System for indoor person localization in a healthcare setting

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1 Acknowledgements

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Contents

2 Abstract

The pressure on the current healthcare system worldwide is increasing. People are living longer resulting in more residents in nursing homes to look after. Additionally, nursing homes are moving towards a more open approach for closed departments where elopements occur more often further increasing pressure on the employees.

At the same time, technologies develop rapidly making computer vision, internet of things and artificial intelligence interesting fields of research for incorporation into healthcare settings. Loogisch B.V. shares this point of view and is looking into further developments of these technologies for their customers in the healthcare sector.

As a result a system needs to be designed that provides localization capabilities in a nursing home. Through interviews and a State-Of-The-Art investigation requirements and possible solutions where formed which resulted in the design of system for person identification without the need for a wearable.

The system consists of a camera streaming a videofeed to a small computer where faces are compared to a known database and in case of a positive identification nurses are notified through an existing notification platform widely available. This platform also provides own appliances for localization and tracking with wearables suited for assets making it a suitable total solution for indoor localization in a healthcare setting.

The design has been tested by testing the different parts of the system separately and in the end as a combined system. The research led to a working prototype which can be used as a proof of concept and opens other possibilities for further development of the system and introduction to modern technologies.

3 Introduction

3.1 Introduction

The demand for more healthcare is growing rapidly, the population is aging, and there are continuously less caretakers available to cope with the increasing amount of patients [1]. Nowadays Internet-Of-Things (IoT) devices are becoming more widely available. So do the fields in which these devices are used. In healthcare, IoT devices have made their introduction as well. Different appliances such as personal alarms collars, fall detection sensors, smart cameras and even smart toilets [2] are making their introduction to nursing homes and home care. In these nursing homes many different types of equipment are used such as wheelchairs, nurse carts etc. By the introduction of IoT in these places, it becomes possible to track the location of this equipment throughout the building or in specific places of the building that can help staff members find specific equipment more easily or help management determining priorities for ordering extra appliances. Next to this application of asset tracking, tracking of clients can help in detecting wandering or falling. Additionally, clients staying in a closed department of a nursery home can be tracked to prevent doors from being mistakenly opened and clients leaving the closed department. These tracking activities are now often carried out by the use of RFID techniques requiring special antennas and cabling throughout the building. By designing a system to do these tracking activities it becomes a less invasive operation to introduce tracking to nursing homes. Additionally, when tracking persons, often some kind of a wearable is used which makes the system cumbersome. How can we track or localize assets and persons inside a healthcare instance such as nursing homes? This paper will investigate upon current tracking techniques available and how the data of this tracking is currently used to enhance access control and equipment positioning.

3.2 Problem description by the client (Loogisch B.V.)

The client would specifically want a system that prevents elopements of patients and clients of closed departments within nursing homes without adding wearables to these people. Different possibilities for tracking or access control systems will be evaluated in the State-Of-The-Art Research (section 6) after which a specific design research question (section 5) will be constructed. After these sections, an ideation and specification for a possible prototype will be explained which leads to the realization phase where a prototype is designed and build. Finally an evaluation of the prototype will be carried out from which a conclusion is drawn.

4 Client information

4.1 Client: Loogisch B.V.

This graduation project has been established in cooperation with Loogisch B.V. in Fleringen. Loogisch B.V. is a company specialized in IT, communication, security and domotics. In the security and domotics department they are investigating the application of IoT techniques. Loogisch B.V. also provides nursery homes and home care organisations with a total IT solution and therefore would like to investigate the possibility for application of IoT in this specific branche. The Innovatiehub Tubbergen connects Loogisch. B.V. with the students and takes care of the initial application process. This graduation project has been created by Julian Elsten in consultation with Loogisch B.V. and de Innovatiehub Tubbergen.

Figure 1: Loogisch B.V.

4.2 Projectcontacts

- Cora Salm - Supervisor UT (c.salm@utwente.nl)
- Hans Scholten - Critical Observer UT (h.scholten@utwente.nl)
- Henry Loohuis - Director Loogisch B.V. (h.loohuis@loogisch.eu)
- Helmich Slutter - Supervisor and health expert Loogisch B.V. (h.slutter@loogisch.eu)
- Pia Platenkamp - 1st Manager Innovatiehub Tubbergen (info@innovatiehubtubbergen.nl)
- Glenn van den Berg - 2nd Manager Innovatiehub Tubbergen (info@innovatiehubtubbergen.nl)

5 Research Question(s)

In order to come up with a value-able research, a couple of research questions are central in this report. For the first phase of this investigation, the State-Of-The-Art research, a couple of questions need to be answered:

Main research question:

- What is a suitable system for indoor asset and person localization in a nursing home?

State-Of-The-Art sub questions:

- What techniques are available for indoor tracking purposes?
- Using what technique can persons be tracked and identified indoors?
- How can we identify people keeping privacy in mind?
- Using what technique can we track assets and equipment indoor?
- How can tracking data be visualized for nurses and employees?
- Should the same technique be used for tracking/localization of people and assets or different techniques?

These question will be answered in the summary as found in section 6.3.

After the State-Of-The-Art investigation a new design research question will be formed based on the outcomes. This can be found in section 6.3.

6 State-Of-The-Art Investigation

In order to come up with a useful system for indoor tracking of persons and assets it is necessary to investigate current techniques and methods available for doing so. Therefore a State-Of-The-Art is carried out where indoor tracking techniques are investigated. The techniques that can be usable in the chosen setup (indoor healthcare setting) will be further filtered and arranged into a group usable for tracking assets and a group usable for tracking people.

First, a brief explanation on an often found concept is explained after which 4 main technologies for indoor tracking and localization are explained in depth. These technologies consist out of RFID, Wi-Fi, Bluetooth and Cameras. At the end of this section a summary on the findings is given and a design question is formed to form the basis of the ideation and specification phase.

6.1 Concept

First, the concept of trilateration is explained as this technology is often found in many technologies. In this section an often seen concept is trilateration. This concept is used in the widely know Global Positioning System (GPS) to calculate the position of appliances outdoor. Signals of GPS do not reach indoor reliably in order to calculate an indoor position. However, the concept of trilateration is applicable in indoor tracking techniques as well. Specific application of this concept will be explored in the State-Of-The-Art section of this report.

Trilateration works by calculating a distance of a track-able device to three listeners or beacons. In case of GPS these beacons are the satellites evolving around the earth. By calculating the distance of the trackable object to every beacon a certain point in space can be given which represents the location of the object. In figure 2 this is graphically shown.

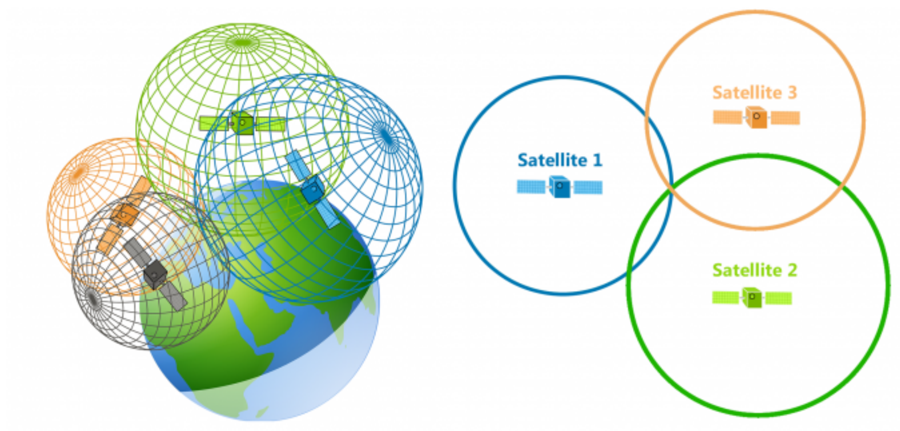

Figure 2: The concept of trilateration as applied in GPS Systems [3]

6.2 Indoor tracking techniques:

There are many different techniques for tracking assets and persons indoor. Typical techniques are Radio Frequency Identification (RFID), Global Positioning System (GPS) and ZigBee. However, due to the recent introduction of IoT many new techniques have found their use in indoor position tracking as well. These techniques include Bluetooth, Wifi and Camera's. In the following section, we will take a closer look at these different techniques and their advantages and disadvantages.

6.2.1 Radio Frequency Identification (RFID)

The most widely used technology to provide indoor tracking is through Radio Frequency Identification or RFID. A typical RFID has two main components. A tag or transponder and a reader. Tags can be passive, active or semi-active. In the following part the difference between these types will be elaborated.

- Passive tag:
  A passive tag had no battery or internal power source. It receives it's power to run the circuitry and communication from the electromagnetic waves transmitted by the receiver. These waves induce an energy when they reach the antenna of the tag which than power the internal circuit of the tag sending the signal back. As the working of this type of tag is dependent on the energy of the reader the range is only a couple of centimeters to a few meters.

- Active tag:
  The other type of tag is the active tag which has an internal power supply to fully supply the tag with power for the internal circuit and the sending of the communication. This results in a much bigger range, typically hundreds of meters, of the tag since it is not dependent of the energy received from the reader. The disadvantages of this system are the corresponding size and cost of the tag.

- Semi-Passive tag:
  The third type of tag lies exactly between the previous two and is the semi-passive tag. These often contain a small battery used to power the internal circuitry but for transmitting a signal the still depend on the energy received by a reader. The internal battery is solely used for internal electronics and circuity such as sensors and output devices. This difference sets them apart from the active and passive tags. As a result they are more affordable than active tags but still have some of the benefits of the active tags.

The types of tags are summarized in the table in figure 3.

Tags and Features	Passive Tag	Active Tag	Semi Passive Tag
Internal Power Source	No	Yes	Yes
Signal by backscattering the carrier wave from the reader	Yes	No	Yes
Response	Weaker	Stronger	Stronger
Size	Small	Big	Medium
Cost	Less expensive	More expensive	Less
Potential Shell life	Longer	Shorter	Longer
Range	10 centimeters to few meters	Hundreds of meters	Hundreds of meters
Sensors	No	Yes	Yes

Figure 3: Overview of the differences between passive, active and semi-passive tags. [4]

RFID based indoor tracking is often used when the position of something or someone does not need to be known constantly but only when passed through important places such as main entrances. This is due to the method where a tag only transmits his ID when an energy is induced in the tag by the reader. When a receiver picks up the signal of a reader this event is stored and logged on a central server in order to facilitate the users with the last known location of the tag. RFID tags can store an unique code which they transmit to the reader. By use of this ID it is possible to uniquely identify objects and persons at certain places in a building.

RFID based tracking would be a possible candidate for indoor tracking of persons in a healthcare setting because it is a privacy friendly technique as the location of persons is only known in certain locations instead of all the time. However, they will need to carry a wearable which makes it a more invasive tracking technique. For tracking of assets it is a less useful system since the location of assets would ideally need to be known constantly instead of only in certain spots.

6.2.2 WiFi

Wi-Fi or a Wireless Local Area Network (WLAN) is used to receive and transmit data from and to devices such as laptops, phones and tablet. These electromagnetic waves substitute the need for a cable used in conventional Local Arena Networks (LAN).

There are three common methods used in indoor tracking of users [5]:

- 1. With help of the propagation model calculating the distance to a known base.
- 2. The relative signal strength from different bases by the multilateration method.
- 3. Fingerprinting by matching a pattern of known Wi-Fi bases to a database of known patterns.

The first two categories often incorporate calculations based on the received signal strength (RSS) as for example used in the Indoor Localization system designed by Salman et al [6].

802.11mc 802.11mc is a wireless standard part of the IEEE 802.11 WLAN standards [7]. By incorporating Round-Trip-Time (RTT) or in this case Wi-Fi Round-Trip-Time (Wi-Fi RTT) it becomes possible to calculate the distance to an access point through a formula for the time a packet takes to be sent and received. This principle and formula can be found in figure 4. When using this technique with only one access point, only distance is possible to calculate but in case of three access points it is possible to calculate a precise location through the concept of trilateration. This technology can be placed in category 1 and 2 of the overview above.

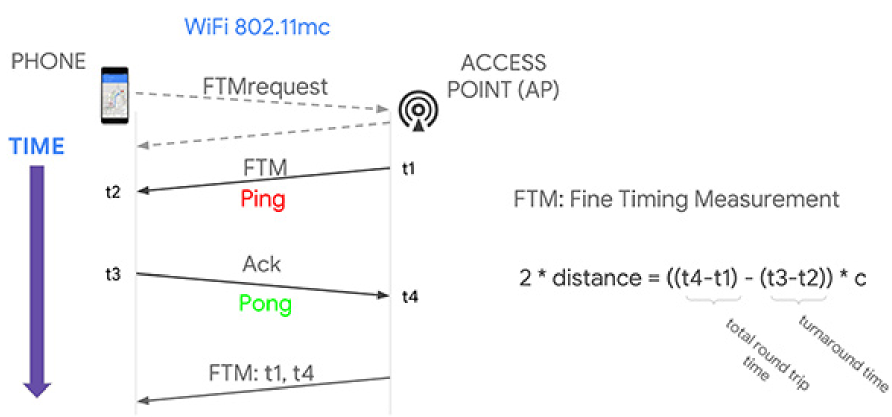

Figure 4: Principle of RTT in 802.11mc [8]

802.15.4z

Fingerprinting Lastly, there is the method of fingerprinting. In this case a map is made of a building where every possible location has their values for signal strength and access points within reach stored. A smart device or Wi-Fi sensors moves through the building and picks up the different access points and their signal strengths. These are send to the fingerprinting server that compares this data with the known coordinates and therefore can estimate the approximate location of the smart device. Such a setup is used in the system of Haider et al [9]. An overview of an indoor Wi-Fi Fingerprint-based positioning system is shown in figure 5.

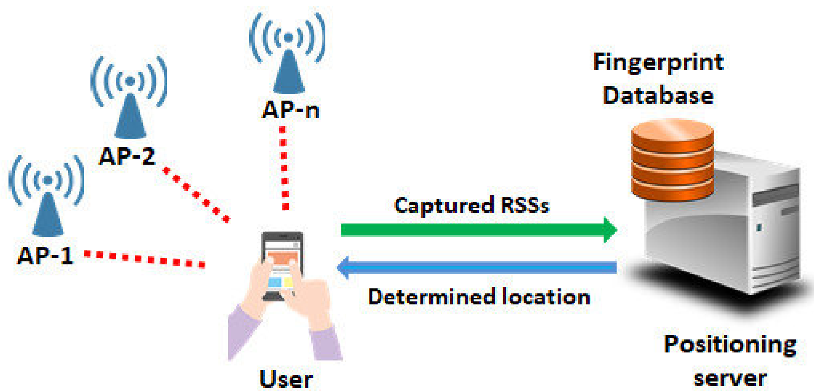

Figure 5: Illustration of indoor localization by aid of a fingerprinting server. [9]

Wi-Fi would be a good technique for tracking of persons and assets. In a lot of healthcare environments a covering Wi-Fi system is in place which would result in less installation costs for such a tracking system. However, a wearable on the tracked person or assets is needed including a battery to power the circuitry and transmission of data.

6.2.3 Bluetooth

Bluetooth was originally designed as an inexpensive wireless communication to facilitate portable devices. Bluetooth has 4 parameters that facilitate the localization purpose. These are Received Signal Strength Indicator (RSSI), Link Quality Indicator (LQI), TX power level and RX power level [10].

There are two main types of application of Bluetooth tracking: With a fixed beacon or with a fixed listener/receiver.

Bluetooth system with fixed receivers A system with fixed listeners and mobile beacons is based on beacons placed on the assets or persons and receivers mounted on the floor, wall or ceiling. These receivers measure the presence of a beacon in the vicinity and the associated signal strength. This information is filtered for environmental disturbances and translated to real world values in order to output for example the distance from a beacon to a receiver. By the help of beacons with a known position, positions of the assets and persons can be determined. This system is schematically represented in figure 6.

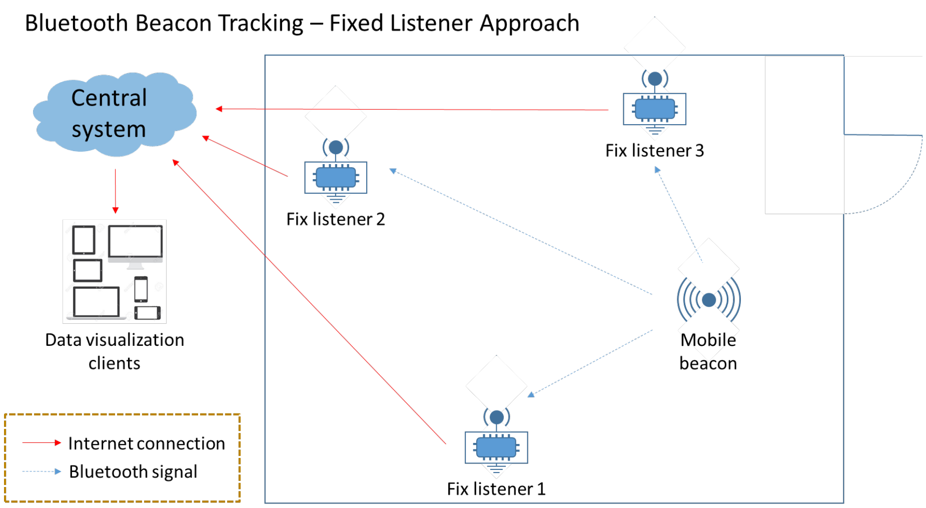

Figure 6: Overview of a system with fixed listeners and a mobile beacon. [11]

Bluetooth system with fixed beacons Another possibility for tracking assets and person indoor using Bluetooth is by implementing the system with fixed beacons and a mobile receiver. These beacons are placed strategically throughout the building and when a Bluetooth-enabled mobile device recognizes one of these beacons within range it sends the signal strength of the beacon to the central system in order to calculate the position of the mobile device (receiver) relative to the position of the beacon. A schematic overview of this system is depicted in figure 7.

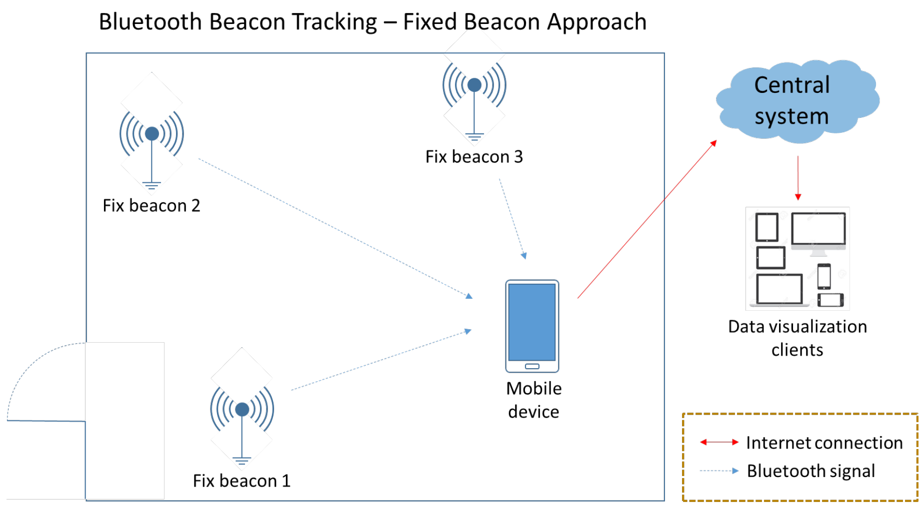

Figure 7: Overview of a system with fixed beacons and a mobile listener. [11]

Similar to Wi-Fi, Bluetooth would be adequate technique for indoor tracking of persons and assets in a healthcare setting. However, it has some disadvantages such as the wearable which is needed including the battery which needs to be charged every once in a while. Additionally the infrastructure for the beacons or listeners need to be installed which adds up to the total costs of the system.

6.2.4 Cameras

Another possibility to track persons and assets indoor is by the aid of cameras. With big improvements in areas such as artificial intelligence, IP-based camera's and computing power this is a very promising possibility. Tracking by use of camera's is already widely used in areas such as sport [12], public security, transportation, military and businesses.

These camera's often work by identifying unique characteristics of a person in every frame it records. These characteristics can be a face, eyes, skeleton (silhouette) or appearance. As cameras become more powerful they are often capable of doing these computation themselves or by help of a local or cloud server. Use of a central server also provides the possibility to combine feeds from multiple cameras.

A big advantage of using a camera system is that this type of system is non-intrusive and more natural as no wearables need to be placed on the persons or assets.

	RFID-Based Technology	Vision-Based Technology			
		Fingerprint	Iris	Face	Body Appearance
Hardware Requirement	RFID reader, tag	Fingerprint scanner	Iris scanner	Close-up camera	Camera
User Intrusion	Wear RFID tag	Provide finger	Show eye	Turn to face camera	Non-intrusive
Detection under Various Poses	Yes	No	No	Limited by angle	Yes
Identification Accuracy	Absolute	High	Highest	Medium-high	Medium-high
Dynamic Illumination	Unaffected	Unaffected	Infrared better	Shadow, lighting	Shadow, lighting
Visual Occlusion	Unaffected	No	No	Limited	Partial
Multi-View Tracking	Not accurate	No	No	Limited by angle	Yes

Figure 8: Comparison of various sensors for human detection, tracking and identification.

When choosing a visual based tracking system, substantiated choices should be made regarding the technology to be used as this will lead to a correct of incorrect working of the system.

Visual tracking is a very good candidate for use in an indoor localization system in a healthcare setting as this is one of the few technologies that does not depend on a wearable on the tracked person or asset. This is specifically important for person tracking as it is a less invasive method of tracking. When looking at the tracking of assets is is less favourable as it becomes difficult to uniquely identify assets through their appearance. Because of privacy considerations such a camera system should only be implemented in certain areas of a healthcare institution as it is not of importance to track clients everywhere but only in important areas such as entrances and exits. This results in a cost efficient system as well.

6.3 Summary

As shown on the previous pages of this report there are many technologies already available for indoor tracking and localization. Some technologies are preferable over other technologies when it comes to person and asset tracking. A distinction can be made for a suiting technology for tracking of assets in a healthcare environment and a suiting technology for tracking of persons in a healthcare environment. The main difference between these two categories is the choice for fitting the object to be tracked with a wearable or not. In case of asset tracking it it not an obstruction to fit instruments or tools with a wearable where as for tracking of persons this might introduce a problem in the case of non-willing or non-cooperative persons.

Another difference is visible when it comes to constantly knowing the location of a tracked object or only in certain places. The term tracking is connected to logging the position of persons or assets where localization mainly focuses on knowing where a person or assets passes certain locations in a building. This property can be found in the overview 9 in the row "constant tracking".

A combined system that primarily focuses on localization within a healthcare institution or nursing home using a combination of new IOT technologies is not yet widely available on the market. Especially when we take the requirement of the client into account where a technology for person tracking would benefit from a no-wearable localization method.

Therefore, a system will be developed to track assets and person in a healthcare setting combining two tracking technologies (one for assets, one for persons). As visible in figure 9, Wi-Fi and Bluetooth are the most optimal indoor tracking technologies for assets when held against the set properties. When looking at person tracking, visual (camera) based localization is the optimal technology as results from the State-Of-The-Art research.

	RFID	Wi-Fi (Fingerprinting)	Bluetooth	Visual (Camera)
Dependent of wearable.	YES	YES	YES	NO
Constant tracking.	NO	YES	YES	NO
Battery depedent.	NO (Passive tags)	YES	YES	NO
Relative Cost.	Low	Medium	High	Medium
Dedicated infrastructure needed.	YES	NO	YES	YES
Suitable for asset tracking.	NO	YES	YES	NO
Suitable for person tracking.	NO	NO	NO	YES

Figure 9: Overview of indoor tracking technologies.

Since technologies for tracking of assets through wearables based on Wi-Fi or Bluetooth are widely available we will focus the prototype on localization of persons without the need for a wearable.

This results in the following design question: What system can localize persons without the need for a wearable?

7 Ideation

In this section a first broad investigation is done on the requirements and ideas for a prototype of the system to localize persons indoor in a nursing home. This knowledge is than further explored in the specification phase and carried out during the realization phase.

7.1 Stakeholders

Many different kind of people are influenced by the system. Therefore it is useful to explore the possible stakeholders that are effected by the design and implementation of such a localization system. Since the system is designed for Loogisch B.V., their employees are stakeholders since they will need to know the functionality to sell it but also the knowledge for installing the hardware and software and giving support. Secondly, we have the employees in the nursing home such as the nurses, managers and maintenance staff. They will need to learn how to work with the system and maintain en manage it. Than their are the residents of a nursing home for which the system is actually designed. They will not be working with the system explicitly but they can be affected by the system.

7.2 Typical Use-Case

A typical customer of the client likely to utilize an indoor localization system for tracking clients and eventually assets has the following parameters as stated by the Healthcare Consultant of Loogisch B.V. Helmich Slutter [13].

- 60 clients or residents in a typical nursing home, not all of them are actually on the closed departments.
- 25-30 rooms.
- Budget available for smart sensors and alarms is most likely between EURO 50000 and EURO 100000 for a total system. This includes installation, documentation, training, hardware and software.

7.3 Proposed system

The development of an indoor tracking system in a healthcare setting can be divided into three main parts; the sensor technology, the communication of the data to a central place and the visualization of the data. When designing these individual components of the system the use in a healthcare setting will always be taken into consideration. This includes privacy aware decision making and high accuracy results. An overview of the system as described above can be found in figure 10.

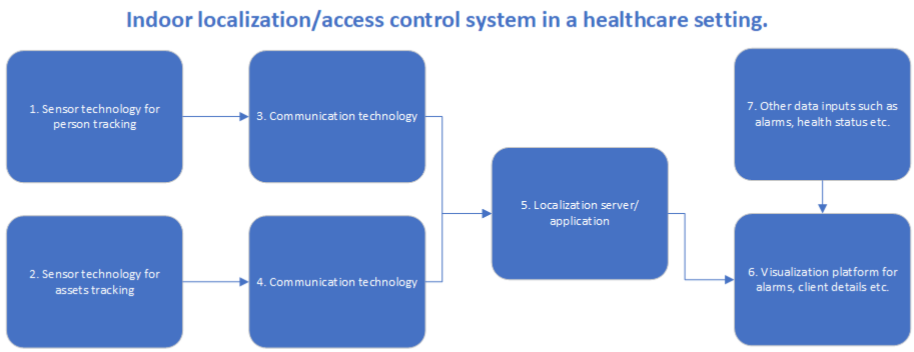

Figure 10: Overview of proposed indoor localization system.

7.4 State-Of-The-Art Findings

As stated in the summary of the State-Of-The-Art section (6.3) the various technologies for indoor tracking of persons and assets all have their advantages and disadvantages. Therefore a total system consisting of two different tracking technologies is the first option to be investigated. For person tracking the tracking by help of camera's and face and/or skeleton recognition is the most promising option because of the non invasive nature of this technology. When we take a look at the asset tracking technology, tracking through wifi or bluetooth is the most promising option since most healthcare institutions and nursing homes have the infrastructure (the Wi-Fi network) already in place resulting in a relatively cheap implementation compared to the other available technologies.

7.5 Privacy

Another point for attention in the choice of system is privacy. Taking the localization of persons in a nursing home there is no need to constantly know their location 24/7. This aspect contributes to the choice for a camera system where only in specific important locations the people are localized. In order to cope with the ethics of this project, a ethical study has been made which resulted in the report as found in appendix D.

8 Specification

For the specification of the system we use the system as proposed in figure 10. The numbers of the sections correspond to the blocks in figure 10.

8.1 1. Sensor technology for person tracking

As stated before in the ideation section and as result of the State-Of-The-Art research, visual (camera) based tracking is the technology that will be used for identifying persons at important location within the building. In the specific use case as set by Loogisch B.v., the location will be the main entrance of the nursing home. This is an important location where many elopements happen when other people enter or leave the building.

In the first phase of the research different open source face recognition application will be tested as well as skeleton recognition.

8.2 2. Sensor technology for assets tracking

As found by the State-Of0-The-Art research, there are many suitable technologies for tracking of assets in a healthcare setting. After consultation with the client, it was decided to not implement a module for asset localisation/tracking into the prototype as the manufacturer of the notification platform already provides trackers for this use-case. Instead of putting effort in development of another system for asset tracking, the focus was has been put to a system for person localization and the system can be extended by the help of existing products and technologies.

8.3 3. and 4. Communication technology

The communication of the data gathered by the location and identification sensors will most certainly be transported through existing or to be implemented UTP (Unshielded Twisted Pair) data cabling and additional network infrastructure as routers and switched.

In order to communicate a positive identification to the nurses and eventually an access control system SAN (Service Area Network) will be used. This is a data bus system often found in nursing homes for alarming and notifying nurses when a client or patients presses a button within their home. The benefit of working with this protocol is that it is already widely adopted for use in healthcare situations including the necessary regulations. A typical SAN-bus system can run many peripherals on one bus. Therefore is becomes possible to extend an existing system with a detecting/identifying camera. A typical SAN-bus can be found in the figures 11 and 12. In figure 11 a SAN-bus is implemented using a bus with splitters.

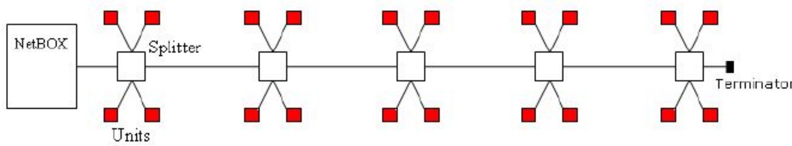

Figure 11: SAN-bus system with splitters.

In figure 12 a SAN-bus is implemented without any splitters and devices are daisy-changed of each other. Of course a combination of both implementations is also a possibility.

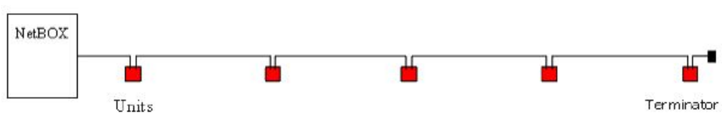

Figure 12: SAN-bus system without splitters.

The NetBOX is the gateway for the bus to connect to the Ethernet and translates the signal in TCP/IP packets. A bus always needs to end with a terminator with resistor in order to prevent reflections in the BUS.

8.4 5. Localization server/application

The software used for identification of persons and fingerprinting of the location of assets should run on an on-premise or cloud server. In the first phase of this research, this software will be ran from a dedicated PC (Raspberry Pi) or virtualized environment on a local server. In the future this could be moved to a cloud environment because of maintenance perspective. However, there should be taken into consideration that the available bandwith is adequate for the amount of images the software needs to process. In addition to this identification server, there should always be a small computer or micro-controller on-site to communicate with the SAN-bus or an alternative and notify nurses as described in section 8.3.

8.5 6. Visualization platform for alarms, client details etc.

In order to make a localization system useful, a visualization is needed in order to communicate the data gathered by the system to the nurses or employees of the nursing home.

The client, Loogisch B.V., is an implementation partner of the Open Care Connect platform [14] of the Eurocom Group. This platform provides a system that combines and connect different applications of different manufacturers. These solutions in a client's living environments are combines into one overview for care professionals and home carers. An overview of the Open Care Connect Ecosystem can be found in figure 13.

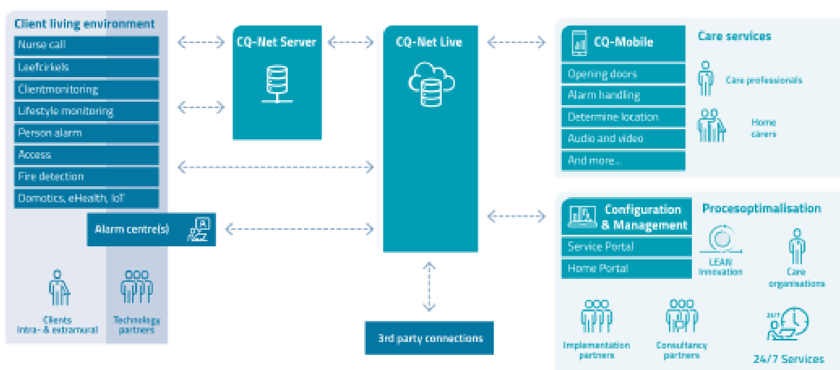

Figure 13: Overview of Open Care Connect Platform [14]

To eliminate the need of another app on the phone of the nurses and home carers an connection to the Open Care Connect platform for the visualization is made. The client is already familiar with this ecosystem and the implementation of it in the environment of end users.

A typical notification for an emergency call as received by nurses and staff can be found in figure 14. Additional to these desktop notifications it is possible to be notified through the Open Care Care Connect application on a phone which will be investigated later in this research.

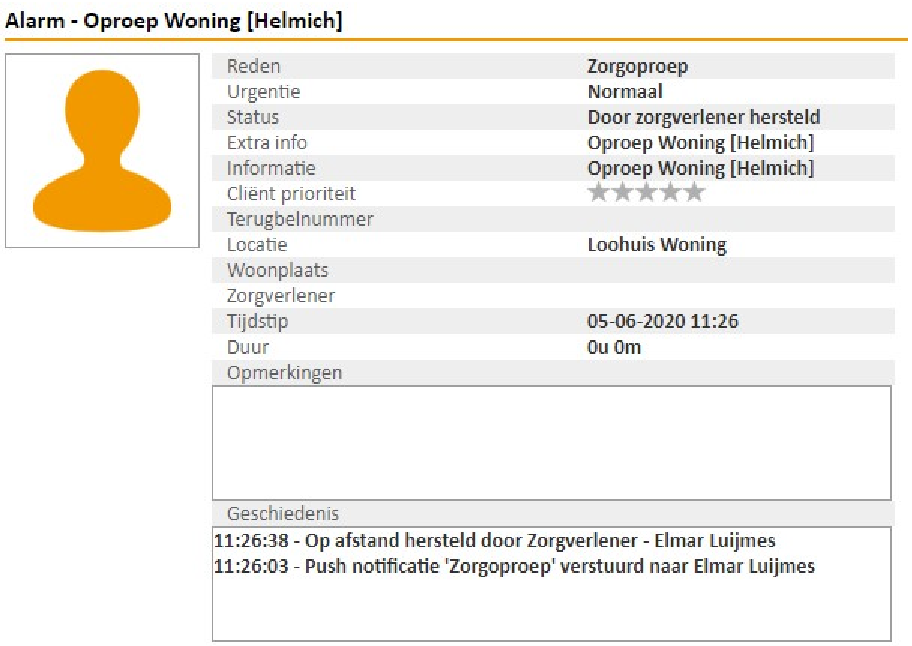

Figure 14: A call for help received on a desktop of a nurse through the Open Care Connect Platform.

8.6 7. Other data inputs such as alarms, health status etc.

The proposed system would benefit from combining inputs into one complete overview. Ideally when the system recognises a person who should not leave the building the name and current status of the client is displayed to the nurses when receiving the alarm call. As we are working with an existing system by the Eurocom Group for displaying the alarms to nurses we are dependent of their technologies for now. It should be possible to at least show the camera's stream to the nurses when someone is detected at the front door but the current health status and name of the person is more difficult as there is no additional data send from the recognizing system to the alarming system other than a video stream and an alarm input.

9 Realization

In this section the process and parts of the system used in the prototype will be investigated and explained. An overall overview of the system can be found in figure 15.

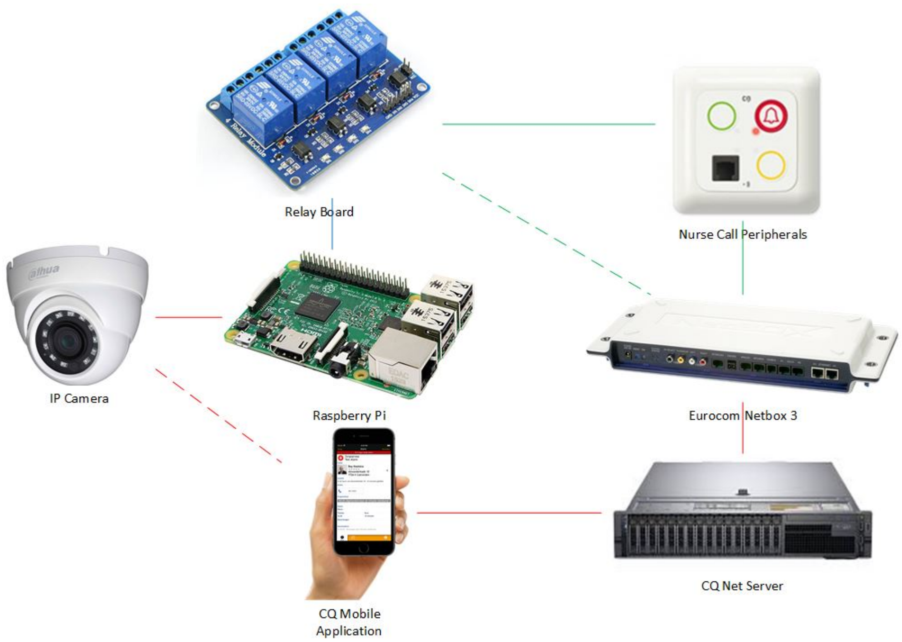

Figure 15: Overview of components in the prototype.

The components (Nurce Call Peripherals, Netbox3, CQ Net Server and CQ Mobile) that are already part of the Eurocom SAN-bus system are needed for the system to work but are not part of the designed components of this research.

Red lines in the overview represents TCP/IP Communication over UTP or Wi-Fi connections. Green lines represent SAN-bus communication which takes place over a six core cabling and finally the blue line represents communication over the GPIO pins of the Raspberry. Dotted lines represent optional connections inside the system. For example when the live stream of the alarming camera want to be seen or when the detection system should connect straight to the Netbox3 instead of over the existing SAN-bus system in a nursing home.

9.1 Hardware

The prototype exists out of some hardware components and some software components. In this section the hardware components used for building the prototype as visible in figure 16 and 21 are explained.

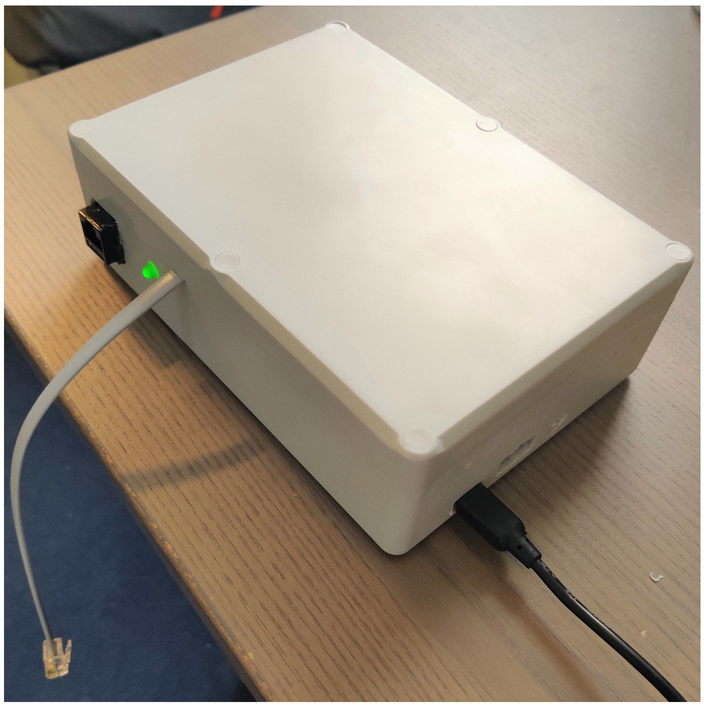

Figure 16: Prototype of the notification/alarming system.

9.1.1 Partlist

In order to build the system as proposed in the ideation and specification section of this report some components and parts will be needed. A list of the hardware parts:

- Raspberry Pi 3B+
- RPi Relay 2.0 BitWizard
- Dahua DH-IPC-HDBW2531EP-S-S2 IP Camera
- CAT6 UTP cable
- RJ12 Connectors
- 12V 2A Power Supply for Raspberry

- 5V DC 30x30x10.5mm fan.
- Kradex housing 176x126x57mm Grey
- Green LED
- Digitus CAT6 Modular Jack
- RJ12 to 6pins Dupont adapter

9.1.2 Raspberry Pi

The heart of the system is a Raspberry Pi 3B+ (figures 17 and 18) with 1GB of RAM memory and a 1.4 GHz Quad-core chip. Additionally it has Bluetooth, Wi-Fi HMDI and sound capabilities. These properties make this little computer board very suitable in the use-case where the Raspberry will process the images captured by an IP-Camera and notify nurses through the SAN-bus system. A more in-depth explanation of the communication through the SAN-Bus system is given in section 8.3.

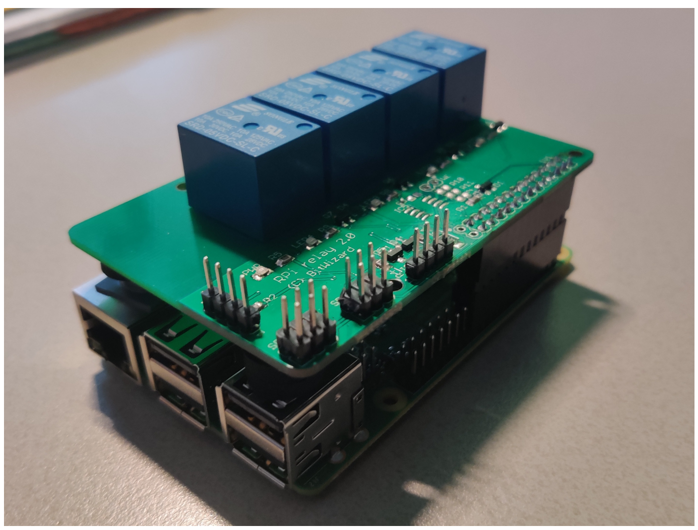

Figure 17: Raspberry with the Relay Board on top connected through the GPIO pins.

9.1.3 Relay Board

In order to open and close potential-free contacts used to connect to existing alarm solutions a relay board is used. The specific relay board used in this project is the RPi Relay Board 2.0 by BitWizard. The relays on this board are Songle SRD-05VDC relays which should be more than adequate for switching the alarm systems. The relay board communicates with the Raspberry

Pi through the 26-pin GPIO connector. Pin 11 (GPIO17), 12 (GPIO18), 13 (GPIO27) and 15 (GPIO22) are used to switch relay 1, 2, 3 and 4 accordingly. The 5V and ground are used to run the board a provide enough power to switch the relays. In order to faciliate signal and power to the other components, wires are soldered to the unused pins of the GPIO of the relay board.

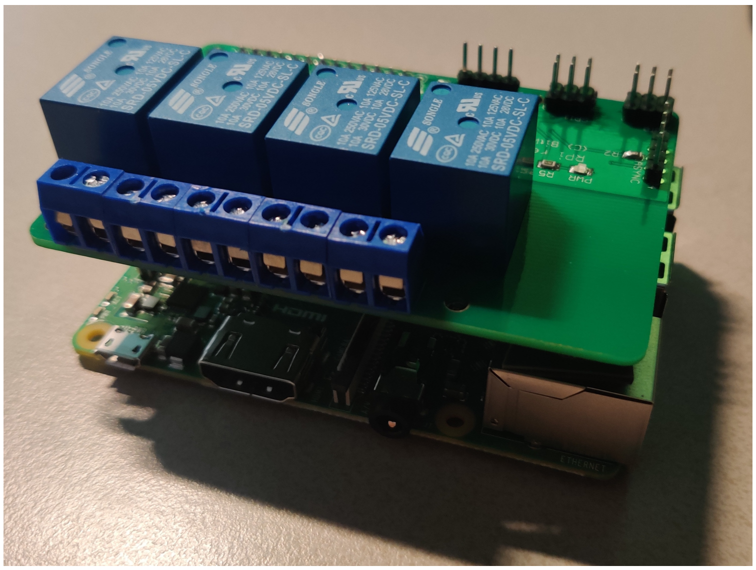

Figure 18: Relay Board on top of the Raspberry with the terminals connecting to the SAN-bus sytem IO.

9.1.4 Camera

In the prototype a RTSP stream is used a video input for the identification software to process. Therefore, every IP-Camera being capable of providing a RTSP stream is suitable for this system. The system would benefit from a camera with a vari-focal lens over a fixed lens as this camera can be adjusted and zoomed to capture purely the faces from the persons. For the prototype a Dahua DH-IPC-HDBW2531EP-S-S2 IP Camera was chosen (figure 19) as this camera was in my personal stock and is commonly seen in commercial buildings reflecting its reliablility and durability. This camera has a fixed 2.8 lens resulting in a field of view of 96 degrees which is on the high side for the goal of identifying faces.

Figure 19: Dahua IP-camera on a tripod mount to provide the raspberry with a video stream.

In order to move the camera around quickly while testing and adjusting it to the correct height, it has been fitted on a tripod with a custom-made wooden mount. The camera is fed over Power-Over-Ethernet (POE) requiring only one cable to a POE switch or POE injector making it fast to set-up without expensive high voltage cabling solutions needed.

9.1.5 Other

To finalize the prototype some smaller component were implemented which will be discussed in this section. In order to connect the Relay Board to the IO-port of a SAN-bus device a RJ12 connector is needed which has multiple inputs and outputs. In this specific project only the input is used since the nurses need to be alarmed. The RJ12 connector is connected to the prototype through a RJ12 to 6 pin Dupont adapter which is connected to the relays of the relay board.

RJ12	Draadkleur (UTP)	IO-bus
1	Bruin	Ingang 2
2	Wit-Bruin	Ingang 1
3	Blauw	Ground
4	Wit-Blauw	+24V
5	Oranje	Uitgang 2
6	Wit-Oranje	Uitgang 1

Figure 20: Pinout of a RJ12 SAN-bus IO port.

Relay 1 switches between pin 3 and 2 of the RJ12 connector. Relay 2 switches between pin 3 and 1 of the RJ12 connector. This is done according to the Eurocom SAN Reference Document [15] which holds figure 20. Currently, only the first input is used but in the future the second input could be used for additional alarmed or different types of alarms.

The housing is made up from a Kradex 176x126x57mm housing. This provides protection for the components inside and makes the prototype easily mountable. Additionally cooling performances of the Raspberry is upgraded by adding a fan to the housing and heatsinks to the hot parts of the Raspberry.

Lastly, the Ethernet connector of the Raspberry is routed to an outdoor Ethernet connector in the housing and a green LED is added to display the status of the system and know when a detection is send out. This LED is connected to pin 22 or GPIO 25 and turned on when the script is running.

All these component together are fitted in the housing which makes the prototype used in this research. The inside and outside of the prototype can be seen in figures 21 and 16.

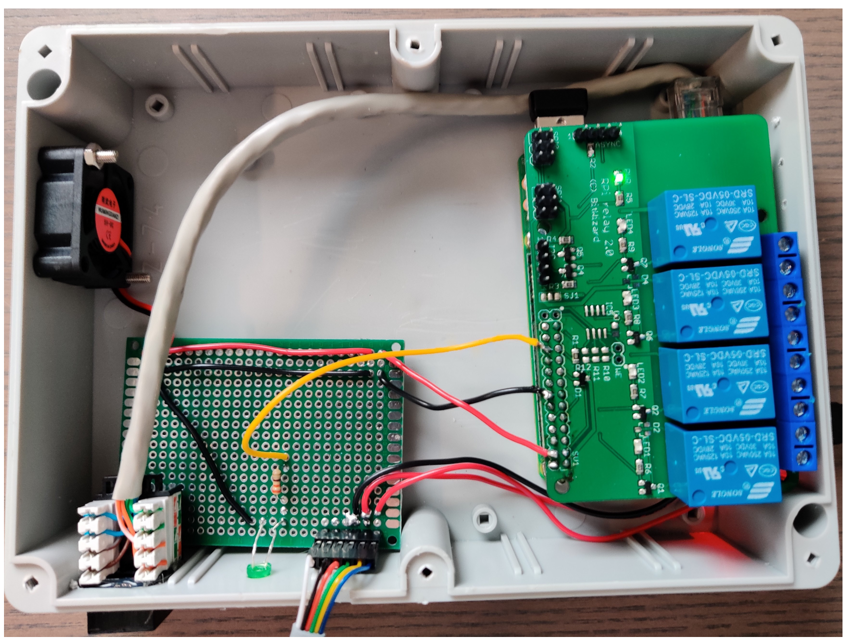

Figure 21: Inside of the prototype with all the components connected.

9.2 Software

9.2.1 Raspberry OS

The main operating system installed on the Raspberry Pi 3B+ is Raspberry OS or better known as Raspbian.The version used in this research is Raspbian version 10 with codename "Buster". This operating system is specifically build for the Raspberry Pi making it very stable and easy to work with. In order to make small changes to code and visualize the received video stream from the camera the packed GUI is used and the standard LXTerminal is used to install and run the specific packages used in this research.

9.2.2 Open CV

Open CV is a function library focusing on real-time computer vision. It can be used under the open-source BSD license making it a free library for commercial use. As the system designed in the research is intended for commercial environments this makes it a very suitable library. For this project we use OpenCV Version 4.1.0 [16]. In order to recognize objects, numbers, faces and much more in images and video machine learning is used. The library has over 2500 algorithms for specific detection and identification tasks. In this specific research we will firstly be looking at the algorithms used for recognizing faces in a video or image and secondly identifying these faces using a known database of face encodings.

9.2.3 Python

The code for the Raspberry as well as the desktop application have been written in the programming language Python. Specifically Python 3.7.3 is used. This was the best option for prototyping since OpenCV works really well with python and the python language is a relatively easy coding language making the code easier to understand for other people. This is ideal for future work and maintenance.

9.2.4 Building the face recognition dataset

The first step into using the system is to learn the faces, encode them and send them to the Raspberry Pi in order to compare them with input from a live videofeed. Therefore, a program in Python was written that can build a dataset of images from a person and afterwards encode these images into 128-d vector encoding which can be send to the Raspberry as a database with known faces. The overall GUI of the program can be seen in figure 22. This application would be ideally ran on a laptop with webcam in the nursing home and used when taking in new patients or clients. Of course it can be ran on other systems as well as long as a videofeed from an IP-camera or webcam can be streamed to it.

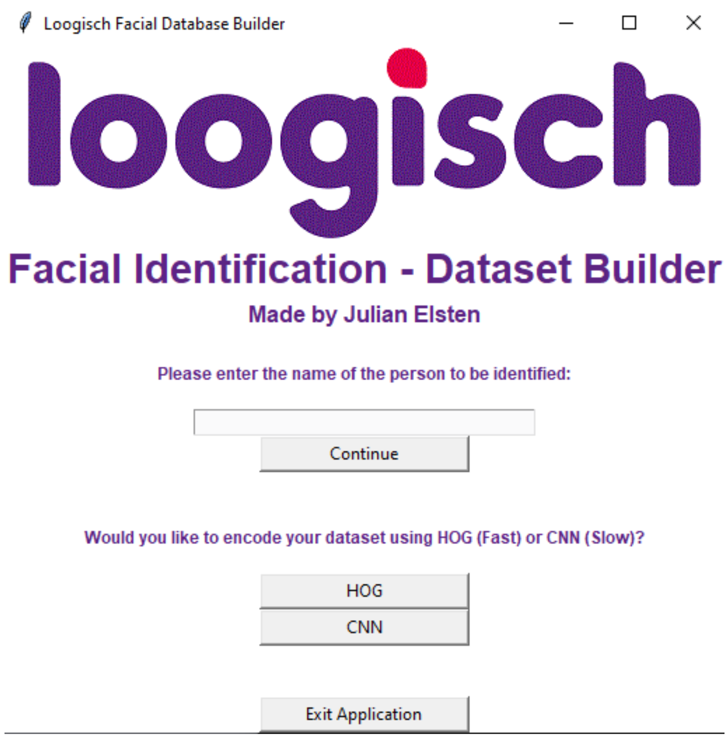

Figure 22: Screenshot of the GUI of the dataset building en encoding script.

The GUI of the application is built through the Python library TKinter because of a very easy implementation and the relatively easy tasks which the GUI should fulfill. In the top section of the application a brief introduction is made with the title, author and brand logo. Underneath in the second section of the program, the user is asked to input the name of the to be identified person. When "Continue" is pressed a camerafeed is opened from the webcam and the face recognition algorithm is ran. When a face is recognized the user can press "K" to save the image to the local dataset. Ideally, this should be done in a couple of different position to capture most angles of a face. About 10-20 pictures per person works adequately. The images are saved to a folder with the name of the client. This name is later used to identify the different persons in the system.

In the bottom part of the application encoding of the dataset of images can be done. There are two main methods for encoding the dataset into 128-d feature vectors. The first option is HOG (Histogram Oriented Gradients). This method works by identifying gradients in a pixel grid of an image. These gradients are created from the magnitude and direction of change. The benefit of this method is that it works really fast. The second method is CNN or Convolutional Neural Network

In this prototype both methods are currently implemented as it falls out of the scope of this current research to investigate which works better for this specific use-case of face-identification. In a future release version of the program only one function should be given to prevent confusion for the end-user. The complete Python code of this program can be found in appendix B.

The images saved to the folder can now be deleted to improve security and privacy as the only data stored in the system necessary are the 128-D vectors of a person's face.

9.2.5 Identifying faces in a videostream

On the Raspberry Pi a Python program runs which takes a video-input from a stream or webcam and through OpenCV looks for faces in this stream. As soon as a face is recognized this face is translated into a 128-D vector and compared with the stored 128-D vectors in the database of known faces. As soon as a face is recognized and identified as being in the database, the relay is switched to give a pulse to the nurse alarming system and the LED is blinked for validation purposes. Additionally an entry is written to the log to test and evaluate the working of the system (e.g. in the evaluation section 10). The system runs this program constantly when in operation.

It is possible to hook a HDMI screen to the prototype in order to actually have a visible output of the computations of the system. In that case a rectangle is drawn around recognized faces with the name "Unknown" in case of a person not being in the database and the name of the person when he or she is actually in the database. This could be a useful feature when using the system for example at a main entrance and security or receptionists would like to keep an eye out. The output to the HDMI screen can be found in figure 23.

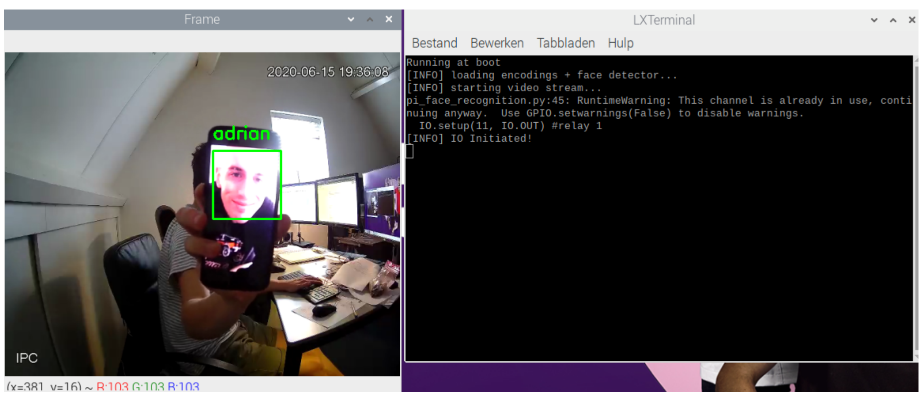

Figure 23: Screenshot of the running Python script on the Raspberry Pi. The recognized face is an example.

The complete Python code of this program can be found in appendix A.

10 Evaluation

In order to test and evaluate if the designed prototype suits the needs of the client, some test were conducted. The first test conducted was the reliability of the identification. Secondly the correct working in corporation with the SAN bus system and the ease of installation is tested with engineers at Loogisch B.V.

10.1 Facial identification

A setup of the prototype and an IP-camera was setup in my office at home. Through the desktop application a dataset of my face was created during daylight conditions and encoded using HOG. After transfer to the Raspberry Pi, the program is started and as a small test I walked through the image of the camera and the relay switched correctly.

In order to validate that all passes of me have actually been identified and none of these have been misidentified I placed a second camera on top of the tripod. This camera's records footage to a SD-card in case it detects motion. Because of this approach I can validate all identifications after the test.

The setup of the camera tripod can be found in figure 24.

Figure 24: Two camera's mounted to a tripod. The bottom camera is used for the identification and the top camera records footage to a SD-card for validation purposes.

The setup has been running for 24 hours in the office where 5 family members (3 man, 2 woman) can be passing the camera. The system is trained to recognize and identify only me. The results of this test can be found below in figure

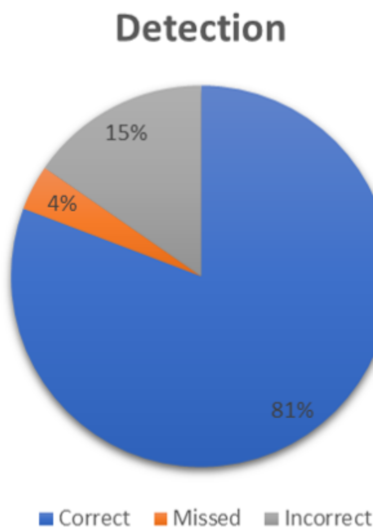

Figure 25: Reliability of the detection by the Raspberry Pi. A total of 26 passes were made during the testing period.

A total of 26 passes where made when the system was active. As soon as the system identified me in the image an entry to a log was made with the corresponding timestamp. After evaluating this log with the footage of the camera mounted above the result of correct identification was 81 percent. The incorrect identification where often made by my brother which looks familiar to me. The system was running for 29 hours including a dark environment where images where captured with help of the built-in infrared lighting of the IP-camera. These problems can be minimized by tweaking the algorithm further or using other facial recognition libraries.

10.2 Integration with Eurocom system

In order to validate the system correctly working with the SAN-bus Eurocom system. The system was hooked up to the test kit of Loogisch B.V. At first it looked like the system was not working correctly as no input was detected at the port of the system. Therefore the service desk of Eurocom was called in order to run us through a troubleshooting process which led to the discovery of a broken port on the test kit. After switching ports the system switched inputs of the SAN-bus system correctly and notifications to nurses are actually correctly send out.

The working of the desktop application was tested here as well. A dataset and facial encoding where very easily build after a short explanation to the engineers. In order to use the faces of the employees of the client as test for the correct working of the system, a request was made for the ethics committee as well as a consent form for the employees. This consent form can be found in appendix B. Since this was the first time running the system on another network, finding the IP-address of the camera and the Raspberry introduced some difficulties. A system where the IP-address of the Raspberry can be more easily found would improve the prototype and the usability of the system. All of the steps were carried out by one of the engineers of Loogisch B.V. [17] and observed by the health consultant of Loogisch B.V. Improvement points for the prototype where noted down for further evaluation. As the current covid-19 situation made it not favourable to test with real end-users in healthcare, it was decided to work with experts from the client company to run through the steps of the system.

11 Conclusion

After working through this research for the last couple of months it can be stated that a functional prototype of a person localization system for elopement prevention was realized by help of a camera and computer vision. Through facial recognition it is possible to alarm nurses in case of a possible elopement. The system works with the currently available notification systems for nursing homes. Specifically the requirement for no needed wearables on the person to track is passed by use of this system. Alongside this requirement, the system fulfilled the basic requirements which were set during the ideation phase such as cost-efficient and implementation with current notification systems. For asset tracking, the platform already provides adequate technologies and appliances to do so and no new developments were necessary.

The system can still be improved to further enhance the user experience and reliability of the system. Some suggestions for these improvements are given in the next section about possible future work 12.

Overall it can be stated that the current system as designed in this study is working for a proof of concept and promotional uses but would need further development and investigation before fully implementing it in commercial environment. Specifically concerning Privacy and law compliance.

12 Future Work

This research answers some questions but also introduces new ones on which further research can be done in the future. A short elaboration on future research ideas can be found here.

To further improve the usability of the system and the level of security of the system, research into training the openCV library into detecting conscious facial hiding could be done. For example training the system to detect a moving human that is actively hiding his or her face by means of a mask, scarf, hands and so on. The system should only allow for opening doors when a person is not in the database and does not hide from the cameras.

The current system is running on a Raspberry Pi, future iterations can benefit from upgrading to a more powerful platform. Even the possibility of running the detection and identification in the cloud would be a possibility when the latency is not too high. This can be investigated upon in a future research.

The position of the camera for optimal face capture can be further researched upon. For example a location where a camera is fitted just above a door handle may be very useful in cases where people need to reach for this door handle and thus need to look at it. These kind of smart camera positions will contribute to an accurate working system. As this investigation could not be conducted during the duration of this research because of time constraints this might be investigated later.

Finally, more investigation should be carried out when it comes to privacy law compliance. The current design has been adopted to comply with privacy regulation in a best-effort manner but has not actually been tested with any laws or regulations.

13 Appendices:

A Python Code Raspberry

Code running on the Raspberry Pi in order to recognize and identify faces and switch the alarms. Inspired by Adrian Rosebrock from PyImageSearch and adapted and changed by Julian Elsten.

```python
# face-recognition system.
# When a face is recognized in the stream of the IP-
    Camera, a relay is switched
# on the raspberry in order to provide an input for the
    warning system.
# Graduation Project - Julian Elsten - S1796755 -
    Creative Technology 2020
# Loogisch B.V. Fleringen

# Packages.
from imutils.video import VideoStream
import face_recognition
import argparse
import imutils
import pickle
import time
import cv2
import RPi.GPIO as IO
import os
from datetime import datetime

# load the known faces and embeddings along with OpenCV's
     Haar.
print("[INFO] loading encodings + face detector...")
data = pickle.loads(open("encodings.pickle", "rb").read()
    )
detector = cv2.CascadeClassifier("
    haarcascade_frontalface_default.xml")
os.environ['DISPLAY'] = ':0'

# initialize the video stream.
print("[INFO] starting video stream...")
# IP address should correspond to IP-Address of the
    camera.
vs = VideoStream(src="TOBEFILLEDIN").start()
time.sleep(1.0)

IO.setmode(IO.BOARD)
```

```
#set the needed GPIO pins as output.
IO.setup(11, IO.OUT) #relay 1
IO.setup(12, IO.OUT) #relay 2
IO.setup(22, IO.OUT) #LED
print("[INFO] IO Initiated!")


# loop over frames from the video file stream
while True:
    #Start LED when system is running.
    IO.output(22,True)
    frame = vs.read()
    frame = imutils.resize(frame, width=500)

    # convert the input frame from (1) BGR to grayscale (
        for face
    # detection) and (2) from BGR to RGB (for face
        recognition)
    gray = cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY)
    rgb = cv2.cvtColor(frame, cv2.COLOR_BGR2RGB)

    # detect faces in the grayscale frame
    rects = detector.detectMultiScale(gray, scaleFactor
        =1.1,
         minNeighbors=5, minSize=(25, 25),
         flags=cv2.CASCADE_SCALE_IMAGE)

    # OpenCV returns bounding box coordinates in (x, y, w
        , h) order
    # but we need them in (top, right, bottom, left)
        order, so we
    # need to do a bit of reordering
    boxes = [(y, x + w, y + h, x) for (x, y, w, h) in
        rects]

    # compute the facial embeddings for each face
        bounding box
    encodings = face_recognition.face_encodings(rgb,
        boxes)
    names = []

    # loop over the facial embeddings
    for encoding in encodings:
        # attempt to match each face in the input image
            to our known
        # encodings
```

```
    matches = face_recognition.compare_faces(data["
        encodings"],
         encoding)
    name = "Unknown"

    # check to see if we have found a match
    if True in matches:
        # find the indexes of all matched faces then
            initialize a
        # dictionary to count the total number of
            times each face
        # was matched
        matchedIdxs = [i for (i, b) in enumerate(
            matches) if b]
        counts = {}

        # loop over the matched indexes and maintain
            a count for
        # each recognized face.
        for i in matchedIdxs:
            name = data["names"][i]
            counts[name] = counts.get(name, 0) + 1

        # determine the recognized face through
            voting.
        name = max(counts, key=counts.get)

    # Update the list of names.
    names.append(name)

    # Switch contact when a known face is detected.
    if name != "Unknown":
        IO.output(11,True) #Enable relay 1
        #IO.output(12,True) #Enable relay 2
        IO.output(22,False)
        time.sleep(0.1)
        IO.output(11,False) #Disable relay 1
        #IO.output(12,False) #Enable relay 2
        IO.output(22,True)
        with open("log.txt", mode='a') as file:
            file.write('Person identified:')
            file.write(name)
            file.write('. Recorded at: %s\n' %
                datetime.now())
# loop over the recognized faces
```

```python
    for ((top, right, bottom, left), name) in zip(boxes,
        names):
        # draw the predicted face name on the image
        cv2.rectangle(frame, (left, top), (right, bottom)
            ,
            (0, 255, 0), 2)
        y = top - 15 if top - 15 > 15 else top + 15
        cv2.putText(frame, name, (left, y), cv2.
            FONT_HERSHEY_SIMPLEX,
            0.75, (0, 255, 0), 2)

    # Print image to HDMI output.
    cv2.imshow("Frame", frame)
    key = cv2.waitKey(1) & 0xFF

    # if the `q` key was pressed, break from the loop
    if key == ord("q"):
        break


# Shutdown.
IO.output(22,False)
cv2.destroyAllWindows()
vs.stop()
```

B Python Code Desktop App

```
# import the necessary packages
from imutils.video import VideoStream
import imutils
from imutils import paths
import time
import cv2
import os
import face_recognition
import pickle
from pathlib import Path
from PIL import ImageTk, Image
from subprocess import Popen, PIPE
import tkinter

# load OpenCV's Haar cascade for face detection from disk
detector = cv2.CascadeClassifier("
    haarcascade_frontalface_default.xml")
window = tkinter.Tk()
window.title("Loogisch Facial Database Builder")
window.configure(background="white")
name = "default"

#functions
def submitname():
        name = nameentry.get()
        print(name)
        rundetection(name)

def exit():
        window.destroy()
        cv2.destroyAllWindows()
        vs.stop()
        exit()

def encodeHog():
        runEncoding("hog")

def encodeCnn():
        runEncoding("cnn")

#GUI elements
logo = ImageTk.PhotoImage(file="loogisch.gif")
tkinter.Label(window, image = logo, bg="white") .grid(row
```

```
    =0, column=0)
tkinter.Label(window, text = "Facial␣Identification␣-␣
    Dataset␣Builder", bg="white", fg="#5C2483", font="none
    ␣22␣bold") .grid(row=1, column=0)
tkinter.Label(window, text = "Made␣by␣Julian␣Elsten\n",
    bg="white", fg="#5C2483", font="none␣12␣bold") .grid(
    row=2, column=0)
tkinter.Button(window, text="Exit␣Application", width=20,
     command=exit) .grid(row=13, column=0)

#Take name information
tkinter.Label(window, text = "Please␣enter␣the␣name␣of␣
    the␣person␣to␣be␣identified:\n", bg="white", fg="#5
    C2483", font="none␣9␣bold") .grid(row=3, column=0)
nameentry = tkinter.Entry(window, width=40, bg="#FAFAFB")
nameentry.grid(row=4, column=0)
tkinter.Button(window, text="Continue", width=20, command
    =submitname) .grid(row=6, column=0)

#Encode the faces
tkinter.Label(window, text = "\n", bg="white", fg="#5
    C2483", font="none␣9␣bold") .grid(row=8, column=0)
tkinter.Label(window, text = "Would␣you␣like␣to␣encode␣
    your␣dataset␣using␣HOG␣(Fast)␣or␣CNN␣(Slow)?\n", bg="
    white", fg="#5C2483", font="none␣9␣bold") .grid(row=9,
     column=0)
tkinter.Button(window, text="HOG", width=20, command=
    encodeHog) .grid(row=10, column=0)
tkinter.Button(window, text="CNN", width=20, command=
    encodeCnn) .grid(row=11, column=0)
tkinter.Label(window, text = "\n", bg="white", fg="#5
    C2483", font="none␣9␣bold") .grid(row=12, column=0)

# initialize the video stream, allow the camera sensor to
     warm up,
# and initialize the total number of example faces
    written to disk
# thus far
def rundetection(nameofuser):
        print("[INFO]␣starting␣video␣stream...")
        vs = VideoStream(src=0).start()
        time.sleep(2.0)
        total = 0

        # loop over the frames from the video stream
        while True:
```

```
# grab the frame from the threaded video
    stream, clone it, (just
# in case we want to write it to disk),
    and then resize the frame
# so we can apply face detection faster
frame = vs.read()
orig = frame.copy()
frame = imutils.resize(frame, width=400)

# detect faces in the grayscale frame
rects = detector.detectMultiScale(
        cv2.cvtColor(frame, cv2.
            COLOR_BGR2GRAY), scaleFactor
            =1.1,
        minNeighbors=5, minSize=(30, 30))

# loop over the face detections and draw
    them on the frame
for (x, y, w, h) in rects:
        cv2.rectangle(frame, (x, y), (x +
             w, y + h), (0, 255, 0), 2)

# show the output frame
cv2.imshow("Frame", frame)
key = cv2.waitKey(1) & 0xFF

# if the `k` key was pressed, write the *
    original* frame to disk
# so we can later process it and use it
    for face recognition
if key == ord("k"):
        print("[INFO] taking photo...")
        pdir = os.path.join("dataset",
            nameofuser)
        pfile = os.path.sep.join([pdir, "
            {}.png".format(str(total).
            zfill(5))])
        Path(pdir).mkdir(parents=True,
            exist_ok=True)
        cv2.imwrite(pfile, orig)
        total += 1

# if the `q` key was pressed, break from
    the loop
elif key == ord("q"):
        break
```

```
        # do a bit of cleanup
        print("[INFO] {} face images stored".format(total
            ))
        print("[INFO] cleaning up...")

def runEncoding(detection_method):
    # grab the paths to the input images in our dataset
    print("[INFO] quantifying faces...")
    imagePaths = list(paths.list_images("dataset"))

    # initialize the list of known encodings and known
        names
    knownEncodings = []
    knownNames = []

    # loop over the image paths
    for (i, imagePath) in enumerate(imagePaths):
        # extract the person name from the image path
        print("[INFO] processing image {}/{}".format(i +
            1,
             len(imagePaths)))
        name = imagePath.split(os.path.sep)[-2]

        # load the input image and convert it from RGB (
            OpenCV ordering)
        # to dlib ordering (RGB)
        image = cv2.imread(imagePath)
        rgb = cv2.cvtColor(image, cv2.COLOR_BGR2RGB)

        # detect the (x, y)-coordinates of the bounding
            boxes
        # corresponding to each face in the input image
        boxes = face_recognition.face_locations(rgb,
             model=detection_method)

        # compute the facial embedding for the face
        encodings = face_recognition.face_encodings(rgb,
            boxes)

        # loop over the encodings
        for encoding in encodings:
            # add each encoding + name to our set of
                known names and
            # encodings
            knownEncodings.append(encoding)
```

```
            knownNames.append(name)

    # dump the facial encodings + names to disk
    print("[INFO] serializing encodings...")
    data = {"encodings": knownEncodings, "names":
        knownNames}
    f = open("encodings.pickle", "wb")
    f.write(pickle.dumps(data))
    f.close()

window.mainloop()
```

C Consent Form

Consent for Participation in Research – Facial Recognition System

Title of the study:

Elopement prevention in a nursing home without wearables.

What personal data will be collected:

Name, facial identification encodings and photos of face.

What happens to your data:

The data will be used to test the correct working of the system and the quality of its identification capabilities. Additionally input, relevant information or reactions of the participant might be stored for further development.

What the experience is about:

The main purpose of the system is to provide nursing homes with a non-invasive system to prevent elopements. This is achieved through recognizing faces and alarming nurses accordingly.

1. I volunteer to participate in a research project conducted by Julian Elsten of the University of Twente. I understand that the project is designed to gather information about my experiences while using and implementing the Facial recognition system.
2. My participation in this project is voluntary. I understand that I will not be paid for my participation. I may withdraw and discontinue participation at any time without penalty. If I decline to participate or withdraw from the study, there are no consequences and the data will be deleted.
3. If I feel uncomfortable in any way during the session, I have the right to decline to answer any question or to end the research session.
4. I have read and understood the explanation provided to me. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this study.
5. I have been given a copy of this consent form.

____________________________ Signature

____________________________ Name

For further information, please contact:

Julian Elsten

j.m.elsten@student.utwente.nl

________________________ Date

________________________ Signature of the Investigator

D Ethical Toolkit Application

D.1 Ethical "Risk-sweeping"

This paper is based around the Ethics in technology toolkit by [18]. The first tool discussed in the Ethical "Risk-sweeping". In order to facilitate the discovery and identification of potential risks, stakeholder are identified and a broad and shallow search is carried out. The risk-sweeping procedure is carried out through the ideation phase up to the evaluation phase to constantly monitor possible ethical risks that may arise during the design process.

The following risks are identified in the project as explained in the introduction:

Technological risks:

- As with most technologies connected to the internet, they are susceptible to hacking.
- People start relying on the technology instead of on their own capabilities to check for person elopements.
- Misidentifying a person and therefore incorrectly locking or unlocking the door.

Privacy risks:

- Images captured by the camera's contain valuable data about the person. Especially when identifying faces and skeletons.
- People that do not consciously interact with the system are also captured and processed.

Other risks:

- People feel watched by the cameras and may start getting uncomfortable within the nursing home building.
- A failing system might result in an elopement of a client.
- Neglecting input from stakeholder(s) because (we feel) they lack design experience.
- Wrong use of technology, for example to see at what times employees enter and leave the building.

D.2 Pre-mortems and Post-mortems

In the previous section the focus was mainly on individuals risks where this section will focus more on the systemic ethical failures of a project for the purpose of learning from them.

D.2.1 Pre-mortems

Pre-mortems are about a potential failure of a project. During a project it is important to constantly identify, elaborate and adapt for possible risks. Especially in teams it is useful to come together to think about possible problems arising from ethical risks. Often these risks look very small on their own but can have a big impact when combined. When using Pre-mortems as a tool the teams come together and pretends the project has failed. Team members can put forward possible causes which highlights weak spots in the current design of the project and enables the team to account for them before launching the project. This process is illustrated in the diagram as seen in figure 26.

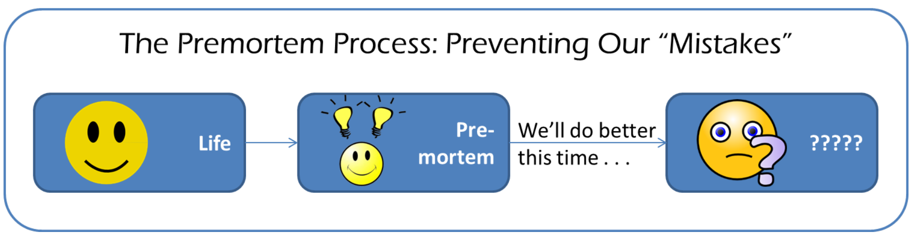

Figure 26: Diagram of the Pre-Mortem Process.

Emphatic design:

In this project the main stakeholders and persons interacting with the system are not the designers or engineers of the project. Therefore, the designers and engineers will need to empathize with the end user in order to come up with a valuable product in the end. Often it is seen that this specific step of empathizing with the end user fails resulting in a poor understanding of the users and theirs needs and desires. In order to cope with this in the best possible way a framework has been introduced to help structure and improve empathic design. [19]

D.2.2 Post-mortems

Where we look at possible risks before launching the project when talking about pre-mortems. With post-mortems we look at the problems that load to the failure of a project and what can be learned from it to prevent the same mistakes from happening again in a future project. This process is illustrated in the diagram as seen in figure 27.

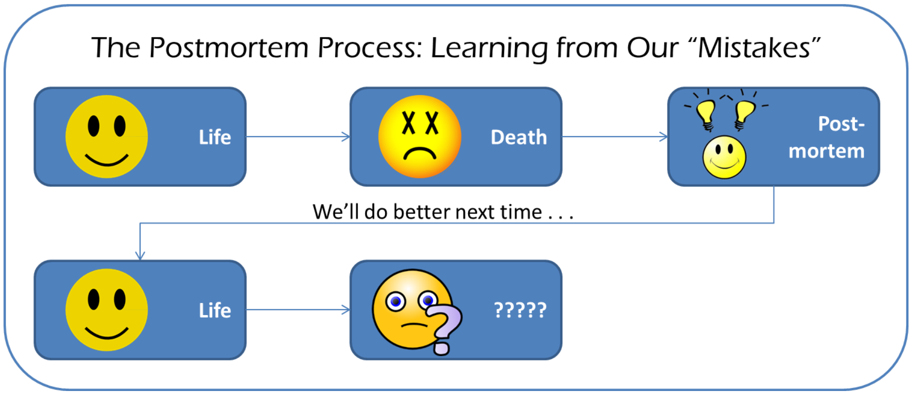

Figure 27: Diagram of the Post-Mortem Process.

Currently the project is still in the phase of development and testing and is not yet adopted in live situations. Therefore, it is somewhat difficult to consider post-mortems currently as nothing has happened yet. At this phase of the project especially the pre-mortems are of importance and when done correctly should prevent damage to the project or company afterwards.

D.3 Expanding the Ethical Circle

In many business schools and other environments they still teach that companies are morally obligated to maximize shareholder profit within the "rules of the game". As a result the public interest is not taken into consideration resulting in possible significant moral harm of a company.

The same can be said from a phenomenon called "Groupthink" en "The 'Bubble' Mentality". In both cases a group of designers and engineers get locked in their group vision eliminating other perspectives than those currently operating. The difference between these two is that in case of the "The 'Bubble' Mentality" this lock is not cause by the group's social dynamic but has more to do with demographic backgrounds. This specifically occurs if the designers and engineers within a group are all from the same background when it comes to life experience, worldviews, geographic and abilities. It is a good thing to create diverse groups of people working on a project in order to prevent a failure from looking at things through one perspective. Failing to do this might lead to a failing project because of missing insights.

In order to prevent such an one-sided operation, stakeholders should be involved in the process and should therefore be accurately chosen and in which manner they should be involved.

The current project does not consist of a very big design and engineers group, actually it is mostly 1 person. So Groupthink and The 'Bubble' Mentality are real risks for a project like this. Especially when becoming enthusiastic about an idea or solution to the problem, risks and other perspectives are hidden and unconsciously left out. In order to prevent this situation from happening external stakeholders should be joined in the process in order to facilitate the other perspectives on the proposed solution. In my specific case this is mainly done through adding stakeholders through meetings and consultations with employees of the company. Especially persons familiar with healthcare technologies can be of helpful insight as they are familiar with risks often manifesting in healthcare technologies. Additionally to these stakeholders, nurses working in a nursing home were asked to give possible risks of implementing such as system as they can introduce another perspective of the system from a less commercial perspective. Of course this is currently all done covid19-proof through online meetings and upon their own offering.

In conclusion it can be said that serious effort is taken in order to include other perspectives in the design process of this project and this will be continuing in the upcoming design steps of the project.

D.4 Case-based Analysis

Often similar cases can be found having parallels that only slightly differ from the current case. Ethical knowledge about the current case can than be extracted from the other case preventing reinventing the wheel concerning ethical knowledge.

D.4.1 IoT Smart Lampposts

At the end of august 2018 a news article was posted on SmartCitiesWorld about the implementation of Smart Lampposts in the city of Hong Kong [20]. These smart multi-purpose lamp posts (MPLP's) serve a couple of different functions such as collection of city data, providing Wi-Fi and real-time traffic data. They collect among other things temperature, air quality, people and/or vehicle data flow related information. Often these MPLP's are adopted as a means to improve public safety, serve a smart city and reduce energy. The rollout of the smart lampposts began in July 2019 but only one month later, during a mass protest, many of these MPLP's were cutted down because of a lack of trust in the governmental surveillance as stated by [21]. And Hong Kong is not the only city where these concerns exist about the introduction of Smart city components in their daily life. In San Jose, California Smart Lampposts were fitted with face recognition cameras and audio recording capabilities [22].

Now, even though this case is not completely similar to the current case where face recognition cameras are used to grant or deny access at entrances and exits in a nursing home. There are still ethical risks and knowledge that we can transfer to the current in order to prevent similar mistakes. For example the trust in the government doing the right things with the gathered data was lacking. In the current case the trust in the management of the nursing home should be consulted in order to prevent a distrust in them and in the extreme case people distrusting them with the camera access system. Because if this would be the case, the system would possible face the same faith as the system in Hong Kong and gets broken down by employees, clients or visitors.

In order to prevent the same mistake, the management and implementation partners of the system should be very transparent about what the system is used for. On the good side a system within a nursing home is only used by visitors, clients and employees of the nursing home instead of the complete public interest. If people absolutely do not want to get into contact with the system, this is possible.

D.4.2 RFID and IoT in a smart hospital

In October 2018 a software development company released a news article on their blog about "RFID and IoT in a smart hospital: benefits and challenges of smart patient tracking" [23]. In this article a lot is explained about the advantages of patient tracking within healthcare institutions such as easily finding of patients, housekeeping planning and patient safety. But such a system does not only have advantages. There are also concern to be taken care of. These concern and ethical issues raised in this article are also applicable to the current project where a similar task is carried out by the system. The illustration in figure 28 illustrate the 3 main risks that need to be taken care of.

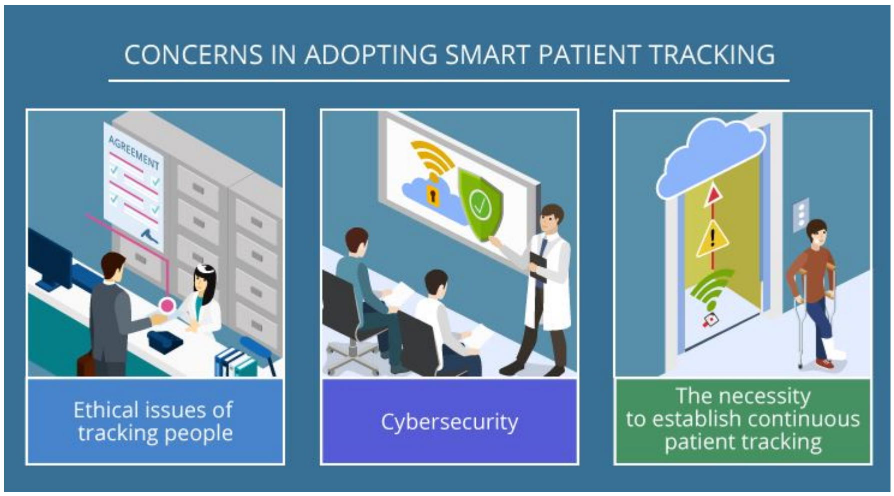

Figure 28: Concerns raised by tracking of patients within a hospital.

These concerns would be valid for a system developed in the current project as well. Privacy issues where a mutual agreement would be needed to track and store a persons face is the first one. Especially when dealing with patients with mental conditions this can become difficult and family or relatives may be required to sign the contract.

In the article [23] they state the following about data security: "Even if a hospital resorts to HIPAA-compliant patient tracking software, it makes sense to mention that careless actions of hospital personnel who have access to tracking info and patient databases and can reveal it (deliberately or not) may provoke data leakages. So, educating on how to use smart patient tracking securely shouldn't be at the bottom of the adoption list for smart patient tracking.". This is true for the current project as well. Technology can be as secure as possible but when the people using it are not well educated and trained to use the software and cope with the confidentiality of such a system a possible leak is still likely to happen. TO cope with this, employees and people working with the system should be made aware of the dangers of a leakage and the vulnerability of the data processed by the system.

D.5 Ethical benefits of creative work

The previous sections of this report mainly focuses on the ethical risks of the project. In Tool 5 [18], the ethical benefits of creative work, a closer look is taken into the positive outcome of the project concerning ethics. In the end most of the project have a goal of flourishing and enhancing a sustainable life for the current generation and future generations. This section includes making these ethical benefits explicit and therefore improving motivation to work for them.

To help this process of keeping the ethical benefits of creative work central a couple of questions can be asked [18]. These question will contribute to a morally good motivated team:

- Why are we doing this?
- Are our customers better off with this technology than without?
- Has the ethical benefit remained at the center of our work and thinking?

For the current project the main purpose of the system can be described as a system to protect elderly people in a nursing home without interfering with their living environment through wearables and invasive technologies. We believe that elderly people and nursing homes are better off while using this new system compared to other current systems. Especially when it comes to fitting these users with bracelets, transmitters or sewed in chips to track them. They often become angry, anxious or rebellious when told to keep a bracelet on as they do not understand the purpose of the system. The new system should eliminate a lot of these problems as the clients and patients do no longer need wearables or transmitters on them to track their position.

The reliability of the system compared to current systems does still need to be investigated as it would not be a suiting solution to trade reliability for well-being as an elopement is dangerous for the well-being as well. However, with current camera-based identification and tracking technologies a high accuracy and reliability should be possible resulting in a new system beneficial to staff and clients.

D.6 Bad people do bad things, with your stuff!

Of course when developing a new system, designers and engineers imagine their work is only used by wise and benevolent people. Especially when focusing on the ethical benefits of the system as described in section D.5. However, as technology imposes power there will always be people misuse this technology for their own gain. Even at the expense of others. A tool to mitigate the opportunities for these people to misuse a system is to think about them beforehand. As a result the system can implement functionalities such as encryption to make it harder or not possible at all to use the system for wrong purposes.

The system as proposed in the introduction is working independent from user input and works mostly autonomous by locking doors and alarming caregivers in case of an possible upcoming elopement of a client. It is possible for the caregivers to turn off the notifications when they feel they are not of importance to them. This can be prevented by Mobile Device Management where the system administrator can check and obligate the notifications on an employee's mobile phone. Another possible threat to the proposed system is hacking. The system works with bio-metric and image data from within the nursing home and connects this data to the internet in order to facilitate the messages. This combination makes it susceptible to hacking. Because of this reason the system should only be installed at the entrances and exits of the building and not in the private living environments of clients. In case of a hack the damage as data win for the hacker is minimal. In case of a hack shutting down the system, the caregivers should be notified in order to pay extra attention to possible elopements and when possible act upon the hack.

Additionally to these countermeasures, the company requesting this project (Loogisch B.V) is NEN 7510 [24] compliant and want to stay so. Therefore the end-product of this project should adhere to the guidelines and requirements set in this NEN 7510. In short, this NEN standard describes rules, guidelines and requirements where system integrators in healthcare, healthcare institutions and health manufacturers need to adhere to in order to maximize the safety of the system and integrity and safety of the patients data. The full NEN standard can be found in the references and downloaded for free [24].

D.7 Ethical feedback and iteration

In a design and engineering process, ethical design and awareness are an ongoing factor. As humanity changes, technological advances change with them and so does ethical impact on society. This is also stated in the article of [25] "History is full of examples of how disruptive innovations have helped man to master his enemies and extend his power and influence. The use of the bow and arrow, and gunpowder in later centuries are instances of how the adoption of a disruptive technology and its innovative application had decisively impacted the creation of new empires and kingdoms.". After such events the society changes, the technologies available and the ethical impact of technologies on society.

As this is an ongoing process that never finishes, companies would benefit from implementing an ongoing ethical analysis in their businesses. Specifically in the design and engineering processes within a company. By involving external stakeholders into the process and together walking through the possible ethical risk will help development of sustainable and public friendly projects and products.

For this specific project this will results in a constant evaluation of the system and possible ethical risks at the different stages of development such as ideation, specification, realization and evaluation. Especially during specification where the elements and overall idea of the system become clear this is an important step.

Finally, the design of the system should add value to the end user in order to become really meaningful. This should be kept in mind during the process.

To summarize, using the tools as described in the sections of this report and continuously coming back to these steps during the steps of the project should contribute to a successful execution of this project.

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