiaomi Mijia or the Tymewear Smart Shirt. Most of the wearables discussed measure ECG, with some articles measuring sEMG, VO2 MAX or acceleration.

One of the most common wearable devices on the market are smart watches. Devices like the Apple Watch [24] and the Samsung Galaxy Watch [25] seen in figure 1 can keep track of many health related variables such as heart rate, sleep, steps and body composition. Often times these devices come with an accompanying app on the mobile phone of the user and/or can be connected to third party health and sports apps. These apps then track the exercises of the user, from calories burned and how long the exercise took to the type and route of the exercise.

(a) The Apple Watch 9 [24]

(b) The Samsung Galaxy Watch6 [25]

Figure 1: Examples of smartwatches.

While smartwatches can track movement in the forms of step counters and/or GPS, they lack in their capability to do proper motion tracking. For this multiple systems can be used, but the one often regarded as the golden standard is Optitrack. This system, as seen in figure 2, uses cameras and physical markers to determine the specific movement of the markers with a precision of less then $200\mu m$ [26]. Due to the flexibility of the human skin this system is somewhat less precise when tracking sport activities. The main disadvantages of a system like this are that it is a stationary system, so it cannot be used for sports like outdoor running or cycling, and its price tag. Their cheapest camera, the Flex 3, already costs $659 per camera as of April 2024. The cheapest version of their main line of cameras, the PrimeX 13, costs $2499 per camera [27].

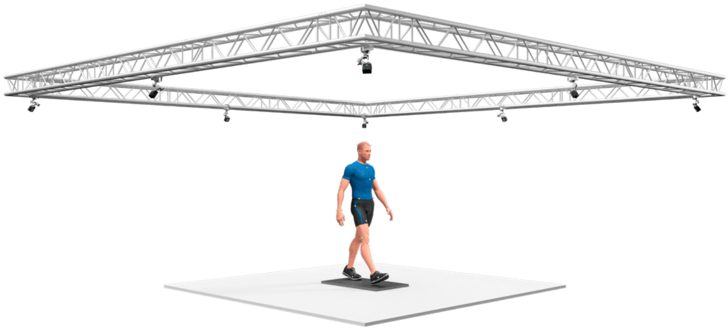


Figure 2: The Optitrack system, consisting of multiple cameras and physical markers on the body of the person to be tracked [27].

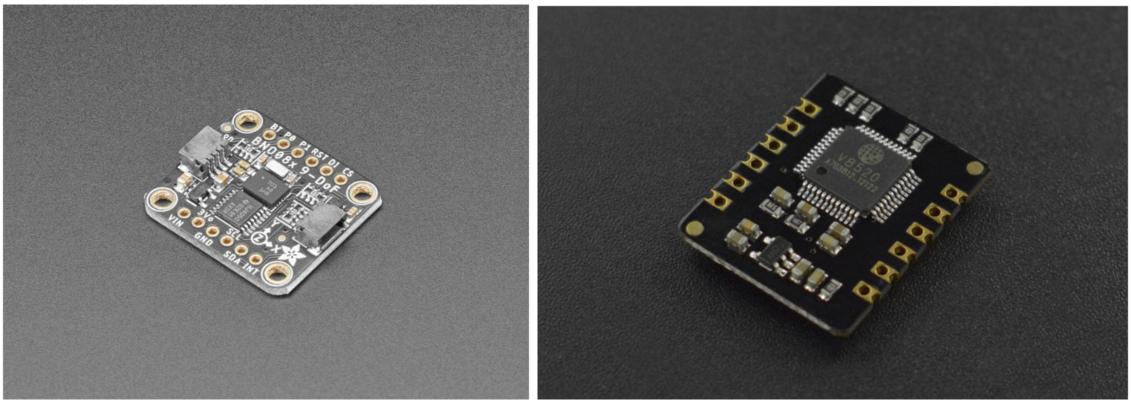
Another way of doing motion tracking, and one that does not require a stationary setup, are IMUs. IMUs, as explained in the literature review 2.1.2, measure acceleration and rotation of an object. A good example of a system of these is the Xsense suit by Movella [28] as seen in figure 3. This suit uses a collection of IMUs to determine the position and motion of the human body. While the suit is still rather expensive, $4590 for their cheapest full body tracking solution as of April 2024, individual sensors in the form of the Xsense Dot can be bought for €132 [28].

Figure 3: The Xsense suit can keep track of relative limb position using IMUs [28].

While this price might be reasonable for sport scientists, students have a much tighter budget. Therefore the teachers of the Creative technology course "Biosignals & Medical Electronics" decided to develop their own IMU sensor systems. Using the MP6050 IMU and a micro controller with Bluetooth capabilities, they made a much cheaper IMU for students to use during their project. The data from these sensors is not pre-processed before it is sent to the students, so it is up to them to do the data processing.

The MP6050 IMU is but one of many micro controller compatible sensors. Companies like Adafruit or DFRobot make complete sensor modules that can be used with most if not all micro controllers (see Figure 4). These sensor modules also include things like EMG, ECG and PPG measurements, but also less medical or health related sensors like flex and GPS sensors. They also sell modules that could be used for feedback. Examples of these are the Adafruit Neopixel series or DFRobot's many LCD displays.

The main advantage these modules have over just the sensor circuitry is that all the important safety components like pull-down resistors or circuit separations are already integrated, making these modules more plug-and-play. However these modules generally do not contain any data processing elements, instead they often have a raw signal as their output. This means that to properly use these modules, digital data processing may be required.



(a) An IMU from Adafruit [29] (b) A PPG sensor from DFRobot [30]

Figure 4: Examples of sensor modules.

Some of these sensor modules also come in a special shape that perfectly fits on top of a development board, eliminating the need for cables. If the development board has female pins, these modules are known as shields. If the development board has male pins, these modules are known as hoods. However, because most development boards do not have the same shape, shields and hoods have to be made to fit to a specific development board. An EMG and ECG shield designed to fit on Arduino-like development boards can be seen in figure 5. One disadvantage of these kinds of modules is that the pins they use on their development boards are predetermined. This means that it is not possible to stack shields or hoods that require the same pin. This can be partially mitigated by using a cable to connect the offending pin on one of the modules to another pin on the development board, but this nullifies the main advantage of these kinds of modules.

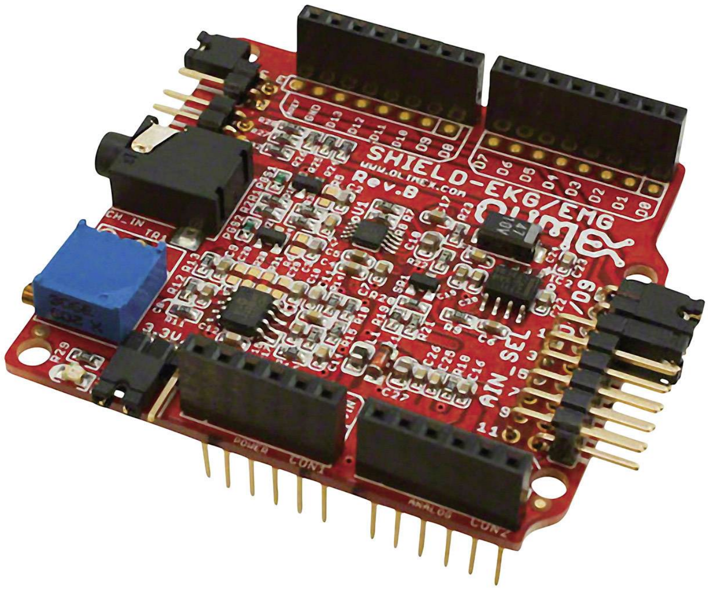
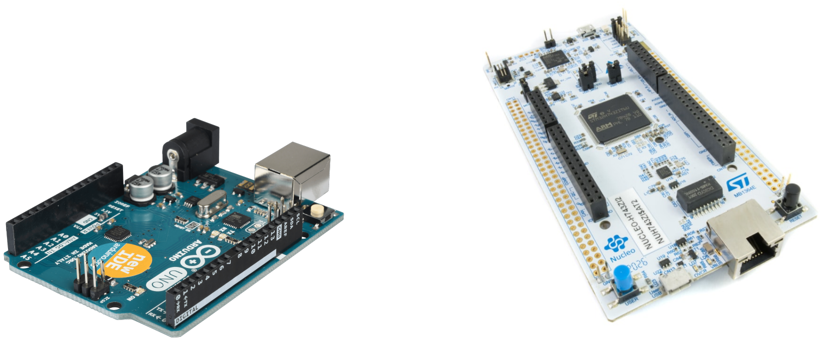


Figure 5: A EMG and ECG shield designed for Arduino-like microcontrollers [31].

The most commonly used development board is the Arduino Uno [32], seen in figure 6a, or one of its clones. Because this design is open-source, many companies have made their own versions of this micro controller. Some with better performance, others with a cheaper price tag. Due to this, the large majority of shields are made to fit the Arduino Uno pin layout. This has further inspired other development board manufacturers to incorporate this layout in their own boards, like the STM32 Nucleo boards (see figure 6b).



(a) The Arduino Uno R3 [33].

(b) The Nucleo H743ZI2 [34]

Figure 6: Two examples of microcontrollers.

Another commonly used development board family is that of the ESP32s. While the name ESP32 technically refers to the processing chip on the development board, using the raw chip is often times too difficult for users. The main advantage of these boards is that all of them come with WiFi and Bluetooth connectivity. This means that they are especially useful in devices that need to be wireless or connected over large distances. To achieve the same with other development boards, separate WiFi or Bluetooth modules are often needed. The ESP32 boards are also programmable with the same language and IDE as the Arduino boards, making it a logical next step for the Creative Technology students.

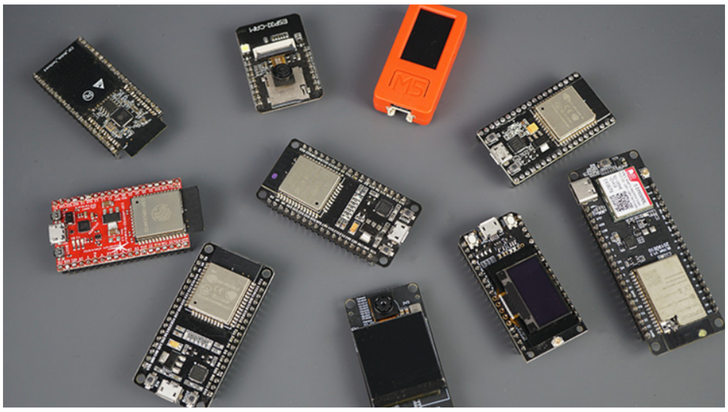
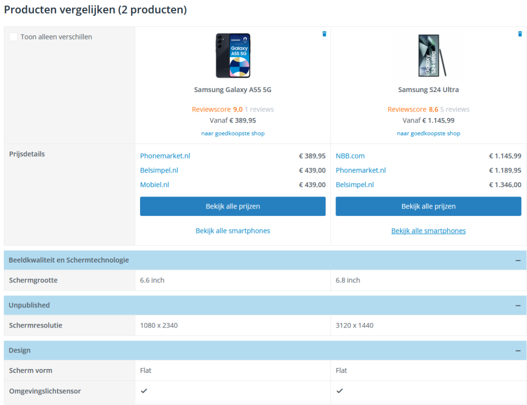


Figure 7: Multiple development boards using the ESP32 chip [35].

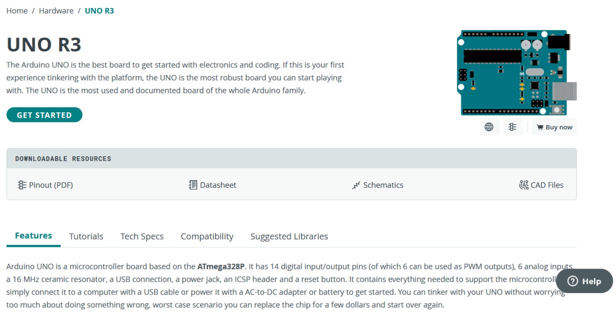
While designing a toolkit for students, it can also be important to hide certain levels of complexity from them. As the students are already rather short on time, they should not be required to figure out all steps of data processing themselves. A good example of this abstraction can be found in Lego Mindstorms (see figure 8). In these sets, users get a central processing block to which multiple sensors and/or motors can be connected. Then, through a visual drag-and-drop interface, the user's creation can be programmed. While the user knows on a conceptual basis what each sensor does, the user is not required to know what physical principles the sensor uses to work in order to use it. For this project, this might be too high a level of abstraction, but it is a good indication of what could be done.

Figure 8: The Lego Mindstorms EV3 set [36].

Furthermore, it may be a good idea to create some form of "configurator" tool that explains the pros and cons of each part that the student may wish to use, as well as a short explanation of what it does and what data you can get from it. This would combine something similar in concept as a comparison site like kieskeurig.nl (Dutch) with a documentation like that of Arduino [37]. However, this tool should not elaborate on exactly how the sensor works or on what physical principles it is based, unless this is deemed important information for making a decision. Examples of the usage of these sites can be seen in figure 9



(a) An example comparison on Kieskeurig.nl [38]



(b) The Arduino Uno R3 Documentation page [37].

Figure 9: Websites that could work as inspiration for a configurator tool.

3 Methods and techniques

In this chapter, the methods and techniques used during this project will be discussed.

3.1 Creative technology design method

The creative technology design method [1] is an iterative design method. It consists of 4 main phases: Ideation, Specification, Realisation and Evaluation. The first three of these phases all have a spiral form, due to the nonlinear nature of design. At any point during the design cycle, previous steps can be revisited to improve the design.

The ideation phase begins with a design question. In the case of this project this was a request by Dees Postma (this projects supervisor and client) to develop a toolkit for sports design. The spiral in this phase covers the problem statement, the idea generation and the collection of relevant information. In the problem statement, a thematic analysis was used to determine the needs of the students, the end users of this product. During the idea generation multiple possible systems were thought up that could fulfil these needs. The possibility of some form of configurator tool was also proposed, as giving students systems without any info on how to use them would not help much in the long run. Multiple relevant sensors were also used to see what kind of information the students would need to implement them. The collection or relevant information not only consists of the literature from chapter 2, but also includes the results from the thematic analysis, interviews with stakeholders and state of the art research. For the stakeholder analysis, experts from the University of Twente were interviewed.

During the specification phase, the ideas from the ideation phase were further prototyped using medium-fidelity prototypes. These prototypes had to already be medium-fidelity mostly because it would be hard to test a toolkit without its components, which by nature don't really allow for low-fidelity prototyping. These prototypes covered the whole functionality of the kit in parts, with the digital selection aid tool and the cards. The goal of this phase was to determine which ideas work and which don't. For the evaluations, the focus was on motion tracking because we had all the materials on hand to support multiple forms of integration. The prototypes were used to test the features of the tools as well as the user experience. From the observations and user feedback during this phase, the prototypes were improved upon and merged into one system. These were then be used to create a product specification and design requirements.

In the realisation phase, the feedback from the specification phase as well as the requirements established were used to create a minimum viable product. The functionality of this prototype was tested on whether it reached the functional design requirements or not. The design was tweaked a few times until it at least partially reached all functional requirements.

The Evaluation phase contains multiple different aspects. Functionality testing was already done in the realisation phase. The final product had to be evaluated on whether it reached the requirements originally proposed during the ideation and specification phases. This was done through use testing. Unfortunately the results could not be compared to similar systems because this system was designed specifically for the ResDesUX project.

3.2 Literature review

For the gathering of relevant information, a literature review was conducted using the literature matrix method. In this method, a matrix is made where the research questions are ordered in rows, and the sources in columns. The sources answer to a research question is then written down in the appropriate cell. Once all the papers and questions have been covered, a synthesis of the answers is created for each of the research questions. These syntheses, combined with the individual results of the papers, are then used to write a proper review.

3.3 Thematic analysis

Thematic analysis is a way of analysing qualitative data by identifying common themes and patterns [39]. As the source of data is reports, no transcribing was needed. Multiple approaches to this method exist, but for this project the following five steps were used. First, every reports abstract, introduction, high-fidelity prototype, conclusion and discussion chapters were scan-read to get familiar with the scope of the plans of the students. Due to time limitations these sections in the reports were coded at the same time. In a more standard approach this first step is divided into familiarisation and labelling. Labelling is where snippets of text at most a few sentences long are highlighted and given a code or label that quickly describes the content of that bit. In case the report was vague about certain points in the sections, the rest of the report was scanned to find elaboration. After this, these labels were grouped into themes. During this step, some less relevant codes were discarded. These themes also had to be reviewed against the data set to make sure they were representative. Some themes needed to be rewritten or merged to make sure they fit the data. Once the list of themes was finalised, a description was added to the themes. This is to ensure there are no misunderstandings on what the theme contains. Finally, a write up was made in chapter 4.1 of this report to state the findings.

3.4 Interviews

To get a better understanding both on what students were struggling with, as well as to find out what educational staff would expect from a toolkit like this, interviews were held. These interviews were of the semi-structured form. This means that, while questions were prepared in advance, the researcher can stray from these questions. This allows for more in-depth follow up questions and thus a better understanding of the interviewees thoughts. This form was chosen over structured interviews as there were only a handful of educational staff that were interviewed and their answers would act as guidance, not data. The interviewees were contacted through email. An information letter was attached to this email. The interview itself was audio recorded and the interviewees signed a consent form before participating. Both the information letter and the consent form can be found in the appendix under 11.3 and 11.4.

3.5 System usability scale

The System Usability Scale, or SUS, is a likert scale based questionnaire consisting of 10 questions [40]. It was designed to quickly determine the usability of any given system. Every question ranges from 'strongly disagree' to 'strongly agree'. For the odd questions, these answers score 0 to 4, for the even they score 4 to 0. Adding all the points and multiplying them by 2.5 gives a final score per participant. The higher the average score, the more usable the system. There are many ways of interpreting the final average. Sauro presents five different ways of interpretation in their article: Percentiles, Grades, Promoters and Detractors, Acceptability and Adjectives [41]. Four of these are visible in figure 10.

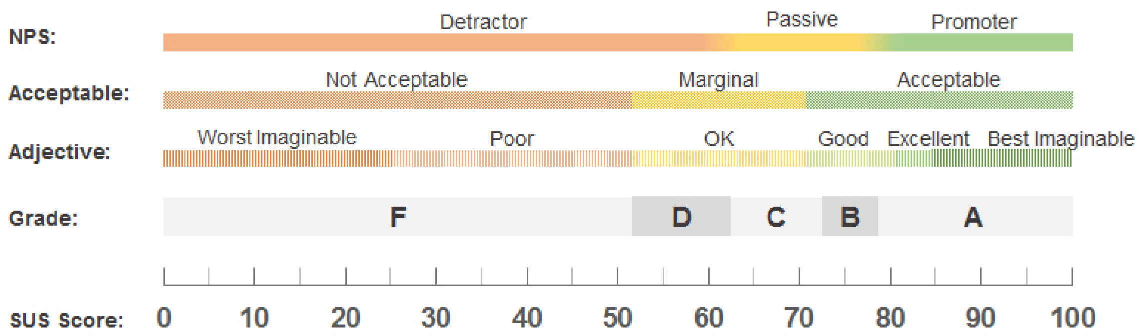


Figure 10: Four ways of interpreting a SUS score, as proposed by Sauro [41].

3.6 User scenarios

User scenarios are a tool where the designer uses personas to give detailed descriptions of how their prototype could be used [42]. These descriptions are often from the point of view of the persona. They can be used to explore why a user would do certain things and what needs they have from the system. There are many ways these user scenarios can be performed, but one common version that is often included and is used in this project is the "sunny day scenario". In this scenario, the user does everything exactly according to how the designer had envisioned the system to be used.

3.7 MoSCoW method

The MoSCoW method is a method for setting up and prioritising product requirements [43]. MoSCoW is an acronym that stands for Must have, Should have, Could have, Will not have. By deciding the requirements over these four categories, a prioritisation can be made on what requirements to focus on (first). The Must category contains the requirements that are absolutely necessary. Without these requirements the project would be a failure. Reaching the Must requirements is thus also equivalent to meeting the bare minimum of requirements. The Should have requirements contain the requirements that would greatly improve the project, but are not strictly necessary to make the project work. The could have requirements contain the requirements that have lesser impact on the overall quality of the project, but may be completed if time allows. Finally the Will not have requirements are the requirements that are not feasible or simply will not be completed within the time frame of the project.

4 Ideation

This chapter will discuss the ideation process of this graduation project. The ideation phase consisted of three main parts that happened at the same time: A thematic analysis, a stakeholder analysis and concept generation.

4.1 Thematic analysis

To get a better understanding of the user needs, a thematic analysis was conducted. In this thematic analysis, 55 anonymized reports from previous students were analysed on what technologies they used and why, as well as determining what the most common forms of prototypes are. Roughly half of these reports could not be used, as they focused on mental health or the physical activities were deemed not active enough for this analysis. This left 28 reports that were used in this analysis. A table with the resulting themes and codes can be found in the appendix 11.2. This table lacks the project type section to ensure the privacy of the students.

There were two main types of systems developed by the students. The first are button based games. This is where there are multiple buttons spread out over an area that the user had to press based on certain triggers. Almost always, coloured LEDs were used for these triggers. The layout of the buttons differed between each project. The interaction with these prototypes was then to press these buttons either in the correct rhythm, order or as fast as possible, depending on the intended use. The 2nd type of system making a regular occurrence were systems that used optical motion tracking for different end goals. While the resulting product differed a lot between these projects, the implementation of their motion tracking was rather similar. Often limiting themselves to a singular computer with a screen and a camera. There is also a noticeable shift throughout the reports, as the older projects tend to favour the button based games, while newer projects used optical motion tracking more and more often.

For the hardware that the student used, buttons and LEDs were by far the most common because they also have many uses outside the button based games. Some projects simply used them as user interface, while other projects needed buttons that could handle people stepping on them. Screens and projectors were used almost interchangeably for more image based feedback. Another form of feedback that was often used was haptic feedback, often through vibration motors. However these students often failed at getting proper power management set up for these systems, or decided to build their own motor controllers which would have most likely taken a lot of time away from the UX design. Something else not always explicitly covered in these papers, but would have been necessary for some of these projects to work, was the integration between microcontroller and a computer or laptop. While Arduinos and computers were the most common for of processing thought the projects, there were a few projects that used both at the same time. The only report that actually explained how they did this used libraries to connect an Arduino to Processing, however Processing does not allow for integration with programs like Unity to make more complex games. Speaking more generally in terms of feedback, there was a lot of integration of visual feedback. And while audio was a commonly mentioned type of feedback, rarely was it properly integrated into the system. More often it was found in the recommendations section.

The most common type of measurement in the reports was by far motion tracking, and specifically markerless optical motion tracking. This was achieved both through computer vision and by using the Xbox Kinect. These systems were commonly completely contained on a single laptop or computer and thus did not need any extra components. As there is a lot of variety in what can be done with motion data, this option also allows for a lot of creativity. Therefore it is important that an explanation or introduction to this kind of system finds its way into the toolkit for the students, even though this is not exactly a hardware component.

The most common supportive software used was Unity, as the optical motion tracking can be integrated with this rather easily. This allowed students to create a more developed game without the need of making something physical, saving both time and effort. In the projects that didn't use Unity, there were a lot that wanted to use a mobile app to give feedback to the participant. But this was often deemed too difficult and time consuming to be developed unless the app was the most important part of the prototype.

Design considerations and limitations generally varied from project to project, but there are a few that might be important for the development of the kits: There was a strong desire for smaller systems, especially in the projects that were making wearables. There were multiple projects that wanted to do wireless communication but not every single one succeeded. Bigger buttons should be strong enough to support human weight, and could possibly have integrated lights. It is important that your feedback is visible for the participant. At the same time, if the project uses motion tracking, the area cannot be too dark. Certain motion tracking systems also do not work with multiple people in frame. Multiple projects used high current devices in their prototype, but not all understood how to properly manage the power on these.

4.2 Stakeholder analysis

As with any product, this toolkit has multiple different stakeholders, each with their own expectations and desires. Identifying these stakeholders and their desires creates a guideline that can be used during the design process. For this, semi-structured interviews were held with teachers 3.4. The list of questions used for this can be found in the appendix under 11.5.

The biggest group of stakeholders are the end users of the toolkit, the students following the ResDesUX project. They will use the toolkit to design their own prototypes. They will expect the toolkit to have at least a few components usable for their prototypes. They want these components to be useful and easy to understand, or be given the information to make them more understandable. Furthermore, this toolkit should act as an aid in determining which components to use. In further research this group could be expanded to all people designing interactive sports systems.

Another important group to consider are the end users of the prototypes made by the students. For them it is important that the products made by the students are safe and with a good use experience. This means that the toolkit needs to help the students improving their prototype in their user experience, while using components that are safe for sport applications.

Then there are the teachers of the ResDesUX project. They will want to support the students using the toolkit. They will want the toolkit to aid in the development of the prototypes of the student without interfering with the learning goals of the project. Furthermore, the kit may also help the teachers themselves give aid to the students when they don't yet understand certain components. The simplifying power of the toolkit could impact the learning because it limits the discovery process, but when the components the students want to use already work this does enable more creativity. As our client is part of this group, they have a large influence on this project.

The final group of stakeholders are the lab managers maintaining the toolkit. These people are in charge of replacing broken or outdated components and software. Furthermore they need to be able to update the toolkit in a way that is consistent with the existing kit. To achieve this, they need a clear documentation for all the components in the kit as well as a guide on how to setup and implement new components into the kit.

4.3 Concept generation

One of the big issues students face when developing their prototype is that there is either no, too much or too complex information out there on the components they want to use. To make sure that the students can properly use the components of the kit, they need to either have sufficient abstraction, or be explained properly enough yet without overwhelming the students. At first, the focus of the kit was on abstracting the components included in the kit. One of the ideas proposed was to partially pre-build the system into "blocks". These blocks, like those from Lego Mindstorms (see 2.2), would then be almost plug and play, only requiring the appropriate code to be uploaded to whatever microcontroller was used in the processing block. However, this was deemed too time intensive and would result in too few components for the kit to truly be useful. Another option would have been to integrate a microcontroller like an ESP32 into every single block to allow for plug and play capabilities, however as this is even more work and this means that a lot of duplicate components need to be acquired, this idea was scrapped as well. Eventually it was decided that the better approach would be to provide the right amount of information, instead of abstracting away difficulty. Leaving the students to develop the applications and if needed middleware to make their system work.

To get an idea on what information to include and how to best present it, tutorials on components already owned by us were followed and relevant information was written down. For the first iteration, most of the information added were surface level things. The first drafts consisted of the name of the part and an image to identify the part. Then a wire scheme to explain to the students how to hook up the part. A short description of what the part did. And finally there would be a part on certain things to keep in mind when using the component like what voltage it ran on or if its measurements could be interfered with.

However, even without any user input it already became clear that this was not enough information to get started on a lot of the more complex components. The considerations were first expanded and split to hardware considerations and software considerations. Where hardware considerations are things to keep in mind during installation such as voltage levels, if the part pulled a lot of current and what kind of communication protocol it used. Software considerations focuses more on the coding aspects of the parts. Things like the libraries needed to run the part, the basics of data (pre)processing and if needed how to install the drivers needed for certain components.

A list of pros and cons was also added for every part. These pros and cons mainly focused on ease of implementation and range of usability, as precision and especially cost effectiveness were deemed less important. This is because the students will be loaned out these parts to use, so unless there are two parts in the kit with the exact same functionality, these comparisons are meaningless. And there would be no reason to have two parts with the exact same functionality in the kit as the better one of the two could instead be added multiple times.

A section of example code was also added for applicable components. These example codes were written in such a way that the students would have all the lines of code to either get the data from the sensor into the serial monitor/plotter, or to have the part perform its desired actuation, but no more. This way, it is still up to the student to find the best way to use the data/actuation of the parts to make their concepts a reality. Instead of being guided by the example code on how to code a specific system.

Specs of the components were considered, but the idea was discarded relatively quickly as it is rarely necessary to know exactly what a component is capable of. If there are specs that should be taken into consideration, these are often already covered in the hardware considerations.

The description was also further expanded before being split into two parts as well. The main part description and a context section. The main description has the explanation of what the part does or can do. This part of the description also gives a short explanation of how the part works if relevant, as sometimes this is important for making a decision on what part to use. The context part of the description is a short description of the possible context(s) the part is most suited for. It also includes a reference to other parts when appropriate. The descriptions explicitly does not cover possible projects that could be made with the part, as the goal of the kit is not to get students to build a predefined project, but to design their own.

Finally, a description was added to the wiring scheme, as at times it wasn't clear exactly why certain cables ran where. This short description is meant to indicate where to attach the wires on both the components and microcontrollers. It also contains extra detail on when other components are needed such as pull down resistors or external power sources.

All these parts were then ordered from most important to make a decision on what part to use, to most important for the implementation of a chosen part. This gave the information the following structure: Name+Image, Main description, Context, Pros and Cons, Hardware considerations, Software considerations, Wiring, Example code. With this layout, the information you need when selecting components is easier to find. Things like wiring schemes and example codes are only needed once you start implementing the part.

After this, different ways of presenting this information were considered. The main possibilities were cards, a booklet or a digital tool. The advantage of cards is that they are more tangible and allow for easy sorting, but only limited amounts of information could be displayed. The booklet is more organised and allows for more information to be added, but may be harder to sort through and compare the components. The digital tool would allow for a near unlimited amount of information to be added, at the cost of tangibility. It would also be possible to combine either the booklet or cards with the online tool, but combining the cards with the booklet would not make much sense. In the end, the combination of cards and digital tool were chosen to strike a good balance between the quick and tangible nature of the cards along with the more detailed nature of the digital tool.

For the cards, it was also important to decide which information would be shown on them. Due to their limited size, only a limited amount of information could be shown. Images of some of the card prototypes with different sizes and information layouts can be seen in figure 11. At first, A6 sized double sided or even folded A5 sized cards were considered to get enough information onto the cards, but these became slightly too chaotic with the information, and their size would not neatly work in a kit. Instead, playing card sized cards were chosen, that would include a QR code to further documentation, so only the most crucial information would have to be displayed on the cards.

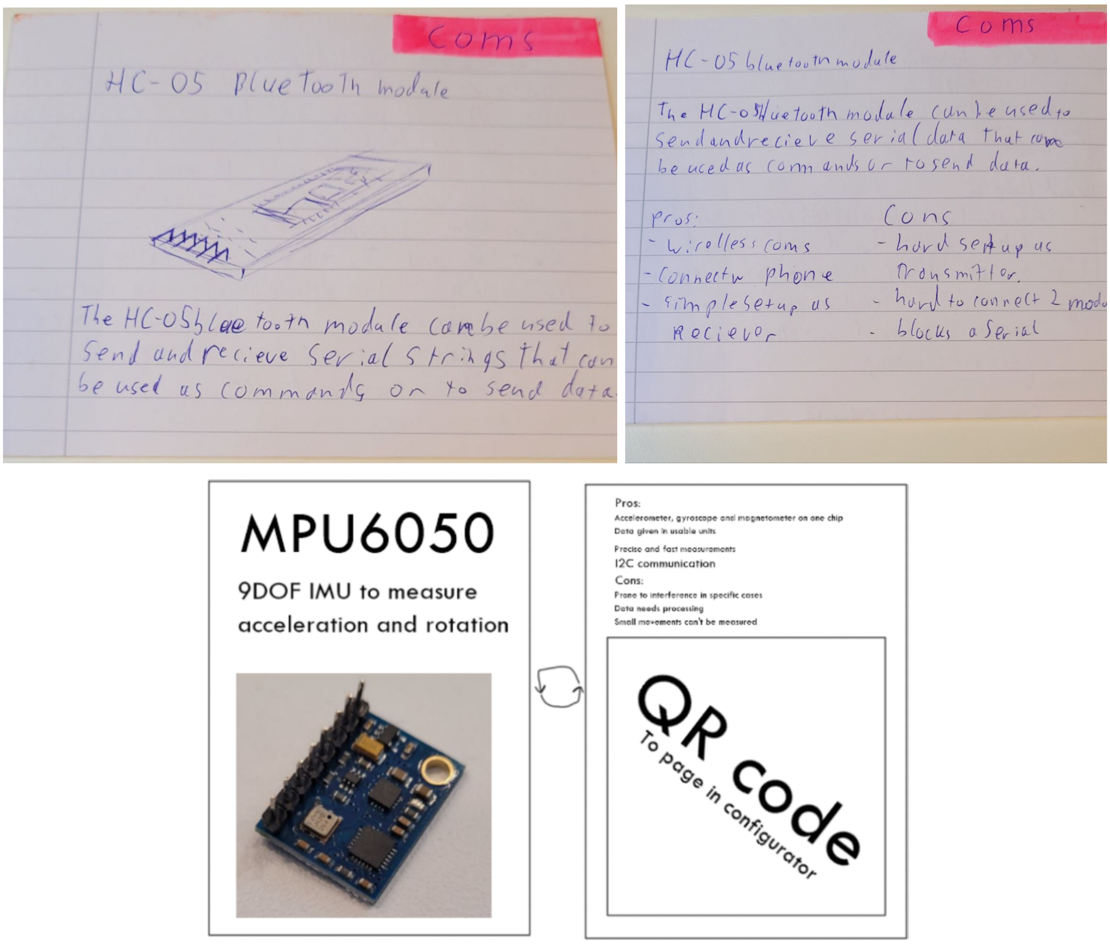


Figure 11: First prototypes of how the cards could look.

To more clearly show the relation between these components, multiple options were considered. These ideas focused mainly on the cards and digital tool as those together seemed like the most promising combination. For the cards, a colour coded label was first proposed. This colour coding would then make it easier to find the type of component you were looking for. This can be seen in figure 11 as well with the pink highlighted 'Coms' label on both cards indicating that the HC-05 Bluetooth module is a communications part. Another idea already present in the paper prototyping stage, but not shown in figure 11 are references to other cards. This happened for example where the ADXL345 accelerometer would refer to the MPU6050 IMU in case the students desired to measure rotation. These references were less designed to help find the components of the type students were looking for, but rather to find the best component within this type.

For the digital tool, two other options were proposed. Filters and a component graph. The filters would work somewhat similar to the colour coding of the cards, but with the advantage of allowing for searching within multiple categories at the same time, allowing for more specific searches. These filters would then order the components from best fitting to least best fitting, and colour the background of the components in a range from green (best fitting) to red (not fitting). An example digital sketch can be seen in figure 12. At first, pros and cons were considered to be placed on the digital cards for the components, but this was later switched to a shortened version of the description to stay more in line with the cards.

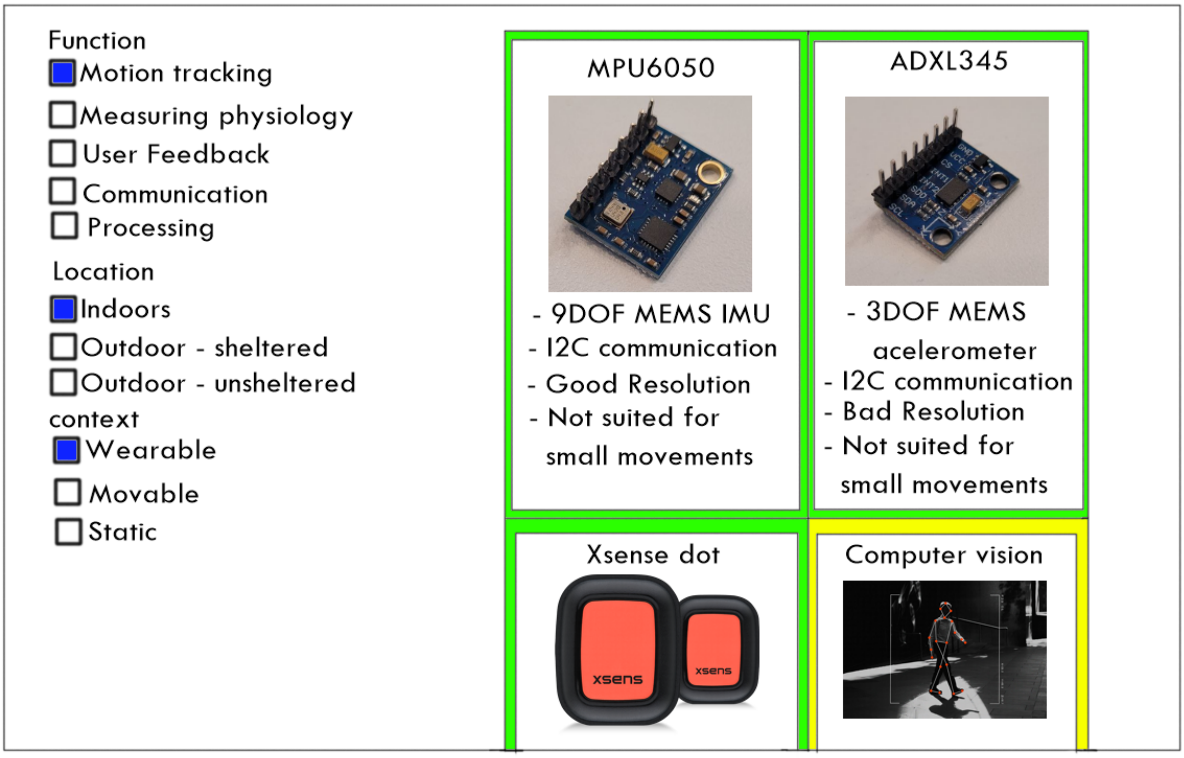


Figure 12: First concept of a filter system. Xsense dot image:[44] Computer vision image: [45].

The component graph was a much more complex system that would show all the components in the kit and how they communicated with each other. The first version of this can be seen in figure 13 The original idea features a node graph for every component, with a big collection node of microcontrollers as these are often interchangeable. The colours of the node would then indicate the functionality of the component, and the colour of the link would indicate the communication protocol between the nodes. The few dotted lines indicated a hard but technically possible implementation, a solid line indicated an implementation supported by the kit. This concept was further developed by Ysbrand in his digital tool during the specification phase [4].

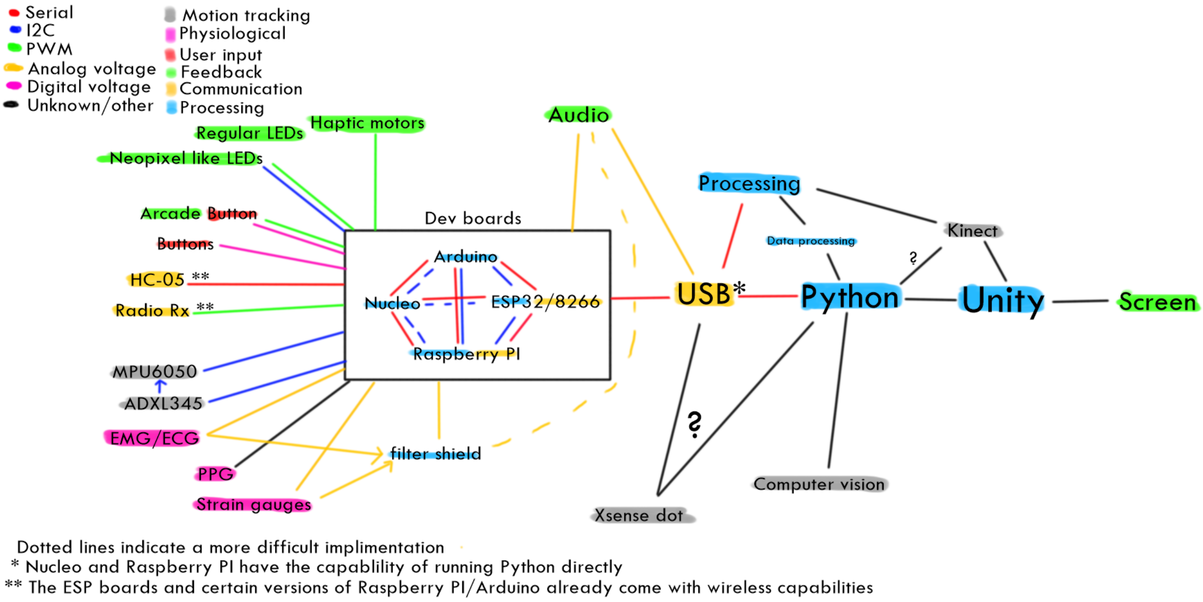


Figure 13: First component graph with all the components envisioned to be in the kit during this phase of the ideation.

5 Specification

This chapter discusses the specification phase of this graduation, which consisted of the development of medium fidelity prototypes, use evaluations of these prototypes and the drafting of the final requirements based on these evaluations.

5.1 Medium fidelity prototype

After the ideation phase, the best concepts had to be tested in order to determine what features improve the toolkit and which detract from it. During the further development of the two main tools, Ysbrand and I also made a more defined split in the project, as a graduation project still has to, in large part, be completed alone. Ysbrand focused on developing the digital configurator tool version of the toolkit [4], while I focused on a more physical approach with cards for every component in the kit. For the first evaluation, it was decided to mainly focus on the options for motion tracking as there we already owned the components for multiple different approaches.

The cards themselves were designed to contain as much information as possible to make a proper decision on what part to use, without overwhelming the students. This means that included on the cards is the name of the part along with an image so students can identify the part. The coloured background of the name helps with quickly finding the type of component the student is looking for. For the specialisation, blue were motion tracking components, grey controllers, pink physiological signals, red user inputs, green actuation and yellow communication. There are three sections of information on the cards: A short introduction, the context in which to use the part and on the back of the card a list of pros and cons. Also on the back of the card is a QR code that leads to a documentation page. This page contains a lot more information on how to implement the component for once the student has made the decision on what part they want to use. Figure 14 shows an example card of the same component as was used in a prototype in 4.3.

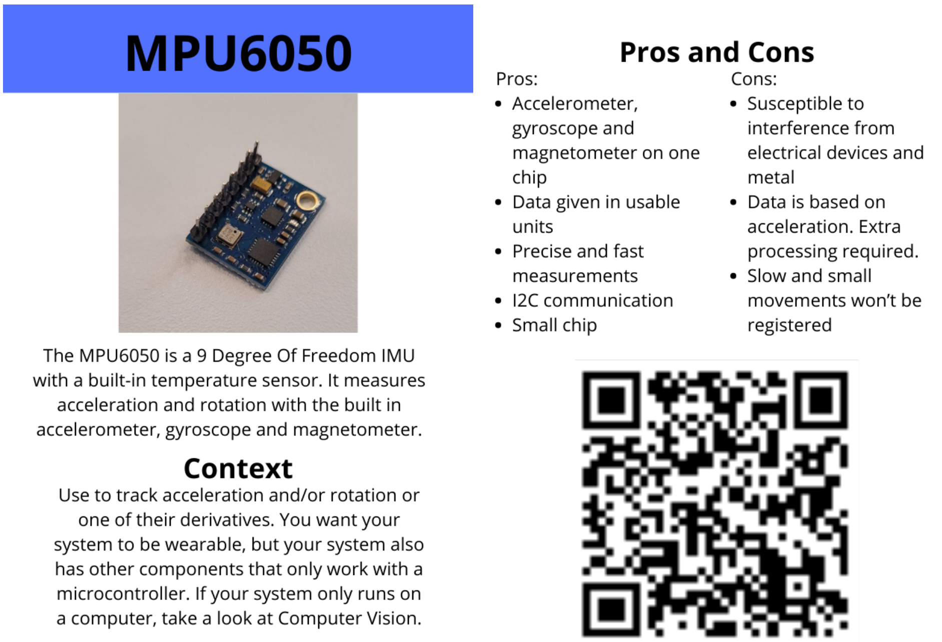


Figure 14: Example of a card used during the specification phase.

For the box, a simple off the shelf storage box purchased from the Action was used. Every component and its accompanying card were placed in a slot as can be seen in figure 15. However, even before the evaluation it became clear that off the shelf boxes like these were less than ideal, as the boxes are much too big for components such as the MPU6050 or the ESP32, while they are too small to fit the bigger components such as the Nucleo or the big arcade buttons.

Figure 15: The toolkit as used in the evaluation of the first card prototypes.

5.2 User scenarios

The envisioned user scenario of the medium-fidelity prototype is slightly different from the high-fidelity prototype and the final product. This is due to the fact that the two medium-fidelity prototypes, the cards and the digital tool, will be merged into one high-fidelity prototype.

5.2.1 User scenario of the medium-fidelity prototype

Jade is your typical Creative technology second year, who loves to make nice looking prototypes. They do not have much experience with electronics, but at least know how an Arduino works. As the rest of their group has even less experience with electronics, they are tasked with designing the electrical side of the groups prototype. For their project, they are making a push-up monitoring system. As they have no clue where to start, they grab the toolkit. From the colour code card they deduct that they most likely need to check the movement cards. While they first select the MPU6050 and ADXL345 cards, as those look like electronics, they come to learn that both of them have a hard time reading slow movements like push-ups. However, both cards point her to computer vision as an alternative possibility. After reading this card, they determine that computer vision may be a viable solution, so they scan the QR code on the back of the card. This takes them to the documentation of computer vision. Here they learn that its possible to integrate computer vision with unity, allowing for an easy way of making their prototype that doesn't even require any electronics. Following the explanations and example code of the documentation they manage to get computer vision to work on their device. Then, they return to the cards and pick the python to unity card. The documentation of this card allows them to transfer their computer vision readings to act as an input in unity. Then, while following some online tutorials and experimenting a bit, they manage to write the code required to give feedback on the push-ups. With this, they have completed the technical side of the prototype, and also aided in developing the appearance of the end result.

5.2.2 User scenario of the high-fidelity prototype

Daan and his group are all still very new to electronics. While they have all passed the module two subjects, they have since let other group members do the technical part of the project. However, as they are all in the same situation now, they need to figure something out themselves. Daan has taken it upon himself to fix the technical side of the project. something that, while he is not looking forwards too, he feels like he needs to do as it is an area he is still lacking in. He and his team have decided to keep the project simple. Just some buttons the user has to press and can light up. Different games could then be coded into these buttons. Having no clue where to start, Daan picks up the toolkit. On the top there is a QR code that links him to a digital configurator tool where he can specify what kind of thing he is trying to do. From this he gets quite a few options. As Daan has no real experience with electronics, he doesn't exactly know what would work best for his situation. But he did see the cards in the box. Picking the cards of the components the digital tool recommended him he compares all of his option and manages to narrow it down to only two components: The arcade button and the big button blueprint. For these, he opens the documentation. After reading the documentation Daan decides that making a button himself is too difficult, so he picks the arcade buttons. The documentation then tells him that there are multiple possible micro controllers that Daan can hook these buttons up to. Reading through the cards of these micro controllers, Daan settles on the ESP32 as it can support wireless communication. Then, using the documentation of both components, as well as some help from his teammates and the TAs, he manages to get the buttons to work and communicate wirelessly with each other.

5.3 Evaluation setup

Goal of the evaluation: Determine the best form of the decision aid and of the box as well as the usability of these tools. This is done by having the participants design a system and after completion interviewing them on their thought process and opinions on the tools. Participants will also be asked to fill in a system usability scale questionnaire [40].

Participant group: Adult (ex) Creative technology students that have completed the Research and Design of User Experience project.

Full design challenge: Design a system that notices when someone is waving their hand and give suitable feedback. Only the components in the box and the laptop provided can be used as its mainly the decision aids that are being tested. The participant can take as long as they deem necessary to finish the system, or end early if they no longer wish to participate.

Procedure:

1. Collect participants. Include the information letter in the invitation, see appendix: 11.8.
2. At random, split the participants into two groups. The first group will use the box with cards, the second will use the digital tool.
3. When the participant shows up, explain that they are supposed to design a system that can measure when someone is waving their hand.
4. Present the consent form, see appendix: 11.9.
5. If the participant has signed the consent form, present them with their decision aid and the box of components.
6. Give the participant roughly 45 minutes to complete the task. Note down observations while they work.
7. If the participants ask for help, only walk them along the process instead of simply giving them the answer, and only after they can't figure it out themselves.
8. After they have completed the design task or have used p their time, have a 10-15 minute semi-structured interview to determine the thought process during the design.
9. Present the participant the system usability scale questionnaire.
10. Thank the participant for participating and answer any further questions they may have.

Observational queries:

- What (type of) components did the participant pick?
- How did they then select the other components they needed to make their system work?
- Did the participant show confusion, frustration or other signs of unhappiness while using the toolkit?

Interview questions:

- Why did you choose the components you chose?
- Did you understand when certain components needed other components to work?
- Were you able to find all the information you needed to make the prototype?
- What would you change about the toolkit, decision aid and/or the information pages?
- Did the colour code help with finding the components you needed?
- Was the information on the cards enough to make a decision?

5.4 Evaluation

5.4.1 Participants

For the evaluation, four participants were found. While this number is lower than hoped, the participants provided enough feedback that the project could continue. As the cards and digital tool link to the same documentation, this was tested four times, while both the cards and the digital tool were tested twice each. The participants ranged from no to medium experience with Arduino and/or code, but for all it had been some time since they last had to use components like those in the toolkit.

5.4.2 Main findings

Whether due to their general inexperience or because it had been some time, almost every participant had to look up information during the design of the toolkit that was assumed students would know. This means that it would be best to expand the information on basic arduino code, include cards explaining communication protocols and adding a card explaining how breadboards work. Furthermore, multiple participants stated that they would like some kind of manual to get started with the box. This manual, according to them, should contain basic information about electronics as well as how the kit and documentation works. The wiring diagram images on the documentation were not always very clear and at times had wires running over the names of pins. Finally, when using boards different from the Arduino uno it wasn't always clear what pins to use.

Alongside the main findings of the evaluation, smaller changes were also proposed. Things like extra comments in the example codes, pin-outs for all the boards supported by the toolkit, making the requirements of components more clear on the cards and making sure that the context on the cards has a consistent structure.

However, even with these points of improvement, the participants seemed to value the prototype. The SUS scores (see 3.5) for the cards version were 85 and 87.5, for the digital tool version were 77.5 and 90. This gives our system an average SUS score of 85. This is on the edge between Excellent and Best Imaginable [41]. The cards were well received, with one participant stating they liked the colour coding while the other participant stated they liked that the cards referred to each other when a better option for a certain context was available. The documentation was also well received by all four participants, even if they did not manage to complete the design task entirely.

5.5 Product specification and requirements

From the findings in both the ideation and specification, requirements for the final product could be made. These requirements in the first place try to work towards the goal of having a toolkit that helps students develop their high fidelity prototypes more quickly, but are also based on the process that the participants of the evaluation used. They were then ordered using the MoSCoW method 3.7 [43]. The requirements can be seen in the list below. Functional requirements are indicated with FR, non functional requirements with NFR

Must have:

- FR: The toolkit must include hardware components.
- FR: The toolkit must have documentation for every component.
- FR: The toolkit must have a way of aiding the students in selecting their components.
- FR: The documentation must have an explanation of what the component does.
- NFR: The toolkit must help the students with finding the components that best fit their needs.
- NFR: The toolkit must help the students with implementing their components.

Should have:

- FR: The toolkit should contain extra information about software only solutions.
- NFR: The toolkit should support as many different projects as possible, within the scope of the ResDesUX project assignment.
- FR: Every components in the kit needs to be able to connect to python only using itself and other components in the kit.
- NFR: The documentation should have a consistent structure.
- NFR: The documentation should have clear wiring instructions.
- NFR: The documentation should have clear example codes.
- NFR: The selection aid should give the students enough information that they can make an informed decision.
- NFR: The selection aid should not overwhelm the student with information.

Could have:

- FR: The documentation could have explanations for the different communication protocols.
- FR: The box could be custom made to have a more ideal packaging of components.
- NFR: The wording on the cards could be made sure to be consistent across all the cards.
- NFR: The selection aid could have categories to make finding components easier.

Will not have:

- FR: The documentation will not have extensive, in depth explanations of how every component works.
- FR: The toolkit will not contain systems not compatible with Arduino, Python or Unity.

6 Realisation

This chapter discusses the realisation phase and goes in depth into the system developed during this graduation project. While this chapter focuses mainly on the work performed by myself, a short description of Ysbrand's part of the system is also included [4].

6.1 Components

Combining the thematic analysis from the ideation phase with the requirements from the specification, a final list of components can be made. Given the requirements "The toolkit must have documentation for every component" and "The toolkit should support as many different projects as possible, within the scope of the ResDesUX project assignment", the most time efficient solution is to have only one component for every important item from the thematic analysis. The full list of components can be found in table 1.

Component	**Type**	**Function**
Arduino uno	Preowned	Microcontroller
ESP32 (2x)	Electrical	Microcontroller
Nucleo 144	Token	Microcontroller
Arcade buttons (4x)	Electrical	User input
Button blueprint	Preowned	User input
MPU6050 (2x) or AXDL345 (13x)	Electrical	Movement
Computer vision	Software	Movement
EMG/ECG shield	Token	Physiological
PPG sensor	Electrical	Physiological
Pressure sensor	Electrical	User input
Individual LEDs (bag)	Electrical	Visual feedback
Neopixel strip	Electrical	Visual feedback
Haptic coins (3x)	Electrical	Haptic feedback
Sound on Arduino	Electrical	Audio feedback
Sound w Python	Software	Audio feedback
Arduino to Python	Middleware	Data
Unity	Software	Visual feedback
VR with Unity	Software	Visual feedback
Unity to Python	Middleware	Data
App interface	Software	User input
External power supplies	Preowned	Power
Micropython	Middleware	Data

Table 1: The entire list of components proposed for the toolkit.

Six types of components were identified while determining what components to use. These are as follows: Electrical modules, Software solutions, Middleware, Preowned components, Tokens and Integrated systems.

Electrical modules The electrical modules are the most obvious kind of component to be included. These are the microcontroller compatible sensor chips, LEDS, speakers, etc. As there are many options here and because the ResDesUX prototypes often end up with at least a partially physical component, this kind of component is the most common in the kit. For the MPU6050 and ADXL345, recommended is to add the MPU6050s to half the kits, and the ADXL345s to the other half.

Software solutions Next to the electrical modules, there were also some functions that were best supported by a software solution. The most obvious of which is motion tracking through OpenCV. The coding language Python also had to be added into the documentation as a separate block due to the way the item graph was set up [4].

Middleware Sometimes someone may want to connect two components that can't directly interface with each other. For this, middleware exists to bridge the gap. Examples of middleware are Arduino-python communication or micropython. both these solutions allow for python and microcontroller only parts to interface with each other.

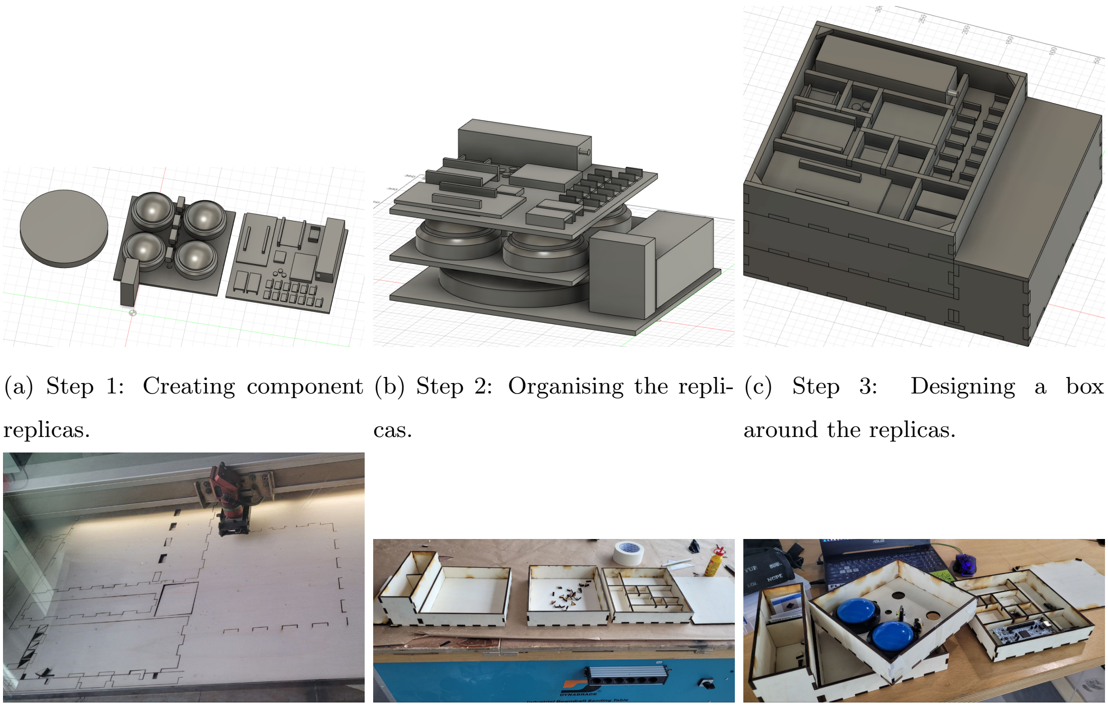
Preowned components Certain components will also already be owned by the students. Think of things like Arduinos or breadboards. Also included in this category are components that need to be bought to the specification of a project and thus can't be included in a hardware kit. These are for example external power sources or the hardware needed to make a custom button.

Tokens The final thing included in the toolkit are tokens for components. Specifically, tokens for the EMG/ECG shield and Nucleo boards. This is because these components will most likely not be used by every group, but when they are used, there are often multiple shields in the same prototype. As these parts are quite a bit more expensive than the rest of the components, it was considered better to only include tokens of these components that can be exchanged for the actual components at the lab managers or TAs.

Integrated systems The type of component that was not included in this kit are integrated systems. In this case this refers to completely built, off the shelf systems that measure or actuate in relation to sports and movement. Good examples of these are the OptiTrack [27] or Xsense dot [28]. These systems are much more of a finished product than prototyping material, meaning that they do not fit into the kit on a conceptual level.

6.2 Physical box

As explained in the specification, the off the shelf box was not ideal for storing all the physical components of the toolkit. After the complete list of components was established, a more well fitting box could be designed. This was done in CAD to create a box that could be laser cut from 6 mm thick plywood. This is both easier for prototyping and possibly cheaper for when a full set of kits is produced for the ResDesUX project. All steps can be seen in figure 16. First, replicas of the components were created that were as big or slightly larger than the real components to make sure they fit into the box. These were then organised in an as compact as possible layout, with as many components as possible directly accessible. During this organising, the 6mm thickness of the plywood was taken into account. After the positions of the components had been decided, the rest of the box was designed around them. This includes separators between the components in the top layer and holes through the bottom of the middle layer for the buttons and LEDs to fall into. The bottom layer was made taller to compensate for the parts that would be extending down. Once the design had been finalised, DXF files of the parts could be created and sent to the laser cutter. The entire box could be cut from a single 1200*600*6mm plate of plywood. The assembly only requires wood glue to keep everything together, because of the finger joints integrated into the design. The final box was first functionally tested with all the components form the final list owned by me, to make sure that everything fit properly.



(a) Step 1: Creating component replicas.

(b) Step 2: Organising the replicas.

(c) Step 3: Designing a box around the replicas.

(d) Step 4: Laser cutting the parts.

(e) Step 5: Building the physical box.

(f) The completed box with test components.

Figure 16: The process of creating the custom box for the components.

6.3 Cards

The cards themselves stayed relatively the same as during the specification, with enough information for the students to make a decision without overwhelming them. The main difference between the specification and realisation cards are the intended use of the cards and the new requirement icons. With Ysbrand's system being much better suited for the students with little experience in electronics [4], the cards became a quick reference tool for the students with intermediate to advanced knowledge. The requirement icons are small icons next to the image telling the students what power the part may need and with which microcontrollers from the kit it is compatible. These are color coded red for voltages and yellow for high current, as well as blue for Arduino, grey for Nucleo and black for ESP32. Every other part only got small tweaks to ensure more clarity and consistency. The names of components now also contains the more general sensor name when applicable. As the final list of components only has the ESP32 for wireless communication, the yellow communication group was left out of the color coding. The contexts of the cards were made sure to always begin with "You want" as this more strongly states what the component can be used for. Finally, the Pros and Cons were checked for consistency in punctuation. An example of the updated cards can be seen in figure 17. All the cards can be seen in the appendix under 11.6.

Figure 17: Example of a card made during the realisation phase.

6.4 Documentation

Most of the time spent during both the specification and realisation phase was on the documentation. The documentation is wholly responsible for the actual aiding of implementation of the components. Every page of the documentation contains all the info a student needs to implement the component into their prototypes, but deliberately does not contain any information on what to use the component for. This is to prevent students from simply copying the examples given on the documentation page. Students are still supposed to come up with their own system. All the pages are hosted on Ysbrands digital tool [4]. This is to centralise as much information into one place. The pages themselves are ordered with the most important information for making a choice between components at the top, and information for implementing the component at the bottom. An example of the page with all the information sections collapsed can be seen in figure 18.

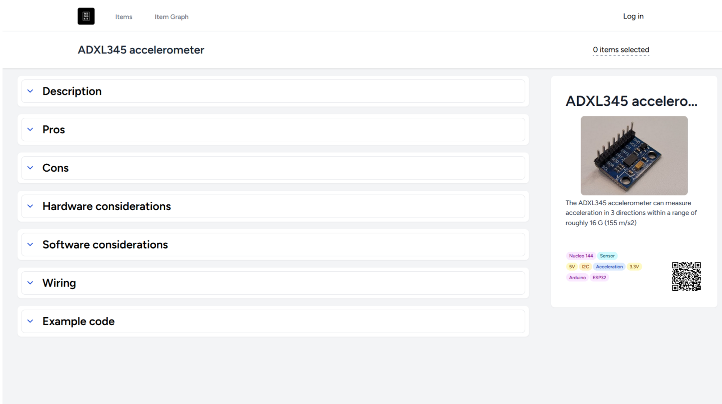


Figure 18: The documentation page of the ADXL345 accelerometer with all information sections collapsed so they fit in the screenshot.

Summary card The summary card contains the name and image of the part so it can be identified, as well as a short summary description, which is the same as the description on the physical cards. This little card scrolls down with the user when they navigate the page so they always have direct access to this information. The summary card also contains all the tags that can be filtered on to find the component. These are more important for the Lab managers maintaining the documentation.

Description The main goal of the description is to inform the students what the component can and can't do, and in which situations the component is best suited. This includes a short explanation of what the component does, how the it works, its range and/or limitations, if necessary an explanation of where it can and can't be used as well as an explanation of the context in which to use the component. The level of detail is kept relatively low here, as this is still focused on aiding a decision. For this reason the context part also refers to other components in case they are better suited.

Pros and Cons The Pros and Cons are two sections that are for the most part a copy from the cards. However these sections do allow for some more elaboration than on the cards. These pros and cons do not take into account the acquisition as the components should either be part of the kit or very easy to get for the students. Rather these pros and cons are focused on quality of the component, use cases and ease of implementation, as these are more important for the students.

Hardware and Software considerations The Hardware and Software considerations respectively contain technical details that should be kept in mind when implementing the components. These are things like mounting, power usage, required libraries or an explanation of how to filter the incoming signal. These are also to inform students about possible issues they may face when using the components and especially how to get around or avoid them.

Wiring The main part of the wiring section is the wiring diagram and possibly a table when specific pins are required. These are made in such a way that after hooking up the component works, but none of the special functions such as interrupts or wake pins are used when they are not necessary. This section also has explanations on how to setup power management or switch circuitry if necessary, as not all components can directly be connected to any microcontroller.

Example code The last section of the documentation is the example code. These bits of code were strictly written to get the "base functionality" from the components. This means that for sensors, it prints the raw data as received by the microcontroller or computer to the terminal or serial. For actuators this is only how to turn the actuator on and off. For middleware all the required code was provided to make the whole system work because the base functionality is all students will most likely need from it.

Manual Next to the documentation, a need for more general basic information was expressed during the specification evaluations. For this, a small manual was created. This manual contains an introductory explanation of how to use the toolkit, a recap of Arduino electronics and coding and an explanation of all the communication protocols supported by the microcontrollers. This manual can be found in the appendix under 11.7.

6.5 Digital website

While I developed all the above mentioned parts of the system, Ysbrand was hard at work on the framework that would support all of this [4]. Next to hosting the documentation, his website has three more functions that are all aimed at helping the students figure out what they need.

Filter system There are a lot of items on the website, one for every component in the kit as well as a separate item for Python which is needed for the item graph. However, showing all of these at once to the students will be rather overwhelming. To lessen this, filters were added to the website. Every item can be given attributes that are grouped within attribute types, both of which can also be made on the website. When attributes are selected in the filters, only items with at least one selected attribute per attribute type are shown. By default the 'Actuator' and 'Sensor' attribute types are selected, as this shows all the possible functions of the system still while hiding the parts only needed to connect the actuators and sensors to not overwhelm the students.

Choice helper While the filters are a great way for students to narrow down what they are looking for as a student. Sometimes they may not even know what they are looking for. For this a choice helper was implemented. This choice helper walks the students through a few questions and based on the answers it sets the filters for them. Leaving only a few components for the students to compare themselves.

Item graph Once the students know what actuators and sensors they want to use, they still need to make sure they work together. While the documentation may be enough for the very experienced student, for most people figuring out what other components are necessary to make the system work could be difficult, especially when one component only works with Python, while the other only works with a microcontroller. To help with this, an item graph system was developed, of which an example can be seen in figure 19. On the item page, a '+' button was added that can be used to add items to this graph. This graph then shows all the components required to connect the selected items. The connections themselves are set while creating a new documentation page by telling the system which components are needed to go from the component to Python. From there, the system determines the shortest path between components.

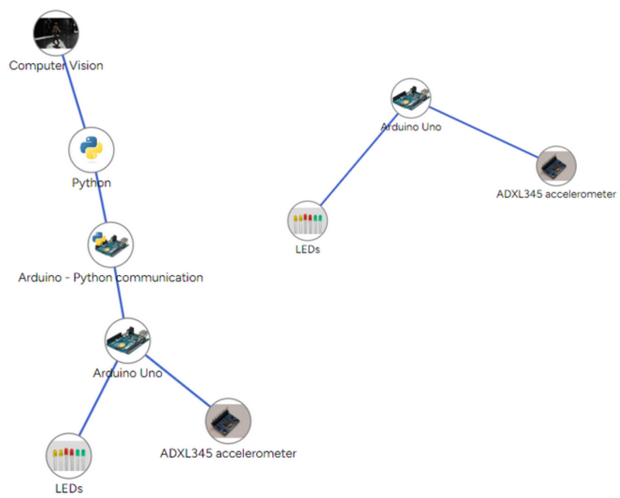


Figure 19: Two instances of the item graph. On the left LEDS, ADXL345 and Computer vision are selected, on the right only LEDs and the ADXL345 are selected.

6.6 Functional evaluation

With the final prototype completed, the functional requirements can already be investigated. The results were formatted in table 2 for a better overview.

Requirement	Reached	Note
Must have		
The toolkit must include hardware components.	Yes	See component list
The toolkit must have documentation for every component.	Yes	
The toolkit must have a way of aiding the students in selecting their components.	Yes	Multiple systems.
The documentation must have an explanation of what the component does.	Yes	
Should have		
The toolkit should contain extra information about software only solutions.	Yes	
Every components in the kit needs to be able to connect to python only using itself and other components in the kit.	Yes	
Could have		
The documentation could have explanations for the different communication protocols.	Yes	But in the manual.
The box could be custom made to have a more ideal packaging of components.	Yes	
Will not have		
The documentation will not have extensive, in depth explanations of how every component works.	Half	In some cases it was necessary to explain how a component worked to aid in the selection of components.
The toolkit will not contain systems not compatible with Arduino, Python or Unity.	Half	Unity compatible systems were also not included due to time constraints.

Table 2: Table of all the functional requirements and whether they have been completed or not.

7 Evaluation

This chapter discusses the final use evaluation performed on the prototype developed during the realisation phase, as well as the results from the evaluation.

7.1 Goal of the evaluation

The goal of the final evaluation is mainly on the usability of the system. It aims to answer whether the system is intuitive in its usage, if it helps students with their implementation and whether the system is comfortable to use. Next to this, further improvements and points of feedback are also recorded but as this is the final evaluation these can unfortunately not be improved upon.

To determine the intuitiveness of the system, observations were once again performed. This time, special attention was paid to exactly what pages and sections on those pages were read. Delay in figuring out something was also given more importance during this evaluation. From these observations, the possible points of confusion could be deducted and either during the interview or after the evaluation solutions could be thought up.

To determine if the system helped with the implementation, whether or not the system was comfortable in its usage and other general feedback points, a semi structured interview was held. The preset questions from the specification were used once again, but this time more importance was put on the observational notes and more questions were asked about what the participant did during the evaluation.

Finally, to get a more quantitative result that can serve as a comparison, the participants were once again asked to fill in a system usability scale form [40]3.5.

7.2 Recruitment of participants

The participant group for the final evaluation were adult Creative Technology students that had already completed the ResDesUX project. This group was selected to ensure that the participants had an idea of what the project would be used for so they could more accurately say whether or not the toolkit had a positive effect. To recruit the participants, a sign up form was created in which possible participants could select all times that worked in their planning, from which they would be assigned a time slot by us. This sign up form contained the information letter on the first page (see appendix:11.8), as well as a mandatory checkbox stating that they had read the information and wished to partake in the evaluation. This form was then sent out in both the second and third year Creative Technology WhatsApp group chats. This way, as many people of the target group are reached at once. A total of six participants were found after three rounds of recruitment. The first two rounds most likely experienced difficulties in their recruitment because all the second years were busy with the build weeks of their projects and most third years were busy with their own graduation project or finishing their minors. The third round took place in the first week of the vacation, meaning more people had time to spare.

7.3 Procedure

The procedure of the evaluation starts with the collection of participants as explained above. The participants will be given a design task before the signing of the consent form and thus the start of the test. This design task will not be part of the information letter as this could have influence on the results of the test as participants may think up ways of solving the design task before the start of the test. The test is performed with one participant at a time, to ensure anyone with any level of experience is able to use the kit.

The design task for the participants for this evaluation was as follows: "Design a system that creates different sounds or music based on different movements". This design task was chosen specifically for the high likelihood that many of the system's functions will be used by every participant individually. The envisioned solution for this design tasks was that the participants would use the choice helper to find the MPU6050 IMU and ADXL345 accelerometer as sensors. This could then lead to them using either the documentation or the cards to compare these two sensors. After that, the participant could use the filters to find a way to find audio solutions. The best fitting solution here would then be audio with Python. But as the sensors only work with microcontrollers, the participants would need to find some way to create a connection between the two. Which is where the item graph would come in and explain what other parts would be necessary.

After the design task is explained to the participants, they are presented with the consent form 11.9. This form contains 7 yes/no questions about the participant consenting to different parts of the research. All these questions need to be answered 'yes' and the form needs to be signed to ensure that the participant understands completely what the test will be about as well as that they consent voluntarily to participate in the test.

If the participant signed the consent form, the evaluation could begin. The participants were simply presented with the toolkit as seen in figure 20, the manual and the website and told to complete the design task. The participants were given roughly 45 minutes out of the hour long time slot to complete the task, to leave extra time for the interview at the end. While the participant was completing the task, observational notes were taken. Like stated before, these focused on the pages of the documentation that were visited, the cards read, the components picked up from the box, whether a participant seemed stuck on a certain part, general feedback or thoughts expressed while using the kit, the usage of external tools outside of the kit and what form the participants' final solution took. When the participants got stuck on a certain section for more then 10 minutes, they would be guided to the page on the documentation containing the information to overcome whatever they were struggling with.

Figure 20: The toolkit as used in the final evaluation.

After the 45 minutes were over or sooner when the participant finished early, a short semi structured interview was held. Like stated before, the 6 questions from the specification were used as a guide for this interview, but these were much more structured as a conversation discussing the toolkit. The first few questions usually walked the participant through the process they went through to get to where they got with their prototype. These were focused on determining if the toolkit and website helped with the finding and implementing of components. This often lead to a general discussion about the toolkit from which points of the system were intuitive or not and why, as well as things they liked and things they felt could be improved on. The final question was always for the participant to give any other feedback they still had. Finally, the participants were presented with the system usability scale (SUS) form [40]3.5. After this, the evaluation was officially over, but the participants could still ask further questions about the toolkit.

7.4 Main findings

During the evaluation, the toolkit was received well by most of the students. Especially the item graph and code examples were well liked. The documentation itself also did what it was supposed to because it managed both to aid in decision making as well as the actual implementation of components. Multiple participants stated that they liked the fact that all the information could be found in one place. The filters were also appreciated but not used much because the choice helper already set the filters for the participants. The choice helper was liked by the participants with less experience with electronics, but the more experienced participants found the questions too simple.

Based on the questions and ratings on the SUS form, as can be seen in table 3, more things can be deduced. All but one user would like to use the system according to the first question and the system. The system also wasn't found to be too complex by most people and they didn't feel like they would need external help to use the system. But at the same time, the system was not the easiest to use, was considered slightly cumbersome and participants were not fully confident in using it.

User:	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Final score:
1	4	3	3	2	3	2	4	3	3	1	65
2	5	2	4	1	4	1	5	1	3	3	82.5
3	2	2	3	2	3	1	2	3	4	2	60
4	4	2	3	3	5	1	5	2	4	3	75
5	5	1	4	1	4	1	5	2	4	1	90
6	5	1	5	1	5	1	4	1	5	1	97.5
Average	4.17	1.83	3.67	1.67	4	1.17	4.17	2	3.83	1.83	78.83

Table 3: The SUS ratings of each user per question. For odd questions, a higher rating is better. For even questions, a lower rating is better.

Where to find certain parts of the system was also not always clear to the participants. The item graph was completely missed by two of the participants, while three participants did not use the cards. This has a noticeable effect on the SUS scores. Those that did not use the item graph gave the system a score of 65 and 82.5, those that missed the cards 60, 75 and 90. The one participant that used the whole system gave it a score of 97.5, only deducting one point on the learnability of the system. This would mean that the user interaction needs to be improved upon so all the systems are much more obvious.

Further smaller details found was that the current version of the 'Audio with Python' page is very limited in its supported use cases. In text images were needed at times to give a proper full explanation. The questions of the choice helper also require further refinement. Documentation pages should be properly checked for spelling and grammar and there should be a possibility for adding items to the item graph from the documentation page. Furthermore, there was some confusion when parts on the wiring scheme didn't match the physical models due to them being named after the IC. Finally, the names of the filters were unclear to the less technically experienced participants.

7.5 Non-functional evaluation

From the interviews and observations the non-functional requirements could also be determined. These are organised in table 4

Requirement	Reached	Note
Must have		
The toolkit must help the students with finding the components that best fit their needs	Half	Experienced participants didn't feel like the toolkit helped much, as they themselves already had the required knowledge. But less experienced participants did feel like the kit helped.
The toolkit must help the students with implementing their components	Yes	
Should have		
The toolkit should support as many different projects as possible, within the scope of the ResDesUX project assignment.	No	None of the Unity based projects were supported, and certain parts of the documentation require more work before they are truly helpful.
The documentation should have a consistent structure	Yes	This was achieved through the way the website was set up.
The documentation should have clear wiring instructions.	Yes	
The documentation should have clear example codes	Half	While most of the code was clear enough for the participants to work with, the 'Sound with python' item's example code was not clear enough.
The selection aid should give the students enough information that they can make an informed decision	Yes	
The selection aid should not overwhelm the student with information	Yes	
Could have		
The wording on the cards could be made consistent across all the cards.	Yes	The exact wording was checked to be consistent across all the cards and tweaked where necessary.
The selection aid could have categories to make finding components easier.	Half	Both the cards and filters have categories, but the categories of the filters are slightly overwhelming and at times redundant. The choice helper works based on questions instead of categories.

Table 4: Table of all the non functional requirements and whether they have been completed or not.

8 Discussion and future work

This chapter covers the discussion of the results of the final use evaluation, as well as what their implications could be and what limitations were faced during this graduation project. This chapter ends with recommendations for future work.

8.1 Findings

The goal of this graduation project was to develop a system that helps students develop a high fidelity prototype within the context of the ResDesUX project, which is a project where students are tasked with developing a system for sports and/or movement. For this a toolkit was developed, with documentation for every component as well as multiple tools to help the students pick their components.

This system reached all but the two 'Will not have' category functional requirements completely during the realisation phase, but did less well during the evaluation with the non-functional requirements. Only half reaching three requirements and even not satisfying one of the 'should have' requirements at all. In terms of usability, the system received an average SUS score of 78.3, however the individual scores were rather spread out, ranging from 60 to 97.5. From the individual question answers, the general opinion was that while the system helps it needs a bit of getting used to.

In terms of more qualitative results, the toolkit was received well by most of the participants of the evaluation. The documentation explained enough to the participants that they could complete the design task, or were at least well on their way to do so if given a bit more time. The cards were not used much, but when they were used the participants used them for their intended purpose: comparing components quickly. The choice helper, filters and especially the item graph developed by Ysbrand [4] also all worked as intended in helping the participant finish the design task. However, like the cards, the item graph was not used by some of the participants.

8.2 Discussion

8.2.1 Requirements

In terms of the functional requirements, the only requirements not met completely were the 'will not have' category of requirements. This is in part due to time limitations meaning that the toolkit also does not have Unity compatible systems. But also because for some components it was simply needed that there was a small explanation on how they worked to make sure students understood how to use them. Furthermore, some of the functional requirements were achieved in a different way from the one originally envisioned while writing the requirements, such as the fact that the tool kit's selection aid is split up into three systems and the explanation for communication protocols can be found in the manual instead of their own items in the documentation.

In the non-functional requirements, more were not sufficiently reached. The toolkit did not help the participants more experienced with electronics in selecting their components, as they already mostly knew what they were looking for. However, this should not be considered a negative, because this just means that the participants need less help from the kit. And as the kit did help the less experienced participants, this is simply a step in the process that the more experienced can skip.

The reason why the toolkit failed to support as many different projects as possible, within the scope of the ResDesUX project assignment, was because of time limitations. Because of the lack of time, I could not research and learn how to use Unity, nor how to connect it to the rest of our system. Because of this and because in the thematic analysis I found that many students that use Unity build their entire system in Unity, I felt it would be better to focus on improving the more physical side of prototyping first. And to, unfortunately, move the Unity side of the project to future work.

During the testing it was also found that the example code for the 'Sound with python' item in the documentation was not clear and did not even work in situations other then the very specific ones they were designed for. There was also a small mistake in the example code for the Neopixel LED strips, where a bracket was missed which prevented it from compiling. However, as this was only a small change this has already been fixed. The bigger issue with the example codes is that because not all components could be bought, not all code could be tested either. This means that the example code of certain items may not work or are very bare bones. For example, the example code of the ECG/EMG shield currently reads the raw data, but for any of the data to be usable filtering should be applied which could not be made because the system could not be tested.

Finally, the categories of the filters on the documentation turned out to be slightly overwhelming. This was both because there were so many as well as that the names of the categories were often times the technical terms instead of more descriptive terms. E.g. one of the filter categories was named 'Actuation', while 'Output' would have been more clear. A lot of the filters also became redundant quickly. E.g. when filtering on 'acceleration', there will be no items that have labels in the 'Physiological sensing' category.

8.2.2 System usability scale

As stated in the evaluation, there was a noticeable difference in the SUS score depending on how much of the system was used by the participants. This is further supported by the fact that both participants that missed the item graph commented that it would have been really useful to know that it existed once it was shown to them after the test, as well as the fact that the two people that scored the system the highest were the only two that read the full introduction in the manual.

While the technical experience of the participants could have had an effect on the score as well, there are not enough results to support this. The more technical participants gave the system a SUS score of 60 and 90, those with moderate experience rated it 65 and 97.5 and the less technically inclined participants rated it 75 and 82.5.

The reason why people exactly consider the system not too complex yet cumbersome and not easy to use is harder to pin down. This could be because the instruction manual is unclear, because the user interface is unclear or because the information is not structured in a logical order for the participants. This uncertainty also shows a flaw with our evaluation setup. It would have been better if the participants had filled in the SUS form right after they used the toolkit, so questions about their scores could be asked during the interviews.

8.2.3 Qualitative results

Qualitatively the biggest issues were in the fact that the cards and item graph systems respectively both were not used by every participant, leading to them finding less use in the system. The most likely reason why the cards were used less was because they were the only source of information not on the website. Some of the participants commented that they found all the information they needed on the website already as their reasoning not to use the cards. Of the participants that did use the cards, one commented however that they were nice to make a quick comparison between two sensors, and another that they helped find the components in the box. The most likely reason that the item graph was missed by some of the participants was the fact that it was located on a separate page from the items which is not indicated well.

8.3 Implications

While there are many points of improvement still, the toolkit has shown real potential during the use evaluations. Most of the requirements were still met, especially the functional requirements. And even with one of the requirements not being met, the system can still perform what it was designed to do, just not to its fullest extent. An average SUS score of 78.83 is also a rather positive result, as this would place the system in the 'Good' category which means its an acceptable solution [41]3.5. While the distribution of the individual SUS scores is something to note, this can also simply be something that had to be considered from the start: The toolkit will not work for everyone. Especially those with a lot of experience in electronics will not see much use in the toolkit except as a source of components and/or the example codes.

Qualitatively speaking, the part of the system that will have the biggest impact will be the item graph. The item graph has on multiple occasions bot during the specification and final evaluation shown to help participants make a system they originally considered not possible, simply because they thought the parts were not compatible. Furthermore, it saves a lot of time on their part because they no longer need to figure out how to combine parts or find out halfway through implementation that they needed another part to make everything work.

8.4 Limitations

The main limitation to this project was simply time. Too much time early on was spent on the background research and ideation in the form of defining the scope and interpretation of the project goal. This meant that there was not enough time to actually develop a full system. A lot of the work ended up being done in a rather rushed manner and barely any time was spent on writing the report during the development of the actual toolkit. This also lead to a rather large amount of components, all based on Unity, being left out of the kit as Ysbrand was still busy with his website and I did not have the time to learn the basics of Unity and the components to make proper documentation for them.

Another limitation was with the planning of the evaluations. Due to the timeline of the graduation project being moved, this also lead to the specification evaluation and especially the final evaluation having to take place during a time where almost everyone of the target group was busy to some capacity which made it much more difficult to find participants. For the final evaluation we had to perform another set of evaluations to get even a slightly significant amount of participants.

The final limitation was money. Not all the components to be included in the kit were owned by me nor Ysbrand, nor could we borrow them anywhere. This meant that some of the components could not actually be tested and it is uncertain if the documentation for them is sufficient. These components are: 'Haptic coins', '100KG load cell', 'PPG sensor' and 'Simple microcontroller audio'. The EMG/ECG documentation is certainly not enough as mentioned previously.

8.5 Future work

8.5.1 Components

The most important thing that still needs to be done to complete this toolkit is to add the Unity based components that were not possible to be added within the current time frame of the graduation project. These are 'Unity', 'VR with Unity', 'Unity to Python' and 'App interface'.

8.5.2 Documentation

Furthermore, every part of the documentation may need to be checked on spelling and grammar as well as accuracy in some cases. Unfortunately, the spell check of google docs is not 100% accurate and I personally would prefer not to use Grammarly due to their collection of user content data [46]. And given that I have dyslexia, it is hard for me to perform these spell and grammar checks on my own. The documentation of the components that could not be acquired for the kit during this graduation project should also be tested, checked and if needed expanded and/or corrected.

8.5.3 User interaction

To help with the user interaction, multiple things could be changed. A solution to help people find the item graph is for it to be included as a popup on the item page and to show as soon as a connection can be made. There could also be a button on the documentation page to add the component to the item graph.

For the physical box, a small but slightly annoying mistake was made during the designing, leading to the main 'square' being sized 24 by 26 cm. this means that while the box looks square, it is in fact rectangular and thus does not stack in two out of four rotations.

9 Conclusion

Within the Creative Technology project Research and Design of User Experience (ResDesUX), students are tasked with developing a prototype that aids in sport or movement. For this, multiple levels of prototyping are used. The students start of with a low-fidelity prototype, usually made from paper or cardboard. After performing tests with these they move on to high-fidelity prototypes with electronics. However, many students struggle with this step. This leads to a lot of time being spent on the functional requirements of the prototype and leaving little time for the development of the user experience. The goal of this graduation project was to create a system that can aid these students with their implementation of hardware in their high-fidelity prototype. To achieve this, a toolkit with accompanying documentation and selection aids was made.

To determine what components should be included in the kit, research was done into what was used in both research settings and previous projects. To determine what kind of measurements were often used in sports research, a literature review was performed using 17 papers. From this it was deducted that the most common kinds of measurement in research are movement monitoring though IMUs, electromyography (EMG) to measure muscle impulses, temperature sensing and electrocardiography (ECG) and photoplethysmography (PPG) for measurements on the heart. Very few papers contained a feedback system where the user was informed about the data, but of the ones that did have a system a simple display screen was the most common. To determine both what components students used, as well as what difficulties they faced during the development of their high-fidelity prototype, a thematic analysis was performed on 28 anonymised student rapports of completed projects. From this a much more detailed list of components was found. Of which the most common were buttons, LEDs, screens or projectors and optical motion tracking. Based on these two analyses, a final list of components was selected.

For all these parts, a documentation page was made. This page consists of a description, a list of pros and cons, hardware and software considerations, a wiring diagram if available and example code. The page is ordered from information that helps more with the choosing of components to information that aims to help with the implementation of the component. All these documentation pages are hosted on a dedicated website. The website also has filters to find the parts the students need, a choice helper that sets these filters for the students with less experience in electronics and an item graph that quickly shows the required components to make actuators and sensors work in a single system.

For the students more experienced in electronics, quick reference cards were also made. These cards contain part of the documentation in summarised version, along with icons that show the power and computational requirements of the components. These cards also have a QR code that leads to the full documentation page.

For the evaluation, participants were given a design task to complete using the toolkit. The toolkit and accompanying systems were received largely positively. Especially by the participants with less experience in electronics. From the feedback of the participants, it was concluded that the main strengths of the system are in the item graph and the example codes. At times it is difficult for some students to find all the components needed to make a system work, especially when more than a single Arduino needs to be used. The item graph proved to be a good tool to help with this. Furthermore, participants appreciated having all the information needed to implement a component in one place. Especially the example code was mentioned multiple times as being very nice to have.

However, while every individual part of the system contributed to helping the participants completing the design task, multiple participants missed certain parts of the system leading to the system as a whole being less effective. They struggled more with the implementation of the components they picked and when shown the parts of the system they missed, they often stated that that part would have helped. Especially in the case of the item graph. This is also represented in the system usability score with the scores being noticeably lower for those that missed certain parts of the system than those that used the whole system.

While the system is not perfect. It has still shown great potential in aiding students with the selection and implementation of functional components in their high-fidelity prototypes. It was able to explain to students who themselves were not confident in their technical skills how to pick and use components. Many of the participants were also able to complete the design task much faster than they would have without the toolkit. And as the system was designed to be maintainable and expandable, many more components can be added in the future. This could also lead to it possibly being adopted in other courses or projects within Creative Technology. However, it may be important that this system does not become the default. This is because when properly used, the item graph may result to be too powerful to the point that students would develop less critical thinking skills in regards to understanding why certain components require other parts.

When students manage to finish the functional aspects of their high-fidelity prototype sooner, they will have more time to work on the user experience of their high-fidelity prototypes. This will thus result in better prototypes overall and the students will get more familiar with designing for user experience. Thus the overall quality of the ResDesUX project will also be improved.

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11 Appendix

11.1 AI disclaimer

During this graduation project, no (generative) AI were used with the exception of Overleaf and Google Docs spelling- and grammar check to ensure a well written report.

11.2 Thematic analysis table

Theme	**Sub-theme**	**Description**	**Code**	**#**
Hardware	Lights	light systems	LED strip	2
			LED ring	2
			(Colored) lights	6
			LED unspecified	4
			Light button combo	3
	Buttons	Button systems	Big button that can handle human weight	8
			Small button	6
	sensors	uncategorized sensors	capacitive sensor	2
			pressure sensor	4
			Light sensor	1
			rotary encoder	1
			stretch sensors	1
			ultrasonic sensor as presence detector	1
			hall effect sensor to measure rotational velocity	1

			pedometer (step counter)	1
	motion tracking	motion tracking systems	IMU	2
			Xbox Kinect	4
			depth sensing camera	1
			Optical motion tracking	8
	position tracking	(global) position tracking systems	GPS	3
			GPS beacons	1
			Compass	1
	Audio	systems to provide auditory feedback	Buzzer	2
			headset	2
			Speakers	2
	connections	data connection types between prototypes and other devices or each other	wired connection	4
			WiFi connection	4
			Bluetooth connection	3
	motors	motor based systems	Haptic motors	2
			motor controllers	1
			On-off motor controller using MOSFETs	2
	processing	main processing unit of the system	Computer as processing unit	9
			Phone as processing unit	1
			Raspberry pi	1
			Arduino	10
			ESP	3
	power	power management of the system	external power supply	1
			Battery power supply	6

			Battery management system	1
			bread board	4
	Displays	screen or image based feedback systems	VR	3
			Projection	10
			Screen	8
	Other		home trainer	1
			smart watch	2
Feedback	visual	visual methods of providing feedback	Light	2
			Color	7
			VR	2
			AR	4
			general visual	6
	audio	auditory methods of providing feedback	sounds	9
			music	5
			Spacial 3D audio	1
	touch	tactile methods of providing feedback	haptic	4
measurements	movement	measurements that can measure the movement of a person	step counter	1
			position measurements	4
			rotational velocity	1
			rotational position	1
			motion tracking	12
	physiological	measurements that can measure physiological data on a person	Oxygen levels	1
			heart rate	3
			breathing	1
	other		presence detection	1
software	interface	ways of interfacing with the system though software	app	9
			website interface	1
	engines	software engines used to code and run the system	Unreal engine	1

			Processing (code language)	1
			Unity	6
	motion tracking	software used for motion tracking	Kinect SDK	1
			Computer vision	4
	other		spotify API	1
			QR codes	1
design considerations	wearables	considerations for wearables	smaller prototype better	4
			integration into fabric	1
	setup considerations	considerations for the (way the system is) setup	wall mounted vs floor mounted	1
			ease of setup	1
			Merging systems to prevent communication overhead	1
			multiple cameras for better motion tracking	1
			wireless capabilities	2
			flexibility of implementation	1
	Button considerations	considerations for when making buttons	Light and buttons integrated together	2
			extra buttons to add to the interaction	2

			Capacitive sensors instead of buttons because of ease of up-scaling	1
			button strength	2
	Controllers	considerations for designing custom input devices	custom controllers (input device)	2
			hands themselves act as controllers	2
	other		Visibility of feedback	3
			Multiplayer capabilities	2
			Chose one technology and tried to build around it instead of looking at alternatives for that technology	1
limitations	audio		audio quality of the speakers	1
	motion tracking	issues students had while implementing motion tracking	motion tracking had issues with detecting depth movements	1
			motion tracking not working well in low light levels	2

			motion tracking stops working when more then one person in frame	2
	component issues	issues students had while implementing general components	Battery life	1
			GPS module did not work well	1
			lack of components	2
			waterproofing	1
			long distance wireless components	2
			motor power	1
	system issues	issues with the system as a whole	system not movable	1
			issues with properly powering system	3
	input	issues with (getting) inputs for the system	real time measurement of acceleration	1
			extra buttons for extra inputs	2
other			data processing of compound movement in IMUs	1
			addition of random movement to a ball through magnets	1

			desire for the system to work while mounted with magnets	1

11.3 Information letter interviews

Information letter: Developing a rapid prototyping kit for the design of Creative Technology for sports and movement

This letter informs you about the research conducted by Sven Rozendom and Ysbrand Burgstede. The research aims to investigate how we can support the design practices of staff and students aiming to design interactive systems for sports and movement.

The session will take about 20-30 minutes. The participant will take part in an interview with the researchers where they will ask questions related to the research topic. The answers will be anonymized.

The benefit of participating in the research is that the end product from the research will be aimed to help the group of staff the interviewee belongs to in creating prototypes and helping their students.S

We do not consider participating in this research to have any risks.

The Interviewee can at any time stop the interview and refuse to answer any questions. They can also request for their previous answers to be deleted. Afterwards, they can contact the researchers by email with a request for their interview to be deleted and not used for the research. (emails listed below)

We will not collect personal information from the interviewees.

The collected data during the interview will be processed by the researchers and afterwards deleted. It will not be made public and will be deleted at the latest when the researchers graduate. The data will be stored on a secure private drive which is only accessible to the researchers. The anonymous transcripts will be included in their final written report and archived on the Graduation Project database of the University of Twente.

If you have any questions or concerns or want to contact the researchers you can do so by email: s.c.rozendom@student.utwente.nl and w.y.burgstede@student.utwente.nl.

If you have any ethical complaints this research is being conducted under the Ethics Committee Computer and Information Science. You can contact their secretary at ethicscommittee-cis@utwente.nl.

11.4 Consent form interviews

Consent Form for Developing a rapid prototyping kit for the design of Creative Technology for sports and movement

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 02/05/2024, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves an audio-recorded interview. I understand the audio recording will be transcribed as text and when this has been completed the recording will be destroyed.	○	○
Use of the information in the study		
I understand that the information I provide will be used for the research for the graduation projects of Sven Rozendom and Willem Ysbrand Burgstede. I also understand the anonymised transcriptions will end up in their final write-ups, which will be stored in the Graduation Project database of the University of Twente.	○	○
I understand that personal information collected about me that can identify me, such as my name, will not be shared beyond the study team.	○	○
I agree that my information can be quoted in research outputs	○	○
Consent to be Audio Recorded		
I agree to be audio recorded during the interview.	○	○

Signatures

______________________	______________________	________
Name of participant	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

________________________	___________________	________
Ysbrand Burgstede	Signature	Date

Study contact details for further information:

Sven Rozendom (s.rozendom@student.utwente.nl)

Willem Ysbrand Burgstede (w.y.burgstede@student.utwente.nl)

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

UNIVERSITY OF TWENTE.

11.5 Interview Questions

- What do you do related to designing interactive sports systems?
- In what area of design do you help students?
- Where do you see students struggle with making and testing these systems?
- Do you feel like the students have all the tools necessary to develop their prototypes?
- How do you think a tool that would aid in the technical design affects the teaching and learning process?
- If it's more positive: What form do you see this aid taking?
- What kind of effect might this have on the developed UX?
- What effect would it have on students if they were given a box of components to use for their prototypes?

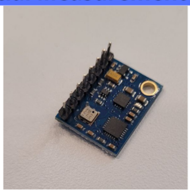
11.6 Cards

MPU6050
Inertial Measurement Unit

Power

5V

3.3V



Boards

A

N

E

The MPU6050 is a 9 Degree Of Freedom IMU with a built-in temperature sensor. It measures acceleration and rotation with the built in accelerometer, gyroscope and magnetometer.

Context

You want to track acceleration and/or rotation or one of their derivatives. You want your system to be wearable, or your system also has other components that only work with a microcontroller. If your system only runs on a computer, take a look at Computer Vision.

Pros and Cons

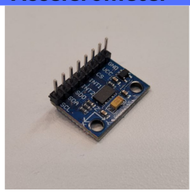
Pros:
- Accelerometer, gyroscope and magnetometer on one chip
- Data given in usable units
- Precise and fast measurements
- I2C communication
- Small chip

Cons:
- Susceptible to interference from electrical devices and metal
- Data is based on acceleration. Extra processing required.
- Slow and small movements won't be registered

ADXL345
Accelerometer

Power

5V



Boards

A

N

E

The ADXL345 accelerometer is a 3 degree of freedom accelerometer. It measures acceleration in in three directions

Context

You want to track acceleration and/or its derivatives and/or you want your system to be wearable. If your system only runs on a computer, take a look at Computer Vision. If you also want to measure rotation, take a look at the MPU6050

Pros and Cons

Pros:
- Very high acceleration measurable
- Small chip
- I2c communication allowing for multiple devices to be connected at the same time

Cons:
- Rather bad resolution
- can't measure small movements
- Data processing required
- Measurements are not very accurate

Computer Vision

Boards

PC

N*

Computer vision is a technique that estimates the position of digital "markers" on a person's body using pre-trained algorithms. This allows for 2D, and to a certain extent also 3D, motion capture with just a simple webcam.

Context

Your tracking doesn't need to be 100% precise, the rest of your system is contained on a computer or you don't want to have users wear a special device. If your system is a wearable, take a look at the MPU6050 or the ADXL345

*Only when running micropython

Pros and Cons

Pros:
- Nothing needs to be worn by the user
- Track slow movements
- Keep the entire system enclosed in a computer setup

Cons:
- Tracking isn't the most precise, especially in estimating depth
- Sometimes loses track of markers completely
- Setup has to be stationairy

EMG/ECG shield

Power

5V

Boards

N

A

This shield can measure EMG and ECG signals. This means that it can measure muscle and heart impulses. However, it sends a simple analog signal to the micro controller. You will need a lot of data processing before you can get something useful from the measurements.

Context

You want to measure muscle impulses or high quality heart measurements. If you only need bpm or heart rhythm, take a look at PPG. Recomended to be used with the Nucleo micro controller

Pros and Cons

Pros:
- High quality readouts
- Shield can be stacked for multiple readouts

Cons:
- Requires a lot of data processing
- lots of wires on the person

Card Color Code Cheat Chart

Position and movement

Physiological signals

User input

Actuation

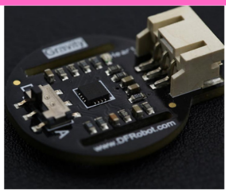
Processing and control

PPG Heart sensor

Power

5V

3.3V



Boards

N

A

E

A PPG heart sensor can measure heart rate and heart rate variability. If you know what you are doing you can also get oxygen saturation of the blood and respiratory rate from PPG measurements. They are much less invasive then ECG setups.

Context

You want to measure one of the above mentioned variables, and you don't need a too high level of precision or you are making a wearable.

Pros and Cons

Pros:

- Compact package
- no electrode cables
- Only three cables to connect the chip

Cons:

- Susceptible to movement artifacts (errors in the data when moving)
- Data cable also susceptible to interference so it can't be too long
- Not as precise as ECG

Arduino Uno

Power

5V

3.3V

The Arduino Uno is the most common micro controler used in both Creative Technology as well as in hobby electronics. It is relatively simple to understand but also slightly limited in its capabilities.

Context

You just need a micro controller to connect sensors to, but you don't have specific needs from the micro controller itself.

Pros and Cons

Pros:

- Familiar
- A lot of shields are made specifically to fit the uno
- Supports Serial, I2C and SPI communication
- Has a lot of example projects and help resources

Cons:

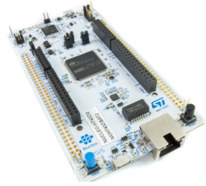
- Single thread code only
- Limited storage space
- Limited number of pins

Nucleo 144
(Nucleo-F207ZG)

Power

5V

3.3V



The Nucleo 144 series are very powerfull but also very complex micro controllers. All the arduino uno pins are supported on these boards, meaning all shields for the uno also work on these.

Context

You need many many pins to the point where even a mega doesn't cut it, you need to run multiple parts of your code at the same time, you are running heavy data processing or you want to run python code on your micro controller

Pros and Cons

Pros:

- Lots of pins
- Multi threading capabilities
- Micropython builds exist for many of these boards
- Relatively large internal storage

Cons:

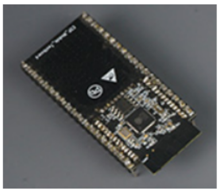
- More complex than other boards to configure
- Requires a few extra steps one time before code can be uploaded.
- The board currently in the kit (F207GZ) does not have a micropython build

ESP32

Power

5V

3.3V



The ESP is a slightly smaller micro controller then the arduino, but in no means less powerfull. The main feature of the ESP32 is its built in capabilities for wireless communication.

Context

You have multiple prototypes that need to be able to communicate with each other wirelessly or you want your prototype to be able to communicate wirelessly with a phone or computer.

Pros and Cons

Pros:

- On the smaller side
- Can be placed directly on a breadboard
- Wireless communication
- Can be programmed from the arduino IDE

Cons:

- Linking 3 or more ESPs is difficult

Micropython

Boards

N

E

A python build specially made for micro controllers. It also contains some special built in libraries specifically made for interacting with a micro controller. Compatible with certain Nucleo boards and the ESP32.

Context

Your system already uses python based programs, or you want to use python libraries for data analysis.

Pros and Cons

Pros:
- Python on your micro controller
- Use Python libraries
- Test the code on PC before uploading it to the controller

Cons:
- Installing micro python can be a little difficult
- Not every board has a micro python built
- Not compatible with arduino

Big Arcade Button

Power

5V

12V

HC

Boards

A

N

E

These big arcade buttons come with a built in 12V LED. The button itself is based on a limit switch but the wiring is the same as any other button. The LEDs require an external power source

Context

You are making a prototype that involves easy to press or big buttons and/or buttons that light up. Requires a microcontroller of some kind to register inputs.

Pros and Cons

Pros:
- Big button
- Built in LED
- Easy to install
- Can be connected using crimp connectors, so no soldering is required

Cons:
- Requires an external power source for the LEDs

Custom Button

Power

5V

3.3V

Boards

A

N

E

Sometimes even the big arcade buttons aren't big enough, or you want the buttons to be able to change color, or you want them square. There are many reasons to want a customizable button. The documentation contains an instruction on how to make your own button.

Context

You are making a prototype that involves easy to press or big buttons and/or buttons that light up. But for what ever reson, the arcade button is not a suitable solution. Recommended to use an ESP32 as a micro controller as long wires can lead to dataloss

Pros and Cons

Pros:
- Customizable size
- Customizable required pushing force
- Customizable design

Cons:
- You have to build the button yourself
- Requires an individual micro controller per button

Load Cell

Power

5V

Boards

A

N

E

Load cells are electrical devices that can convert a force or pressure into an electrical signal. It does this by using stretching cables which resistance changes when they are stretched. These bars can handle up to 100 KG.

Context

You are making a prototype that either involves measuring weight or force of some kind, or you need a button that can withstand much more force then usual.

Pros and Cons

Pros:
- Measure weight and force up to 100 kg
- Can act as a high impact resistant button

Cons:
- complex to understand how it works exactly
- Rather large
- Requires an amplifier

NeoPixel
LEDs

Power

5V

12V

HC

Boards

A

N

E

NeoPixel like LEDs are RGB LEDS that come in many shapes and sizes. Most commonly you will find them in strips, but they also exist in matrices, circles and individual LEDs. These LEDs are all individually programmable, but only use a singular pin on a microcontroller

Context

You want visual feedback through either light or color. This feedback is part of a physical setup. Requires a microcontroller.

Pros and Cons

Pros:
- (Almost) no limit on the amount of LEDs used
- Program all the LEDs with a single pin on the micro controller
- RGB support

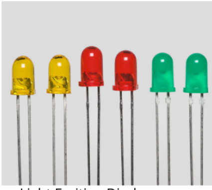
Cons:
- Reqires an external power source if you're using more then 10 LEDs
- Solder pads are very fragile

LEDs

Power

5V

3.3V



Boards

A

N

E

LEDs, or Light Emitting Diodes are very simple lights that come in many colors. As they are diodes they only allow power to go through in one way. Because of their small size they get damaged easily so a resistor is needed in series to protect the LEDs.

Context

You want visual feedback through either light or color. This feedback is part of a physical setup. Requires a microcontroller.

Pros and Cons

Pros:
- Simple to use
- Small
- Come in different colors

Cons:
- Fragile
- Require resistors

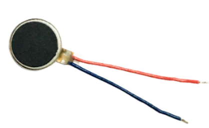
Haptic motor
Coin

Power

5V

3.3V

HC



Boards

A

N

E

Coin haptic motors are designed for "small" haptic feedback like those in phones or smart watches. Don't underestimate these little things as they can still vibrate quite strongly.

Context

You have a small object that needs to vibrate or you want specific parts of a larger object to vibrate. Requires a microcontroller

Pros and Cons

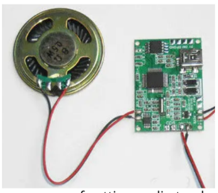
Pros:
- Small
- Enclosed
- Suprisingly strong vibrations

Cons:
- Requires an external power source
- Without a controller vibration strength can't be set

Simple audio
For microcontrollers

Power

5V



Boards

A

N

E

A very easy way of getting audio to play with your microcontroller is simply by using the audio modules from those gift cards that play a song when you open them.

Context

You want some kind of audio feedback in your system, but you only need one sound/song to play. You also are only using microcontrollers. If you're also using a pc, consider playing audio using python as this allows for multiple sounds to be played.

Pros and Cons

Pros:
- Easy to use
- Decently high quality audio
- Doesn't strictly require a micro controller

Cons:
- Only one file can be played and stored

Sound with Python

Boards

PC

N*

E*

It is possible to play sounds with python. There are multiple libraries for this depending on what you want to play specifically. Windows has a built in library called winsound. Furthermore you could use Pygame and/or pyglet. It is even possible to play sounds using the python file manager

Context

Your system is (primarily) running on python and you want auditorial feedback

*Only when running micropython

Pros and Cons

Pros:

- Easy to impliment
- Many options of libraries

Cons:

- Certain libraries are limited in what they can do
- Finding the best library may be a little difficult
- Some libraries have to be installed

Arduino Python communication

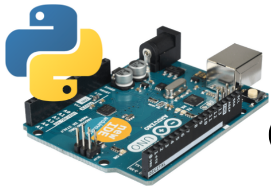
Boards

PC

A

E

N



Certain things only work in python, others only in Arduino. That makes things a little difficult when you want to use both. Luckily there are bits of code with which you can establish a communication between the two using Serial communication.

Context

Your system uses both micro controllers and python running on a PC and you need to communicate between these

Pros and Cons

Pros:

- Establish communication between two otherwise incompatible code languages

Cons:

- Blocks the serial, so debugging becomes harder

External power sources

Boards

A

E

N

There are multiple ways of getting more power to your components. Which is needed if you want to use high current or voltage components

Context

Your system needs a higher voltage then 5V and/or you are using high current components and/or you want your system to be wireless

Pros and Cons

Pros:

- Higher current available
- Higher voltage possible
- Less wear on the microcontrollers
- No longer require a PC for power

Cons:

- Possibility to fry your boards and components
- May require a lot of soldering
- Risk of fire with Lithium based batteries

11.7 Manual

ResDesUX high-fidelity prototyping kit

The ResDesUX kit was designed with the intention to ease and speed up the implementation of your high fidelity prototype, so you as the designers have more time to develop the user experience. To achieve this, the kit has multiple selection aid tools and some documentation per part. For those completely new to the kit and/or not very familiar with electronics, we recommend going through all the steps listed below in order. For those with more experience, you can also explore the kit and tools on your own.

The kit itself consists of three "parts": A website with the documentation, the choice helper tool and filters. The cards with summaries on what the components need and do, with a QR code to the documentation. And the box with components itself.

How to use the kit?

The kit was designed with a specific set of steps in mind. These can be grouped into three big steps: Selecting the main components, determining what other components are needed, implementing the components. The kit was not made to help ideate your concept, so you will need to have a decent idea of what you want to do before you start using the kit.

Selecting the main components

Go to the website that comes with the kit: ysbrand.dev. Here, you can use the choice helper to filter on parts you may need, or use the filter selector on the left of your screen to do so yourself. Once you have a selection of possible components, you could either use the full documentation of every single component to compare which is best for your project, or take a look at the summarised versions on the cards. From these options, you can find what parts you want to use for your sensing, actuating and possibly also what microcontroller you want to use.

determining what other components are needed

Once you know what parts you want to use, you can add these components to the item graph from the items page. On this page, simply click on the + button on the bottom right of the component cards. Once you have all your components selected, you can go to the item graph at the top of the page or by hovering over 'X items selected'. This graph will show you all the other components and software you will need to make your system work. Clicking on one of the nodes will take you to its respective documentation page.

implementing the components

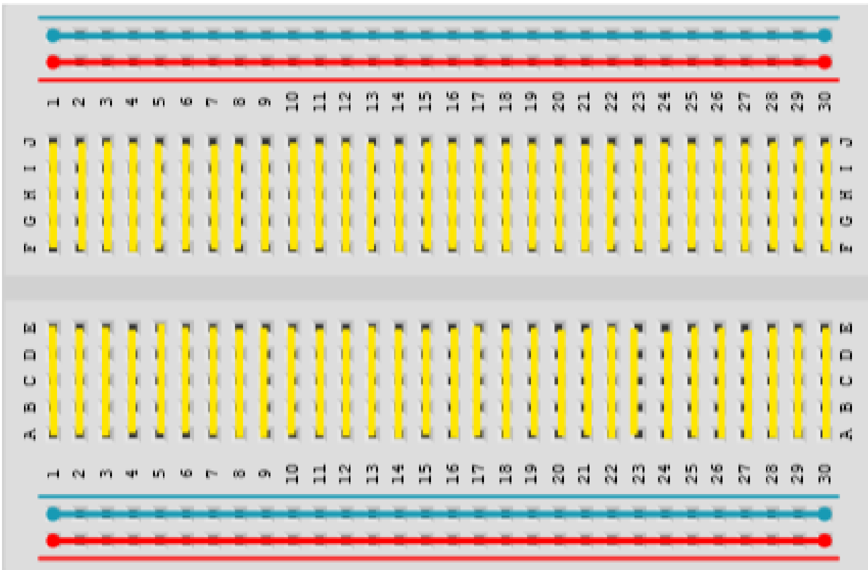
When on the documentation page, there will be multiple dropdown views. These will provide you with extra information you may need to implement the components such as a more detailed description of what the component does, which communication protocol they use or what power you need to provide. At the bottom of the page there will be a wiring diagram and some example code if available. In case of the microcontrollers, the wiring diagram will be replaced with a pinout scheme. If the pinout contains a table, this means that very specific pins are required that can't (easily) be changed.

Recap on Arduino and electronics

It might have been some time since you've last used an arduino or electronics. So this is a quick recap on the most important parts that didn't really fit into the cards or documentation themselves.

Creating connections

The most common way to get your parts wired up is using a breadboard. While you don't strictly need one for most parts in this toolkit, it's good to know how they work. Solderless breadboards are breadboards where you can simply plug in your components and it will make sufficient contact for current to flow. These boards have holes in rows of 5 that are connected together (see image). Most solderless breadboards have two long connectors on either side that can easily be used for power. Breadboads like these can't handle huge amounts of power however, so if you want to use high current components like motors you may need to solder your own PCB on a through hole soldered breadboard.



Coding 101

A very important part of getting your arduino prototype to work is to properly code it. While there is not enough space here to go over all the functions in arduino (check out the documentation for that:docs.arduino.cc) This is a list of the most important functions and what they do.

pinMode(pin, INPUT/OUTPUT);	Initialise your digital pins. Analog pins don't need initialisation.
digitalWrite(pin, HIGH/LOW);	Set a digital output pin to high or low.

digitalRead(pin);	Read a digital pin.
analogRead(pin);	Read an analog pin on a range from 0 to 1023.
Serial.begin(baudrate);	Start a serial for communication or debugging.
Serial.println(message);	Print something to the serial.

for(int loops = 0; loops < 10; loops++){
//Code
}
	The for loop runs as long as the condition is met.

while(condition){
//Code
}
	Like the for loop, the while loop runs as long as the condition is met, but the while loop tests an external condition instead of an increment.

if(condition){
//Code
} else if(condition){
//Code
} else {
//Code
}
	If/else statements allow for testing conditions once, and running certain code if true.

int variableName = 0;	Create and initialise an integer.
float variableName = 0.1;	Create and initialise a float.
String variableName = "string"	Create and initialise a string, watch the capitalisation.
bool variableName = true;	Create and initialise a boolean.

Communication protocols

There are a few different protocols some components use to communicate to microcontrollers. All of them have their pros and cons, but generally speaking each component only has one way of communicating.

Digital communication
The simplest form of communication. At a certain voltage, generally around 2.4V, on a digital input pin the state switches from low to high, or in code from reading a 0 to a 1.

Analog communication
Like digital communication, this is based on the voltage on the pin. But instead of a threshold, the voltage is read more precisely. The arduino splits the range of 0-5V up into

1024 small steps it can measure, as it has a 10 bit (2^10) analog to digital converter (ADC). A higher bit count on the ADC will result in more and smaller steps.

Serial communication

Serial communication is a rather simple form of communication where a string of bits is sent over a single cable in series. To get communication both ways, two wires are thus needed. Serial communication always goes from Tx (transmitter) to Rx (receiver). Matching the pins will not work. This is also the communication type that arduino uses to upload code as well as use the serial monitor. So when you are uploading code, pins 0 and 1 need to be disconnected.

Pulse width modulation (PWM)

Like the name states, PWM is where the duration of pulses is changed to send different analog values. This can be used to dim an LED or to send control signals to things like motor controllers or servos. PWM signals can be sent using analogWrite(pin, value), where the pins can only be the ones with the tilde (~) and the value ranges from 0 to 255.

Inter-Integrated circuit (I2C) communication

I2C communication is a type of communication that uses addressing. This means that you can connect multiple boards to the same 2 pins. These pins are a clock (SCL) that makes sure that the receiver understands the speed at which data is sent, and a data (SDA) pin. On the arduino, pin A4 can act as an SDA pin and pin A5 as an SCL.

Serial Peripheral Interface (SPI) communication

Like I2C, SPI uses addressing for communication. However, SPI uses 4 pins instead of two. 2 for data (COPI + CIPO), a clock (SCLK) and a chip select (CS). The main advantage of SPI over I2C is its speed. On arduino, these pins are once again set: 10(CS), 11(COPI), 12(CIPO), 13(SCK). You may find MOSI and MISO online instead of COPI and CIPO. These are the old abbreviations using master/slave instead of the preferred controller/peripheral.

11.8 Information letter use evaluation

27-5-2024

Information letter: Developing a rapid prototyping kit for the design of Creative Technology for sports and movement

This letter informs you about the research conducted by Sven Rozendom and Ysbrand Burgstede. The research aims to investigate how we can support the design practices of staff and students aiming to design interactive systems for sports and movement.

The session will take about an hour. The participants will take part in a user test and subsequent interview with the researchers. Here they will interact with the prototypes made and be asked questions related to the research topic and prototype. The answers will be anonymised.

The benefit of participating in the research is that the end product from the research will be aimed to help future students during their design process for the Research and Design of User Experience project.

We do not consider participating in this research to have any risks.

The interviewee can stop the test and interview anytime and refuse to answer questions. They can also request for their previous answers to be deleted. Afterwards, they can contact the researchers by email with a request for their interview to be deleted and not used for the research. (emails listed below)

We will not collect personal information from the participants.

The collected data during the interview will be processed by the researchers and afterwards deleted. It will not be made public and will be deleted at the latest when the researchers graduate. The data will be stored on a secure private drive which is only accessible to the researchers. The anonymous transcripts may be included in their final written report and archived in the Graduation Project database of the University of Twente.

If you have any questions or concerns or want to contact the researchers you can do so by email: s.c.rozendom@student.utwente.nl and w.y.burgstede@student.utwente.nl.

If you have any ethical complaints this research is being conducted under the Ethics Committee Computer and Information Science. You can contact their secretary at ethicscommittee-cis@utwente.nl.

11.9 Consent form use evaluation

Consent Form for Developing a rapid prototyping kit for the design of Creative Technology for sports and movement

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 27/05/2024, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves interacting with the prototypes made by the researchers and doing an audio-recorded interview about the interaction. I understand the audio recording will be transcribed as text and when this has been completed the recording will be deleted.	○	○
Use of the information in the study		
I understand that the information I provide will be used for the research for the graduation projects of Sven Rozendom and Willem Ysbrand Burgstede. I also understand the anonymised transcriptions may end up in their final write-ups, which will be stored in the Graduation Project database of the University of Twente.	○	○
I understand that personal information collected about me that can identify me, such as my name, will not be shared beyond the study team.	○	○
I agree that my information can be quoted anonymously in research outputs	○	○
Consent to be Audio Recorded		
I agree to be audio recorded during the interview.	○	○

Signatures

_____________________ _____________________ ________

Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

________________________ __________________ ________

Willem Ysbrand Burgstede Signature Date

Study contact details for further information:

Sven Rozendom (s.rozendom@student.utwente.nl)

Willem Ysbrand Burgstede (w.y.burgstede@student.utwente.nl)

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

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