Visualizing alarms on the patient window through Augmented Reality in ICU

To support the workflow of nurses at night

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ABSTRACT

Clinical alarms, which were initiated to draw medical staff's attention when there are changes of a patient's condition, are simultaneously bring out negative influences for patients' mental and physical health as well as clinicians' well-being and work efficiency (Cvach, 2012; Drew et al., 2014). Aiming to reach silent patient rooms as well as reduce the alarm fatigue for nurses, an initial idea of using Augmented Reality to visualize alarms on patient window at night from outside the patient room was proposed. Through the context research and user research, it has been found that the biggest support that ICU nurses need regarding alarms is the information from other rooms when they are inside the patient rooms. Thus, the direction of project shifted from displaying alarm information from outside to inside where the idea is most benefial for ICU nurses. The findings from expert interviews and nurse interviews lead to a clearer design goal, which is to design a display system which supports ICU nurses to check real-time alarm information from other patient rooms and respond with touchless interaction through the patient window during night shift. The design goal was divided into three sub-goals: transparent display, touchless interaction and alarm information interface. For each sub-goal, the design went through iterations separately. After an benchmarking research, projection film was chosen to use in the project; by testing with 8 participants, gestures which have the best error rate were chosen for implementation; by sending out questionnaires to nurses, the alarm interface was iterated and improved based on 11 nurses' response. In the end, three part were integrated and the final design was evaluated by 5 ICU staff (including one technician and 4 nurses) at EMC. With the final design, the nurses are able to get real-time alarm information when they are in another room and remotely deal with the alarm right away. The final design is perceived by the nurses in general as an easy to understand, attractive and practical design. However, there still remain needs from nurses that are not fulfilled and more relevant possible research topics were found out. More possibilities should be researched and tested for development. The recommendations regarding these needs and possibilities are provided at the end of the project.

TABLE OF CONTENTS

ABBREVIATIONS

EMC	Erasmus Medical Center
CAL	Critical Alarms Lab
AR	Augmented reality
LoR	List of requirements
HR	Heart rate
SpO2	Saturation of Peripheral Oxygen
RR	Respiratory rate
NBP	Noninvasive Blood Pressure
MinVol	Minute Ventilation
Ppeak	Peak pressure
VTE	Expiratory Tidal Volume

1 General Introduction

This chapter introduces the project background and the main research question of this project. Moreover, an overview of the design approach throughout the project is presented.

GENERAL INTRODUCTION

1.1 Background

Nearly every medical device in ICU is outfitted with an alarm, like infusion pumps, ventilators, bedside monitors tracking blood pressure, heart activity, and even beds are alarmed for detecting fall movement. Those clinical alarms, which were initially designed to draw medical staff's attention when a patient's condition goes beyond the proper range, are causing a new alarm hazard problem (Borowski, 2011). Those medical alarms can produce sound levels in ICU between 70 dB and 90 dB, which are much higher than 35 dB during the day and 30 dB during night recommended by WHO(World Health Organization). Even in an empty patient room, the background sound level in ICUs could reach 30 dB. In addition to the existing symptoms of illness, an excessive level of sensory stimuli may negatively influence patients not only psychologically but also physiologically, to some extent, by means of sleep deprivation. Sleep deprivation is a common phenomenon for patients in ICU which can lead to many negative effects, such as heart rate increasing and altered blood pressure, slower healing and increased length of stay, and even delirium. Therefore, the negative effect of medical alarms on patient experience should be improved without hindering nurses' need for medical information.

As the medical equipment in ICUs are made from different brands and have different communication protocols, they do not follow the same principle. Even the alarms are designed in different ways. For example, alarms sound in different ways, and some alarms are not informative enough. It adds difficulty for nurses to directly distinguish different types of alarms and the urgency levels to react effectively.

Also, to achieve a seamless and real-time display, the patient window will be used as the display instead of any electronic device (iPad, monitor, etc.) or wearables for complying with infection prevention protocols. This is where Augmented Reality (AR) could help. By adding specific input into the real-world context instead of replacing the real-world, AR can keep users contextualized and more informed. In this graduation project, the opportunities with window-based AR will be explored in the context of displaying alarm information.

Thus, this graduation project was initiated to explorethe technological possibilities of supporting nurses' workflow in Intensive Care Units (ICU) with visualized alarm information to help achieve silence in the patient box in ICUs.

The main stakeholders in this project are ICU patients and nurses. Patients staying in ICUs are usually critically ill and need to be monitored and mechanically supported. Those patients need monitoring devices that collect data regarding heart rate, blood pressure, and organ support devices such as mechanical ventilators to assist breathing. Nurses working in ICU are those who monitor the status of patients and react to alarms that result in the telemetric function of these devices. In the Dutch ICUs, nurses sit in front of a desk located between two patient rooms, and the patients' vitals are shown through the monitor on the desk. With the patient windows in the wall, they can look through into the patient room. (see Figure 1)

This graduation project is a collaboration between TU Delft Critical Alarms Lab (CAL) and Adult ICU Department of Erasmus Medical Center Rotterdam (EMC) from where much relevant research has been done and can be helpful resources to get a better understanding of the context of this project. Also, collaborating with EMC brings the opportunity to conduct research with the target group and evaluate the result of the project.

Figure 1. Nurse workstation in ICU at EMC

1.2 Research question

The main research question of this project is formulated as follows:

"What possibilities are there to use Augmented Reality to visualize the alarms in ICUs?"

The answer to this research question will be found throughout the whole project.

1.3 Project approach

In order to answer the research questions defined in the previous section, the following design approaches were used throughout the project. An overview of the design process can be seen in the Figure.

Context research

Due to the Covid-19 situation, it was impossible to go to the hospital for observation and interviews at the very beginning. Thus, context research relies highly on online research, expert interviews, and results from previous graduate students at CAL.

User research

An interview was conducted with nurses in the hospital to get more detail about the nurse's workflow during the day and especially at night. The interview findings revealed the ICU nurse's needs when working at night and then led to design opportunities and a design goal in the end.

Prototyping separately and integration

After forming the design goal, the concept was divided into three parts for further research and development. Firstly, transparent displays were researched and tested with the projection film. After choosing the Leap motion controller for the gesture control, a user test was done to test the controller's performance and at the same time found out the most suitable gestures to use when using the Leap Motion controller. Then, the user test of interface design was done separately.

In the end, having gone through their own small iterations, the three parts were integrated and prepared for the final evaluation.

Evaluating the design

In the end, the last design was evaluated by ICU nurses at EMC. Design evaluation is of vital importance for giving insights of the current design and revealing the possibilities for further development.

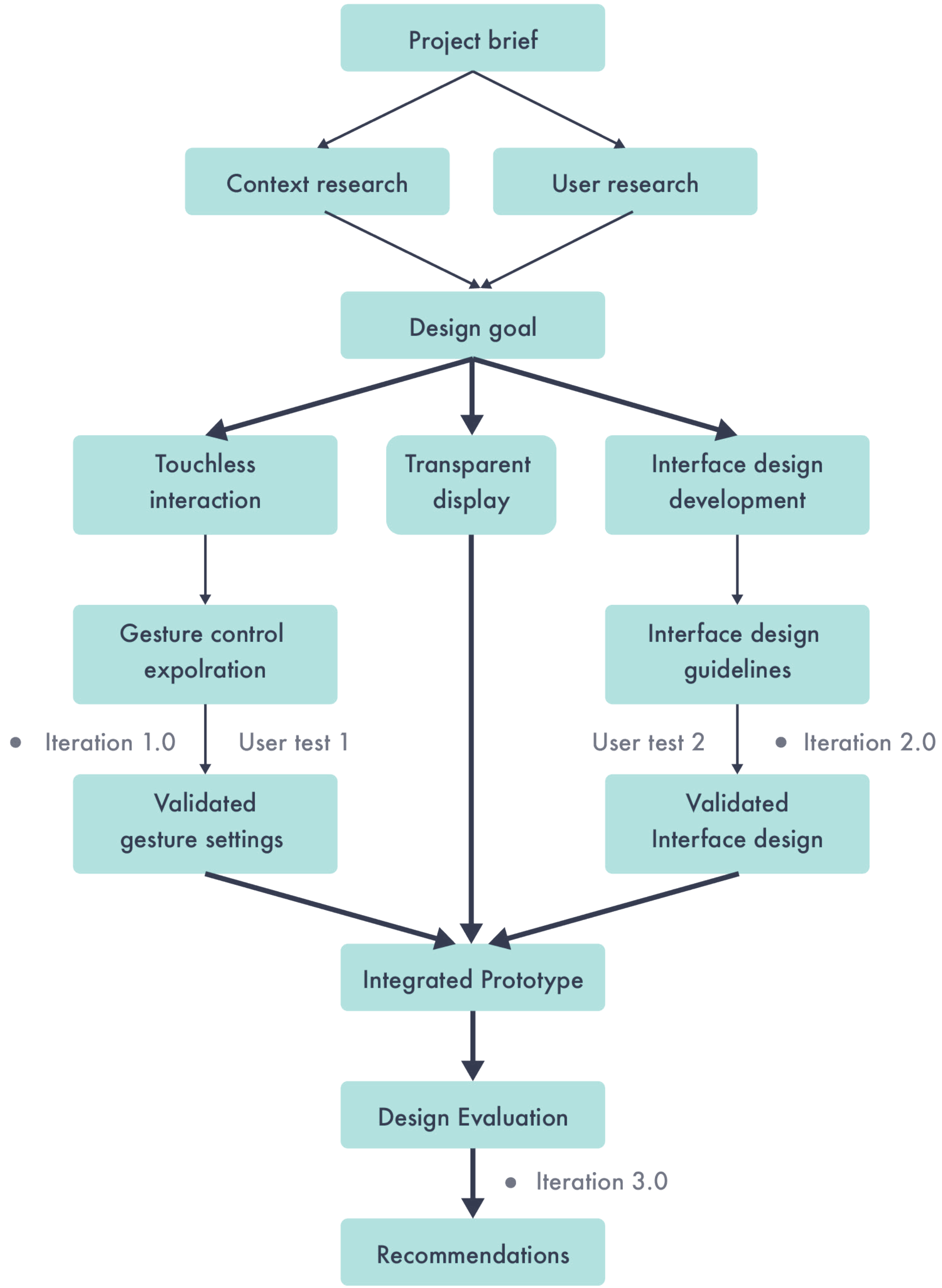


Figure 2. An overview of design approach

2 | ICU Context Research

In this chapter, the main goal is to research on the ICU environment and get a better understanding of the ICU context. The research findings from literature review and online research will be presented in this chapter.

CONTEXT RESEARCH

2.1 Background

Context research is of vital importance for designers to get a better understanding of the design context at the beginning of the project. To visualize alarms as stated in the project research question, it is important to find out the role of alarms in the context. In this chapter, research on the ICU environment was conducted to investigate the role of alarms in current ICUs.

Research questions
The main research question is formulated as follows:

What is the role of clinical alarms in current ICUs?

To answer the main question, the following sub-questions are formulated:
- Who are the users of alarms?
- How are alarms designed?
- Where do alarms come from?

2.2 Method

Due to the effect of the Covid-19 situation, it is not possible to go to the hospital for observation. Thus, the main method used for context research is desktop research, including literature review and online research.

2.3 Findings

Each year, more than 80,000 patients are being admitted to an Intensive Care Unit (ICU) in the Netherlands. (Amsterdam UMC, 2020) The ICU is a highly specialized care unit for patients with life-threatening illnesses or injuries, such as sepsis, heart failure or trauma.

2.3.1 Alarms

Clinical larms are generated on crossing a limit. Nurses can set up a limit in advance, and the devices generate alarms when the value crosses the limit. Currently, monitoring systems provide an alarm setting on most physiological data which leads to a great number of potential alarms. Audible alarms are designed to be a crucial work tool for clinicians, but simultaneously bring out negative influences for patients' mental and physical health as well as clinicians' well-being and work efficiency (Cvach, 2012; Drew et al., 2014).

Currently, clinicians feel more distressed due to the complexity of the information to be received and processed and of the type of information channels such as alarms, graphs, text. For example, apart from the noise problem caused by alarms, nurses are under much stress as they need to differentiate more than ten alarms during work as manufacturers distinguish the priority and the type of an alarm with different signals such as different tones. Taking CARESCAPE R860 Ventilator (Figure 2) as an example, for high priority alarms, the ventilator will generate a series of five tones twice while for medium priority alarms, it will generate a series of three tones. For blue alarms, there will only be a single tone.

Priority	Color	Light	Tone
High	Red	Flashes red	Series of five tones twice
Medium	Yellow	Flashes yellow	Series of three tones
Informational	Blue	Solid blue	Single tone

Figure 3. CARESCAPE R860 ventilator alarms

False alarm
As alarms are designed with a 'better-safe-than-sorry'-logic, there exist a large number of false alarms. In spite of being honest about the monitoring device (the parameter did cross the limit), they have no clinical significance. (Chambrin, 2001)

Figure 4. ICU environment at EMC

2.3.2 Source of alarms

Alarms are generated in three ways, directly from the alarming equipment, from the monitors at the nurse's workstation, and from the pagers carried by nurses all the time.

Equipment inside patient room

Medical equipment used in ICU patient rooms ranges from common and basic ones like patient monitors and ventilators to others like kidney support equipment. Here some of the most commonly used medical equipment are introduced.

Other devices outside the patient room

Apart from medical devices inside the patient box, there are also some devices used outside the patient box that generate alarms as well. These devices are of vital importance to support ICU workflow.

Ventilator

Ventilators are commonly known as breathing machines as they help patients breathe or even take over breathing for patients completely. Thus they are also referred to life support machines.

Dialysis machine

Dialysis machine is used to remove excess fluid and waste products from the blood when the kidneys stop working properly. It often involves diverting blood to a machine to be cleaned.

Patient monitor

Monitors used in ICUs turn the patient's vital data into numbers, graphs, and sonification. (Ozcan et al., 2018) Patient monitors provide real-time information on expected values, thresholds, and out-of-limits. Patient bedside monitor generates the largest number of alarms, as it monitors diverse variables of biorhythm, which are essential for ICU patients. (Cho, 2016)

Infusion pump

An infusion pump delivers fluids, such as nutrients and medications into a patient's body in controlled amounts. As infusion pumps are frequently used to administer critical fluids, including high-risk medications, failures from infusion pumps can significantly influence patient safety. Many infusion pumps are now equipped with safety features, such as alarms as well. (FDA, 2018)

Central patient moniors

The patient monitors are equipped with a centralized system which supports nurses with all patient information in one system. Nurses can have access to the status of all patients in the unit. The centralized patient monitor system is placed at each nurse workstation.

Pagers

The paging system such as the Ascom paging system supports ICU staff with real-time alarm notification. Also, pagers can be used for communication between ICU staff.

2.3.3 Users of alarms

ICUs are equipped with many staff. In addition to physicians and nurses, there are other healthcare professionals who work in ICUs, including physiotherapists, dietitians, therapists and other support staff.

All these staff can hear the alarms when they enter the ICUs. However, beside the nurses, they don't interact directly with the alarms.

2.4 Conclusion

To sum up, among all ICU staff, nurses spend the most time with patients, monitoring them ans taking care of them. Moreover, only nurses interact with alarms. Thus, it can be concluded that the end-user of this project are only nurses and the nurses should be most important stakeholder in the project.

Physicians

Physicians in the ICU are also referred to as intensivists. They do not spend much time monitoring each patient but they will do a patient round daily to assess their patient's progress and decide following treatment and care. According to the insights from nurses who monitored the patient more closely, the critical care team could discuss and figure out the future treatment plan.

Nurses

Among all the ICU staff, nurses spend the most time at the bedside with patients, doing care activity inside the patient room, giving medication and fluids prescribed by doctors, monitoring patients closely, arranging family visits, talking to visitors, etc. They are able to notice the changes of the patients and identify if the doctor's treatment plan has reached the intended result. They share their insights with doctors during the doctor's visit to help doctors decide the following treatment plan.

Physiotherapists

Physiotherapists attend to patients in ICU (often when they are asleep) to exercise muscles in their arms and legs to prevent joints from becoming stiff and sometimes help them breath. Moreover, they are there to help recovering patients with exercises to aid their physical strength after a long period in bed, preparing them to become mobile again.

Nurse helpers

There are also nurse helpers in the ICUs at EMC. After a patient is transmitted out of the ICU, the nurse helpers are responsible for changing the bedsheet, cleaning the room and preparing the room for the next patient.

Dieticians

Dieticians make diet plans for patients according to patients' nutritional needs and ensure that they are receiving adequate nutrition to meet their body's needs in the best way.

Technicians

ICU technicians are responsible for maintaining, repairing, using, and educating other staff on all ICU equipment. During emergencies, they have to be there, making sure the life-saving equipment is doing what it is supposed to do.

Pharmacists

Pharmacists attend ward rounds and offer nurses advice regarding medications as well as ensuring a supply of medication for patients.

3 | Augmented Reality in ICU

After getting a better understanding of the context, the following question to be answered is how augmented reality can help in the ICU context. This chapter presents the researcher's journey to find the answer to this research question.

AUGMENTED REALITY IN ICU

3.1 Background

Improvements in electronic medical records lead to large amounts of data being obtained in the healthcare context these days. The ICU is a highly technological environment where thousands of data can be generated by each patient every day. However, most of this data is usually limited to computer screens and paper printouts. Large amounts of information are displayed to the user, but it lacks context. Augmented reality technologies enable us to add context to the computer information.

Apart from the gaming field, where AR attracts public attention with the game Pokemon Go, healthcare and medicine workers are also among the first realizing and exploring the benefits of AR technologies. Augmented reality is implemented in healthcare facilities across the world today, including vein visualization applications, surgical visualization methods, and education applications.

Vein visualization
The company AccuVein uses AR with a handheld scanner that projects over the skin and shows nurses where the veins are inside the body. It helps solve the problem that nurses miss the vein when making intravenous injections, especially for children and the elderly. (Figure 5)

Figure 5. The handheld scanner by AccuVein

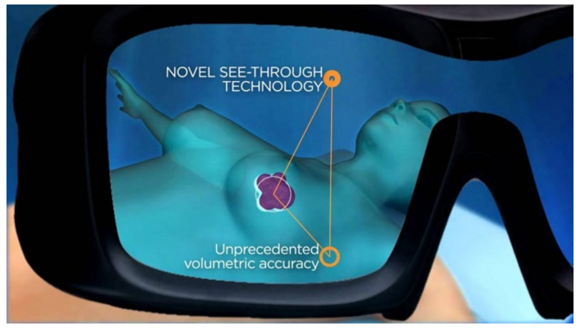


Figure 6. The glass for surgeons to see through

Figure 7. HoloAnatomy app

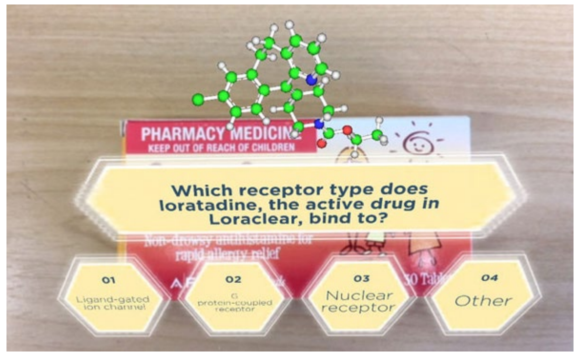


Figure 8. An app developed by the Department of Pharmacology and Toxicology

Surgical visualization
Precision is of vital importance when it comes to surgery. The company Medsights Tech developed software using augmented reality to create accurate 3-dimensional reconstructions of tumors. And with the see-through technology, the surgeon can see through the skin and know precisely where the tumor is. (The medical futurist, 2018) (Figure 6)

Education
Education is an application of augmented reality in the healthcare field. Healthcare workers have to learn a huge amount of information about anatomy and how the human body works. With the help of AR applications, learners are able to visualize and interact with three-dimensional representations of bodies. The app called HoloAnatomy visualizes the human body in 3D instead of traditional 2D images and enables users to see which will transform medical education. (Figure 7)

However, not only healthcare workers are benefiting from this technology. It is also providing a huge advantage as a tool for patient education, allowing medical professionals to help patients understand the way medicines work and surgical procedures. (TD Madison & Associates, 2018) One example is that the app in Figure 8 allows students to aim their mobile devices at a range of over-the-counter medicines to see a specific medicine's three-dimensional chemical structure. (University of Otago, 2016)

After investigating how AR is implemented in the general healthcare context, the following question to be answered is how augmented reality can help in the context of this project, which is ICU. This chapter presents the researcher's journey to find the answer to this research question.

The main research question is formulated as follows:

How augmented reality can help in the ICUs?

3.2 Method

Based on the previous context research, an initial idea was formed, which is to use Augmented reality to visualize the alarms on the patient window outside the patient room. Through displaying these alarm information on the patient window, the idea aims to reduce the chances for nurses to go inside the patient room and provide better sleep for patients.

While lacking direct contact with nurses at this stage, experts were invited to share their opinions on if the idea fits in the context. Besides, if the idea is beneficial enough for further development were discussed.

3.2.1 Participants

In total, 5 experts were interviewed online. They all work in different expertise in the EMC or closely work with EMC. Thus they provided a lot of context information regarding the workflow and information flow in the ICU and shared their opinions of visualizing alarms in ICUs. The profiles of experts can be seen in Figure 9.

Expert	Gender	Working experience
1	Male	Expert at EHR HiX Thorax Center, work on research and IT projects at EMC
2	Male	Senior Staff Clinical Engineer at Dräger
3	Male	Manager medische technologie at EMC
4	Male	Project manager infusion pumps & drug libraries at EMC
5	Male	UX/UI designer in Philips

Figure 9. Participant profile

3.3 Result

Combining the insights from literature research and expert interviews, there are two main problems with alarms in the ICUs of EMC.

Firstly, alarms are not informative enough. It's a challenge for nurses to distinguish between alarms only by audible alarms. Now nurses have the pager system for help, for example, patient monitors are already able to present more detailed information on the pager. However, this is not for all equipment. The biggest obstacle for the hospital technicians is to get relevant detailed data from the equipment, which means from the manufacturer. It is a challenge faced by the hospital for now.

Secondly, there are too many unnecessary alarms, like non-actionable alarms.

"Reducing alarm fatigue is not about switching off the alarms; it is about to fundamentally reduce the non-actionable alarms," said Andreas Walden, one of the interviewees.

When it comes to reducing non-actionable alarms, apart from manufacturers' work, there should also be training programs for nurses to learn how to use the equipment, to set the limits more properly. Also, before there's a proven and safe enough solution, manufacturers will not allow to switch off alarms generated from equipment.

3.4 Conclusion

To conclude, the initial idea of visualizing alarm information on the window display is not beneficial enough. There are two main reasons which are stated below.

Alarm itself
Instead of being a continuous information flow, alarms are more of a short real-time notification. The most important is to ensure nurses get the notification wherever they are. From this aspect, the pager system helps a lot.

Nurses are moving around.
One of the main reasons that the initial idea is not beneficial enough is due to the truth in ICUs that nurses don't always sit in front of the workstation. For most of their time, they might be in the patient room, taking care of their patients at the bedside, washing patients, giving medication, etc. Apart from that, they might also be in the cafe room, in the medication room, talking in the corridor. Nurses will not sit in front of the window all the time. From the experts' perspective, showing alarm information on the outside window won't help much.

3.5 Discussion

In these interviews, the initial idea was discussed in a general scenario. No time was specified and the discussion was not focused on the night in ICUs. This might have an influence on the result of this discussion.

Thus, the following questions comes up: What will happen at night in ICUs and will it be different at night? These will be answered in the following chapters.

4 | User Research: ICU nurse

After a big picture of the design context is drawn in the previous chapter, this chapter focuses on understanding of the end-user, the ICU nurses, to get a better understanding of how they work, the current problems in their workflow and to discover their needs in the end, especially in the night scenario.

USER RESEARCH

4.1 Background

In the previous chapter, AR implementation in general healthcare is studied, but how AR can help in the design context of this project, ICU, remains unknown. Thus, in this chapter, user research is a useful tool to discover the users' needs and design opportunities. To get more insights about nurses' needs in ICU workflows, especially during the night shift which is the focus of this project, an interview with one staff nurse and one former nurse was conducted in the office of 6th floor ICU at EMC.

Research questions
The main research question are formulated as follows:
What are ICU nurses' needs regarding ICU workflows and what are the design opportunities?

To answer the main questions, several sub-questions were formulated:

- What are the differences between night and daytime in the ICU?
- How do ICU nurses work at night? How often do nurses interact with patients and other nurses at night?
- How can ICU nurses be supported at night?
- How do ICU staff use the patient window now?

4.2 Method

4.2.1 Participant

The interview was conducted with two ICU staff from EMC. Their profiles are described in Figure xx.

Gender	Role	Nursing experience	Night shift
Male	ICU technician	> 8 years	No
Male	ICU staff nurse	15 years	No

Figure 10. Participant profile

4.2.2 Procedure

A list of questions were prepared in advance. The interview was conducted with two interviewees together. Firstly, a brief introduction about the project was given. Then, the researcher started the discussion with both interviewees following the question list. The interview took one and half hours. After the interview, the researcher was given a quick tour in the ICU on the 6th floor.

4.3 Results

In this section, insights collected from the interview are presented in four parts, corresponding to the predefined sub-questions.

4.3.1 Differences

In total, from the interview, there are three main differences between daytime and night in ICU (see Figure xx).

Less traffic
During the daytime, there are a lot of events happening in ICUs, from nurses assessing patients, physicians examining patients, family visiting patients, to admission new patients and discharging patients. All these events result in a lot of movement and a lot of traffic. However, as most of these events don't normally happen during the night shift, there will not be less traffic.

From 9 to 11 in the morning is normally the busiest time in ICU during the day. Patients who are leaving the ICU will be prepared and transmitted one by one during this period. And directly after all the empty rooms have to be cleaned and prepared for new patients.

Fewer people
During the daytime, there are different kinds of people moving around in ICUs, not only nurses, but also physicians, nurse helpers, the family of the patient, and also other visitors. However, during the night shift, only about 10 % among these remains there in IC, mainly nurses. Taking the 16-patient-unit in Erasmus hospital as an example, normally only 9-10 nurses work at night.

Far less noise
Noise happens most when there are a lot of movements and events which mainly happen during the day, for example, during the doctors' visit, patient admission, patient transmission, etc. However, normally, patients are not admitted at night. Also, there are fewer nursing procedures at night, for example, nurses wash patients only during the day instead of at night.

"People create noise, and nurses create noise." According to Teus, one of the interviewees.

Moreover, there are fewer alarms during the night. Alarms are far fewer than during the day. Alarms happen when you interact with patients. If there are fewer interactions, there are also fewer alarms which all lead to less noise at night.

Differences between day and night in ICU

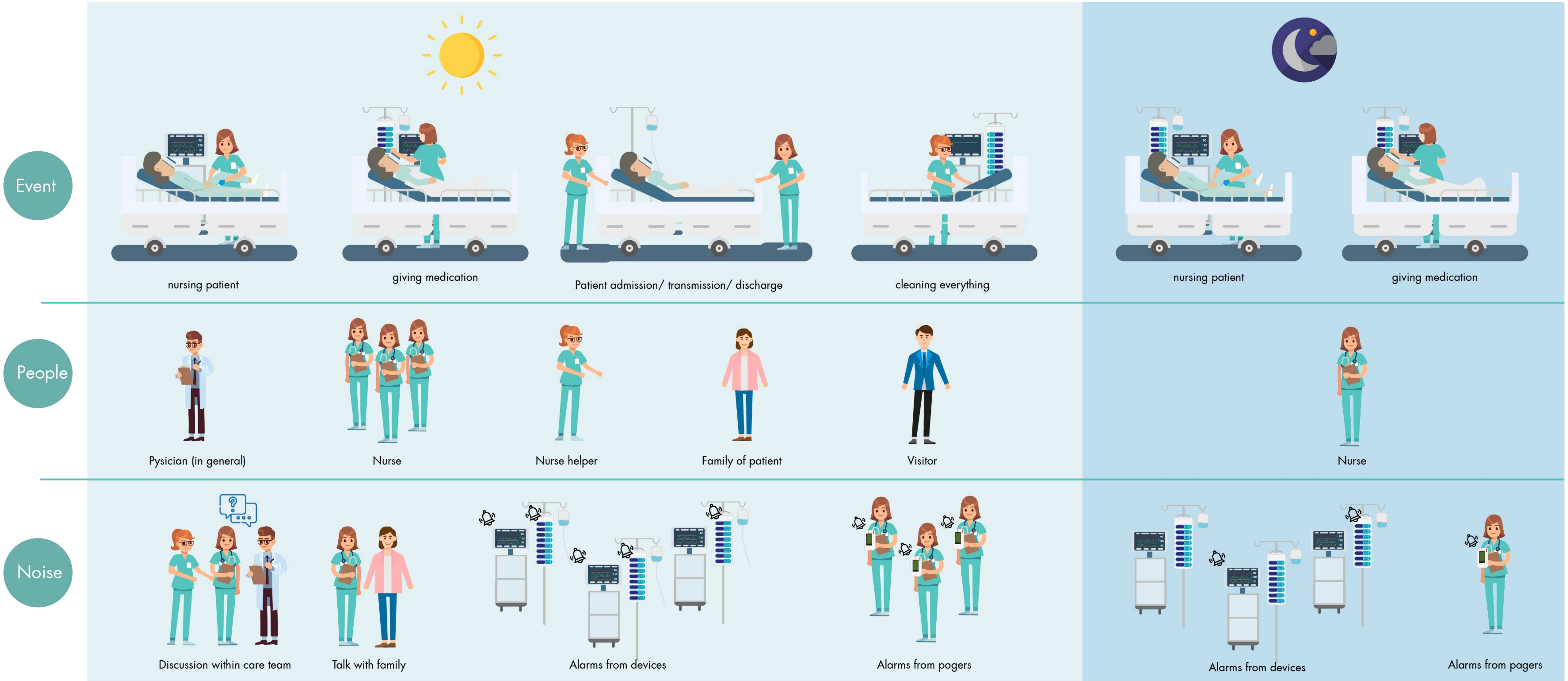


Figure 11. Differences between day and night in ICU

4.3.2 Nurse journey map

After getting a better understanding of how ICU nurses work at night, a nurse journey map was visualized (see Figure xx). It explains the nurses' work during the night shift from 'when', 'what' and 'where'.

To conclude from the journey map, there are four scenarios nurses stay during night shift, with the patient inside the patient room, sitting in front of the nurse workstation outside the patient room, medication room(pharmacy department), and lunchroom. (see Figure 12) The layout of these places can be seen in the Figure 13.

In different scenarios, nurses have different needs.

Sitting at the workstation

During the night shift, nurses have fewer tasks. Thus they spend more time at the workstation. When the nurse is sitting at the workstation, they have access to all patient monitor-related data from the centralized system.

Inside patient room

Normally patients are sleeping during the night, but there are times nurses have to nurse patients, turning them around, helping them get off the bed, etc. For relatively stable patients, nurses have to go inside the patient room every 2 hours. They can see all the visuals on the centralized monitor system but it is of vital importance to check the patients face to face. If the patient is critical, nurses have to spend more time in the patient room, and more often, like every hour. For stable patients, each check lasts about 10 minutes, but for critical patients, it might take up to half an hour. As normally, one nurse will take care of at least two patients, the nurses spend the most time taking care of the patient inside the patient room. During the night, nurses will only go inside the patient room when necessary.

Medication room

Apart from being inside the patient room, nurses can be in the medication room to get medication. During the night shift, normally medications need to be given twice, at 12 p.m. and 6 a.m.

Lunchroom

Besides the above three scenarios, nurses can also be in the lunchroom to take coffee or take a rest.

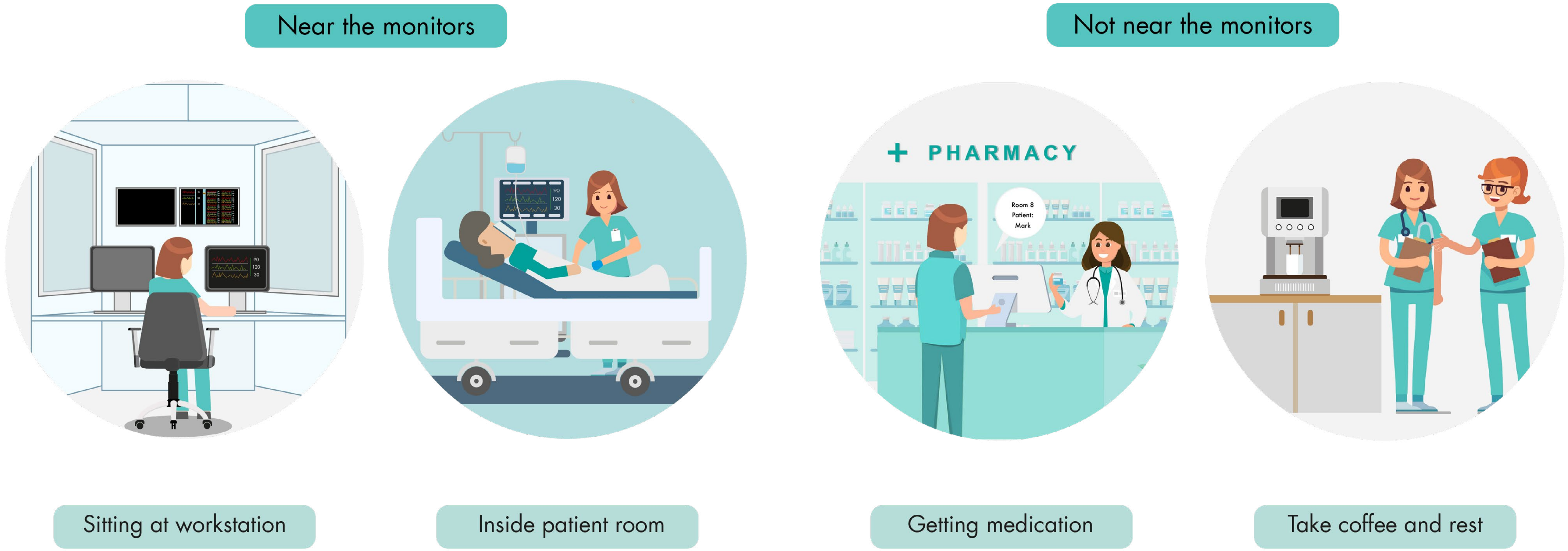


Figure 12. Main scenarios at night in ICU

4.3.3 Discover nurses' needs

As nurses have several different tasks at the night shift, they have different needs when conducting different tasks or in different locations. In total, six different needs are concluded as follows. The detailed explanation can be found in Figure 14.

Lack of information of other rooms

When the nurse is nursing one patient, the other patient's alarms go off, the nurse cannot drop the current patient. But they would like to know what happened to the other patient.

Hands occupied

When the nurse is nursing patients, the alarms in the other patient go off, the nurse cannot drop the current patient and cannot respond to alarms at the same time. As they cannot check and respond from the pager right away, the paging system will send alarms to more nurses which cause much more noise.

Communication between nurses

While the nurse cannot go check the patient, they might need help from other nurses, but they cannot communicate without the pager. And they do not know if there is a nurse going there.

Pagers not informative enough

When nurses in the lunchroom and medication room, they have no access to monitors and alarm information if alarms go off. They can check the pagers which they carry with them. However, the information from the pager is not enough for them to judge if the alarm is true or false. Also, because of the distance, they cannot respond to alarms right away.

Lack of information from outside

As nurses have no access to alarm information of devices apart from the patient monitor, they have to go inside the patient room every time the infusion pump or ventilator alarms go off which increases their interference inside the patient room.

Help from other nurses

When patients are not critically ill and only need basic care, one nurse can do 3-4 this kind of patient if needed. If they have critically ill patients, then every 2 hours the nurses have to start to nurse these patients. When nursing those critical patients, sometimes the nurse in charge needs help from other nurses. Between nurses, they highly rely on verbal communication. They will use pagers for calling as well.

4.3.4 The use of patient window

As this project aims to explore the possibility of using the patient windows to support the workflow in the ICUs, it is important to first know the use of the patient window now. For now, nurses use the patient window to check the movement of the patient, especially when the door is closed and the nurse is not able to hear clearly the sound from the inside. Patient window is a helpful tool for them to see when the patient is trying to move or get off the bed. When possible, the shutter will be closed for privacy.

Large display

In current ICUs at EMC, several PC monitors are used outside each patient room, two computer monitors for nurses' work and one central patient monitor on the wall. However, none of them are large displays. With respect to shared cognition, large displays have a significant advantage over small displays as large displays facilitate teamwork by using shared (Thomas et al., 2017) Also, large displays could show a better and clearer view from a longer distance. Furthermore, apart from showing an overview, large displays can include more content to present more detailed information.

ICU Floorplan

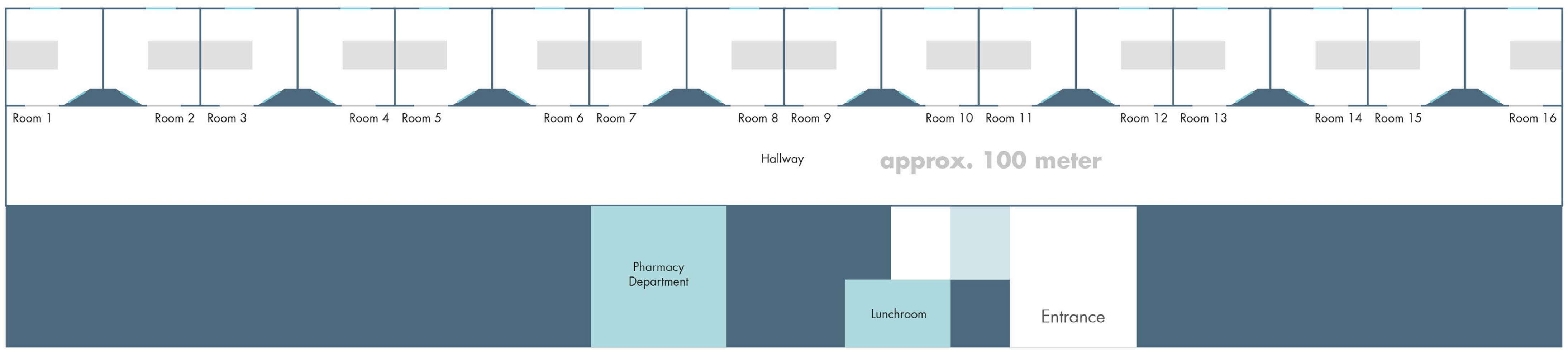


Figure 13. Floorplan of 16 unit ICU at EMC

Figure 14. Visuals of different priority alarms for infusion pumps, patient monitors and ventilators

4.4 Conclusion

At the begining of this chapter, the following research question was defined:

"What are ICU nurses' needs regarding ICU workflows and what are the design opportunities?"

In this section, the question will be answered.

Based on the result of the interviews, it can be concluded that there are design possibilities for supporting ICU nurses during the night shift. There are six needs discovered based on their activities during the night shift and from these needs, five design opportunities were proposed as follows.

Providing information from room to room

At night, nurses spend most time taking care of their patients inside the patient room. Nurses usually take care of two or more patients at the same time and these patient rooms might not be close to each other. Providing nurses the alarm information of other rooms when they are inside one patient room would be helpful for raising their awareness of their patients.

Hand free

When the nurse's hands are occupied and cannot go check the other patient as well, presenting them with alarm information of the other patient in a hand-free way would help.

Provide Interaction between nurses

Apart from presenting information, when the nurse cannot go check, helping them notify another nurse positively with simple interactions and providing feedback if another nurse is going there can also help.

Provide detailed information on pager

When the nurses are not near the patient room and mainly rely on the pager, providing more information on the pager can help.

Providing more detailed information from outside

Providing more detailed information of the infusion pump and ventilator to help nurses filter more false alarms and help them silence from outside. In this way the chances of them going inside everytime can be reduced.

To conclude, the discovered design opportunities give a good summary of the user research and provided a clearer direction for the project.

5 Design Conceptualization

Based on the context research and user research, the potential design opportunities have been found. This led the project to a much clearer direction. This chapter presents the design goal and list of requirements. And based on the design goal, a concept will be proposed.

DESIGN CONCEPTUALIZATION

5.1 Design goal

Based on the design opportunities discovered in the previous chapter, the design goal of this project is formed as follows:

To design a display system which supports ICU nurses to check real-time alarm information from other patient rooms and respond with touchless interaction through the patient window during night shift.

There are three sub-goals highlighted in the design goal which are further explained below.

Alarm information presentation
Alarm information forms the content of the interface which nurses will have direct interaction with. The alarm information here refers to the information from other patient rooms.

Touchless interaction
The interaction between the window and the end-user should be touchless. In the context, nurses' hands are occupied as they are taking care of patients wearing gloves. Introducing touchless interaction in the concept brings out a big benefit of freeing nurses' hands.

Patient window (transparent display)
Patient window is the platform to present the alarm information interfaces.

5.2 List of Requirements

According to the design goal and insights from previous research, design requirements are listed to guide the later design and evaluation, which can be found below. The requirements are described in terms of three sub-goals.

Alarm information presentation

1. The interface should be easy to understand.
2. The interface should be highly simplified, containing only the necessary components.
3. The interface should contain enough alarm information that nurses need when responding to alarms. This should be based on the nurses' needs and it varies from each medical equipment. The detailed requirements are listed in the Function list (Figure XX).
4. The interface should be readable and allow users to quickly find the needed information.
5. The interface should be visible within 3 meters when presented on the patient window.
6. The interface should be able to indicate and differentiate alarms of different priorities.
7. The visual features should match the prioritization of alarms.
8. The interface should be eye-catching when it is activated.

Touchless Interaction

9. The interaction should be touchless. The interaction should be highly simplified.
10. The interaction with the interface should be kept within 30 seconds each time.
11. The interface should prepare enough time to allow users to get all information on each page.

Transparent display

12. The display should only be activated when alarms go off.
13. The display should provide enough visibility for nurses to look through anytime.

5.3 Function list

To limit the scope, it is decided that only three devices are taken into consideration in this project, including patient monitor, ventilator and infusion pump which can be seen as the most common devices and generate most alarms in the ICU.

According to the previous user interview, nurses also have different needs for different devices.

Patient monitor
There are central patient monitors at each nurse workstation. From the central patient monitor system, nurses have access to a centralized system that presents all patient monitors data in the whole unit. At each workstation, they can check all patients' conditions at any time and silence the alarms there without going inside the patient room. From the interview with nurses, it is found out that nurses are highly satisfied with the current patient monitor system and most of their needs are already covered.

Ventilator and infusion pump
Apart from patient monitors, other devices including ventilators and infusion pumps have no such centralized system yet. The only way to interact with those devices is to go inside the patient room to interact with the equipment.

Furthermore, for infusion pumps, there are usually several pumps, however, this is not defined in the alarm. Thus, when the infusion pump alarm is going off, nurses lack information of which pump is alarming, what alarm it is and which medication is in that pump if they are outside the patient room.

Due to the complexity of the alarm information, a function list was made to explain the needed information in different cases more clearly. (see Figure 15) The function list also provides a wireframe structure for the interface design later.

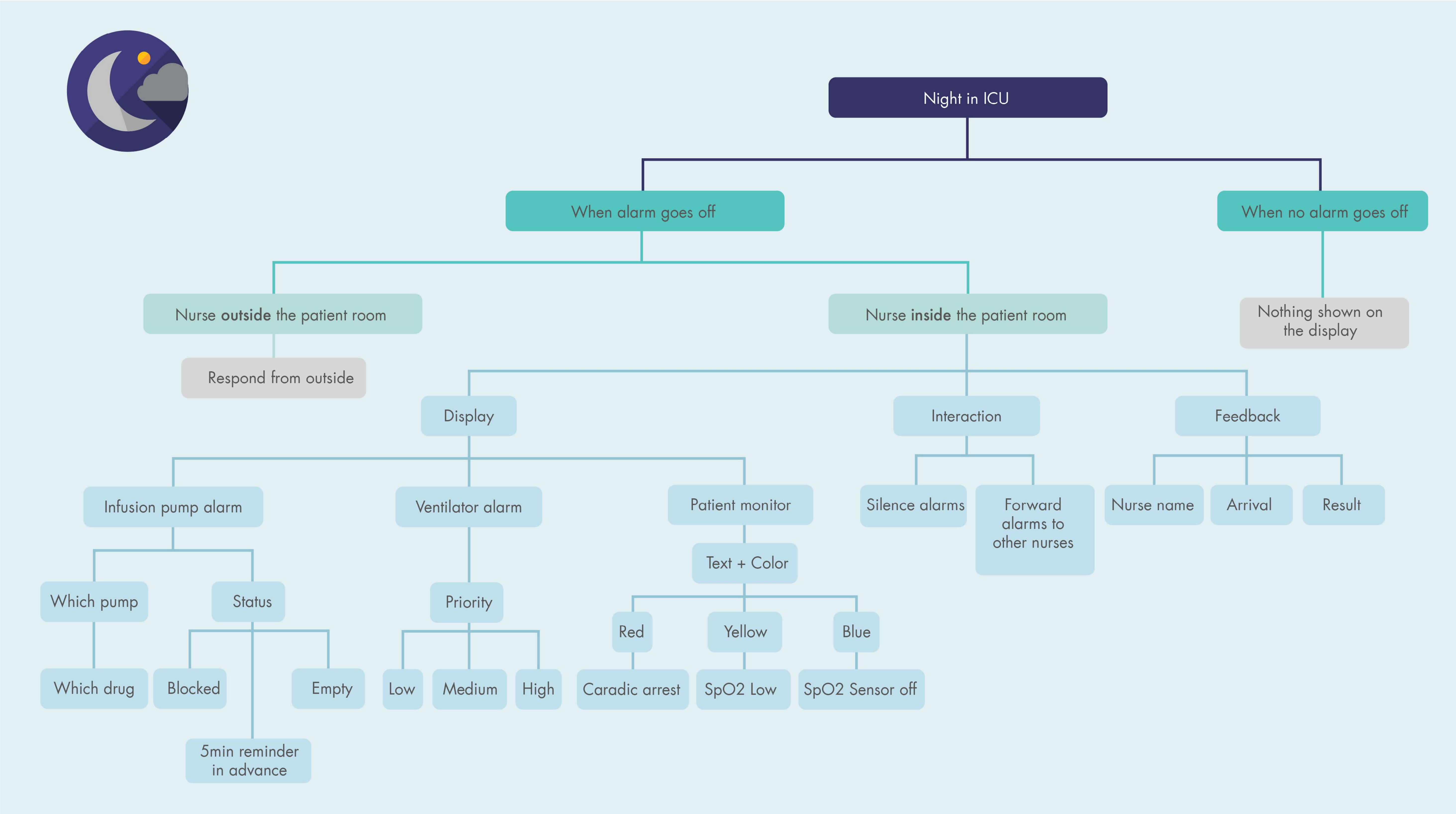


Figure 15. Function list

5.4 Concept

Based on the user research, the biggest support nurses need is information from room to room as they are facing a dilemma that is described in Figure 16. To reach the defined design goal, the concept shown in Figure 17 was proposed.

The nurse is taking care of one patient inside the patient room with gloves on. When the alarm goes off, the alarm information will be shown on the window display.

Without any physical contact, the nurse can respond to the alarm, either silencing the alarm directly or forwarding the alarm to her colleagues for help. After that, the nurse can continue caring for the current patient. Without leaving the room and dropping the current patient, the nurse is able to receive the alarm information and respond right away.

Different alarm information visuals were proposed on diffrent equipment. (see Figure 18)

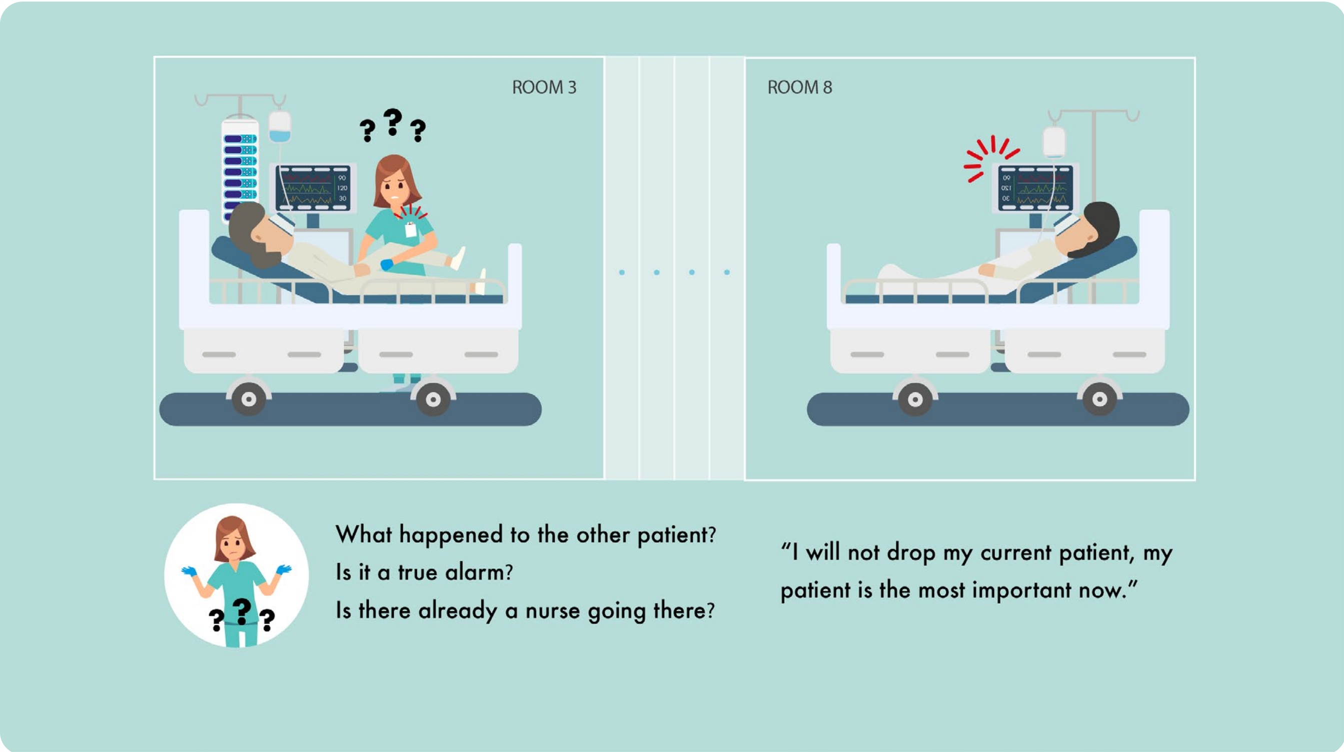


Figure 16. Problem found in the user research

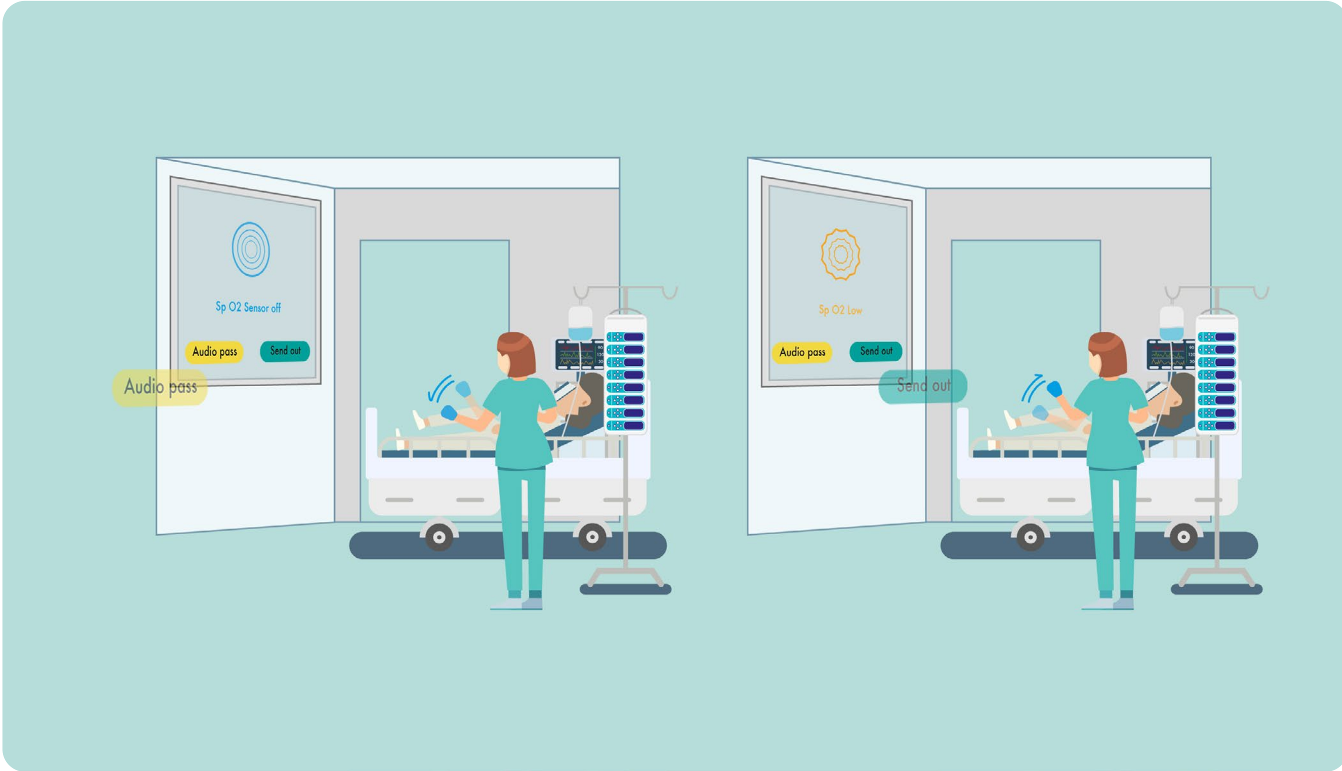


Figure 17. Proposed concept

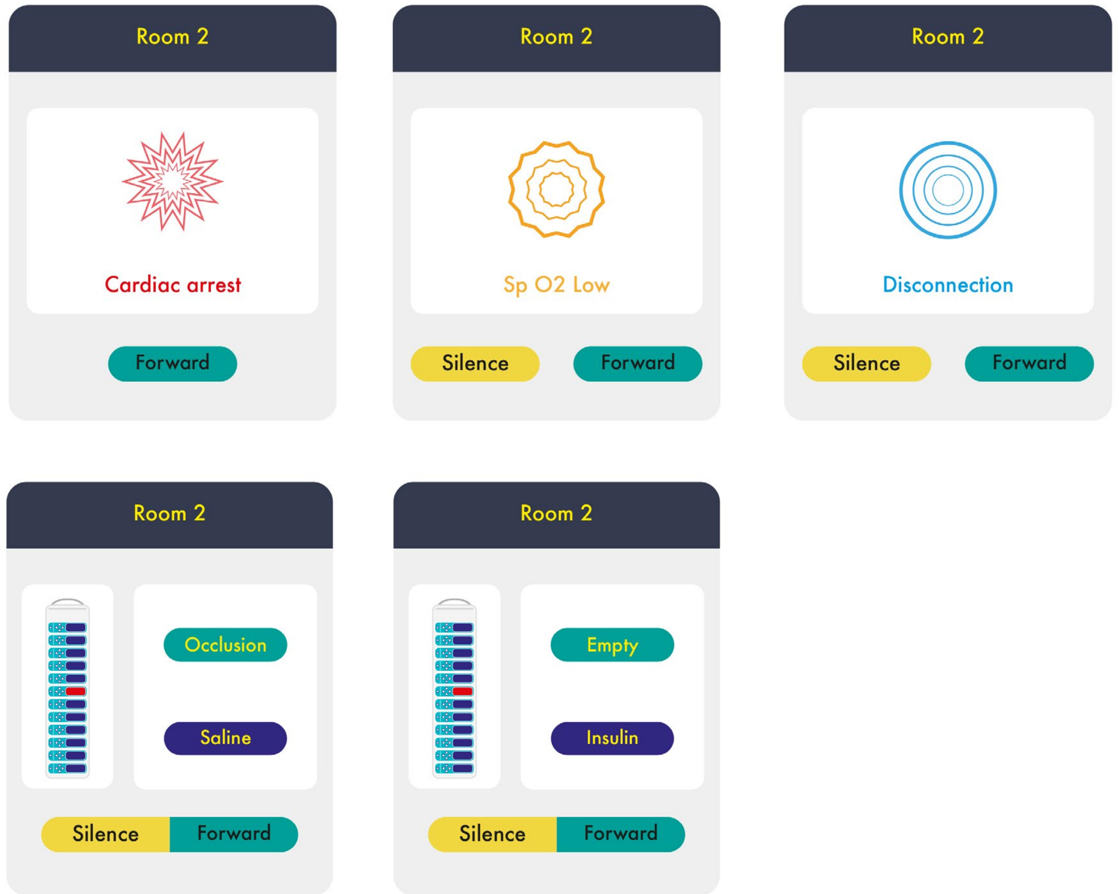


Figure 18. Alarm information examples

5.4 Future scenario

This concept aims to be implemented in a future context when all medical equipment in the ICU are connected through a highly centralised system. For now, in the ICUs, only patient monitors are equipped with a centralised system which helps nursing staff to get real-time information and control patient monitors from the outside. For example, nurses can silence alarms generated by patient monitors from the outside through the centralised patient monitor system. However, for other equipment like infusion pumps and ventilators, there is no centralised system for now which makes it impossible for nurses to operate and control those medical devices outside the patient box. From the expert interview, one of the insights is there is a need for a more centralised system in the ICU and the hospital is making an effort to develop the system. At the current stage, the hospital is facing the difficulty of getting real-time data from the manufacturers and being limited by the current protocol.

6 | Transparent Display Research

This chapter focuses on investigating the first technology sub-goal: transparent display. The technology research is conducted and the prototyping will be presented in the end as well.

TRANSPARENT DISPLAY

To further develop the concept described in the previous chapter, more technology research needs to be done before prototyping. The concept involves three parts, transparent display, gesture control and interface design. In this chapter, more research has been done on the first two technology parts separately.

6.1 Background

As the concept is based on the transparent patient window, one of the technology questions is how to display information on the window. Thus benchmarking research was done on existing products, aiming to get a better understanding of the technology and what is the best performance to be achieved.

Research questions
The main research question are formulated as follows:
What are the available technologies for transparent displays and which fits best for this project?

6.2 Method

To answer the research question, the main method used for researching transparent displays is desktop research, including literature review and benchmarking research. Researching the existing products or technologies on the market helped the researcher to get a better understanding of the technology and the possible choices for this project.

6.3 Findings

With the fast development of electronic devices like smartphones, TVs, display technology is also developing quickly. There are four options for transparent displays on the market: transparent OLED displays, LED displays, projection screen and the other one is window rear projection film.

OLED (Organic Light-Emitting Diode)
OLED, as emerging display technology, uses thin films of organic materials to make efficient, thin and high-quality displays. OLED panels can be made flexible, rollable and transparent. (OLED-info, 2019) Nowadays, many display makers are putting effort into developing transparent OLEDs. Big companies like LG, Samsung and Panasonic all unveiled their own transparent displays.(Figure 19)

Transparent displays can be used in many scenarios, such as store windows, exhibitions, and even broadcasting studios. One of the biggest advantages of transparent displays is it helps create an interactive and open atmosphere as transparent displays are able to blend into surroundings seamlessly and naturally. (Xiaomi, 2020)

However, there's no mass production of those transparent OLEDs yet. Samsung has been making transparent OLEDs since 2008. The company decided to discontinue the transparent OLED line in 2016 as the quantity around the world is not high enough for Samsung to justify the investment. (Techradar, 2016) Afterwards, LG has been developing its own transparent OLED displays.

LED display
A LED display is installed close to the glass of the shop window or large glass building wall. Small-sized LED chips are used to improve transparency while ensuring the colour homogeneity at the same time. It looks like a highly transparent led video wall from far away(when more than 10 meters). However, it looks like window-shades when coming near. Those big LED displays are widely used for shopping malls, hotel walls, vehicle shops, luxury stores, etc. It can support all kinds of videos, graphics, images, text, etc.

Projection screen
Transparent projection screens can be manufactured from transparent acrylic or glass. It allows the audience to see through the screen, with or without any image presented by a projector.

Self-adhesive projection film
Compared with rigid projection screens, this self-adhesive projection film can be applied onto all smooth surfaces, glass or clear plastics. This projection film is available in a few different colors, such as transparent, light grey, dark grey, and black which lead to different transparency levels. The transparent one can reach 89% transparency and performs better

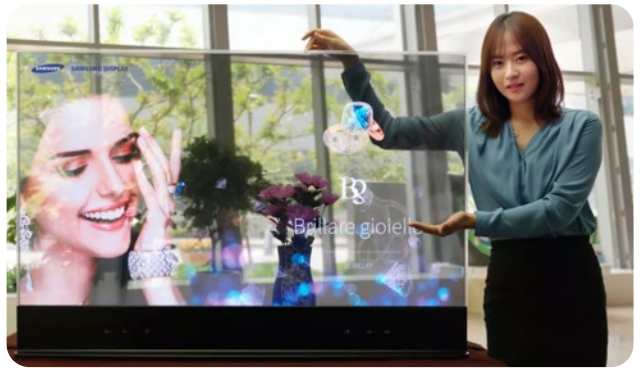


Figure 19. Samsung Transparent display

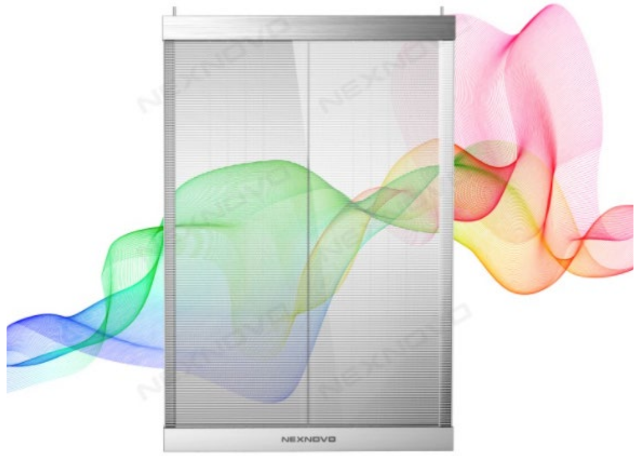


Figure 20. Transparent LED display

Figure 21. Projection screen

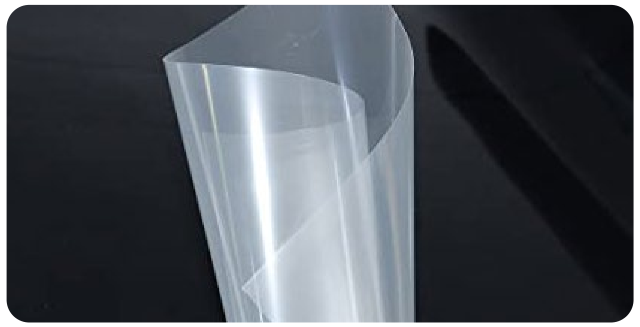


Figure 22. Projection flim

in darker environments like indoors or at night.

6.4 Conclusion

After researching all options, a comparison chart was made to help make a choice. (Figure 231)

Projection film is the best when it comes to the cost, delivery as it is the cheapest among all and comes in small sizes. Also, it is also easier for installation compared with all other options because OLED or LED displays, and projection screens have to remove the original window while projection film only needs to be applied to the existing glass. OLED displays have a big advantage over the projection screen and projection film as it does not need a projector. But it is the most expensive way and the hardest to get as there are now only two manufacturers, LG and Pro display, producing OLED transparent displays and they are not in mass production yet. Overall, considering the cost, availability and feasibility, projection film is the best choice for prototyping in this project.

Type	Cost (16:9 111x62cm)	Availibility	Feasibility
OLED	EUR 17332 (from LG)	Low	Low
LED	EUR 750	Medium	Low
Projection screen	EUR 250	Medium	Meduim
Projection film	EUR 100	High	High

Figure 23. Comparison chart of four transparent display technologies

6.5 Prototyping

After choosing the transparent display technology, the prototype is made, including all physical components which are transparent glass (acrylic board for simulation), projector and projection film. As for now it is not possible to apply the projection film directly onto the patient window in ICU, a separate display(made with a transparent A4 size acrylic board) was made for testing. The performance of the display in two different light conditions can be seen in Figure 24, 25.

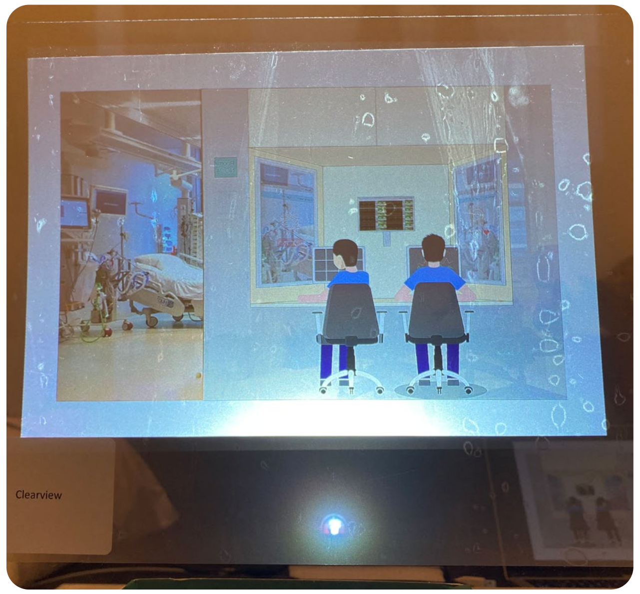


Figure 24. Performance in dim light environment

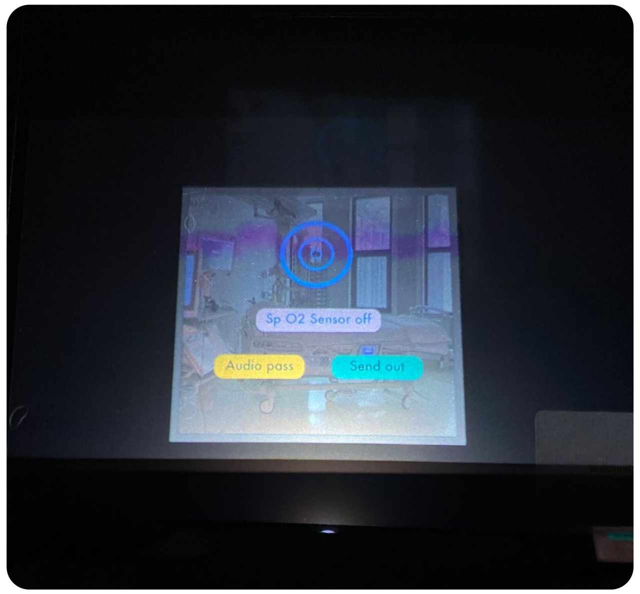


Figure 25. Performance in dark environment

7 | Touchless Interaction

This chapter focuses on investigating the second technology sub-goal: touchless interaction. First, the chapter starts with a general research on touchless interaction. Then, a deeper reseach into gesture control is conducted. To conclude, this chapter presents conclusions from a user test on gestures.

TOUCHLESS INTERACTION

7.1 Touchless interaction research

7.2.1 Background

Most current and most used interaction between humans and machines rely a lot on touch-based technology. For example, when people press buttons, keep touching the screen for a few seconds, or when we use mobile devices like phones or when people use mouses or keyboards on computers, etc.

As described in the design goal of this project, the interaction between nurses and the display should be touchless.

Research question

The main research question in this section is formulated as follows:

What possibilities are there for touchless interaction and how it can be implemented in this project?

7.2.2 Method

The method used for researching touchless interaction is desktop research, including literature review and online research.

7.2.3 Findings

Touchless control technology enables people to interact with machines without physical touch but through speech or motion. Touchless control is not far away from us. It is widely applied in some simple and common contexts in our daily life. A simple example would be automatic hand dispensers that activate when we place our hands under them. Apart from these simple examples, there are also face recognition like face ID and voice recognition like Siri used for Apple devices which require more data storage and are more complicated.

Starting mainly from the game and entertainment field, touchless communication is now growing in maturity and spreading beyond entertainment into critical engineering fields, like industrial automation and healthcare. For example, with touchless technology, it is possible for surgeons to access CT scans during the surgery without the mouse or keyboard. (Iqbal, M.,Z., Campbell, A., 2020) Especially during this epidemic period, there is an emerging need for touchless interaction.

As touchless technology seems to be very potential and can bring big benefits in many fields, it is also facing some difficulties. Touchless system users need to respond or interact in a specific pattern in order to be understood by the system. It has a high requirement for learning and mastering the system. The user’s commands can be misunderstood when the user is not interacting in the way it understands. This leads to users having to go through a training period before they can adapt to the system and use the system effectively.

This leads to a discussion over voice control and gesture control. There is no standard answer of which is better than the other, as they are applicable mostly in different fields in response to specific tasks requiring their use. Gesture recognition’s main weakness is a light condition because gesture control is based on computer vision, which heavily relies on cameras. One big advantage of gesture control over voice control is gestures are used unconsciously. One example is that automotive manufacturers like BMW and Volkswagen all lean towards gesture control as an alternative to haptic control. The main reason is the use of voice can affect a driver's visual attention while gestures are spontaneous and natural. (Program-Ace, 2020) The main difficulty voice recognition is facing is the complexity of human language, which is complicated and can be expressed in numerous ways. Everyone has their own way of speaking and it adds many difficulties for recognition. Voice control is more difficult to implement practically, because it requires a regular updated database for different languages.

7.1.4 Conclusion

To conclude, when it comes to touchless interaction, the answer is either speech or gesture. Looking from a broader view, this project aims to silence the ICU patient room to provide better sleep for patients. Gesture control will not add noise to the patient room while voice control is adding noise into the room, especially when it cannot be executed successfully at the first attempt. Thus, gesture control will be studied for this project for the next stage.

7.2 Gesture control implementation

This section presents the research findings of the gesture control.

7.2.1 Background

In the last section, a general research on gesture control and voice control was conducted, focusing on choosing one. However, deeper research on how gesture control works and how it can be implemented in the project need to be done.v

Research question

The main research question in this section is formulated as follows:

What technologies are there for gesture control and which fits best for implementing in this project?

7.2.2 Method

The method used for researching touchless interaction is desktop research, including literature review and online research.

7.2.3 Findings

The development of gesture control devices started from wired gloves in the 1970s. (Lee, 2018) With sensors placed in the gloves, the bending of the joints can be sensed when the user is wearing gloves. Apart from wired gloves, there is also vision-based gesture recognition. It uses cameras to capture hand gestures and movement. With conventional 2D cameras, the kinematic parameters of hand joints cannot be collected which makes it not suitable for applications that require a more detailed representation of hand interaction with virtual objects in 3D space. In recent years, as 3D cameras that can perceive depth have become much more broadly available and cheaper, more and more developers are taking 3D cameras into the development of gesture control devices.

In 2020, gesture control technology is not new anymore and there are already some widely-used products, such as Kinect developed by Microsoft and the Leap motion controller from Ultraleap.

A deeper look has been taken into these two most used and popular gesture recognition devices on the market now. The research focuses on how these two devices work, and which situation they are suitable for. Julien's research provides many important findings related to the differences between these two devices.

Leap Motion

Leap motion is a small-sized sensor device (8x2.9x1.1cm3) that supports hand and finger motions as the input. It is analogous to a mouse, but without any hand contact or touching. The device observes a roughly hemispherical area within a distance of about 1 meter.(Figure 263) The LEDs generate pattern-less IR light and the cameras generate almost 200 frames per second of reflected data. (Leap motion, 2020) This is sent through a USB cable to the connected computer, where it is analyzed by the Leap Motion SDK software.

The Leap Motion controller has a smaller observation area. It is able to track fine gestures of two hands at a high frame rate and thus it can be used for high

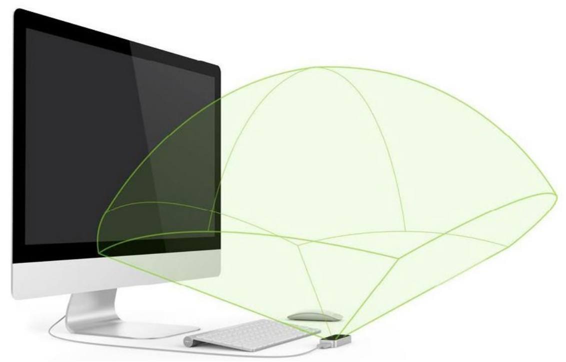


Figure 26. Leap Motion controller

precision and control activities, such as navigating a website, high-precision drawing, using pinch-to-zoom gestures on maps, and manipulating complex 3D data visualizations. (Lee, 2018)

Kinect

Kinect shows strong ability in three-dimensional body and hand motion real-time capture, freeing game players from physical input devices like keyboards and joysticks. Kinect is more suitable for whole-body tracking on a floor surface of 6m2. (see Figure 27) The gesture movement has to be wide enough to be sensed. It involves the entire upper body, which might be tiring when used for a long time. Besides, the user has to get out of the interaction zone to stop or have to use voice control to activate or deactivate.

Figure 27. Kinect

7.2.4 Conclusion

To conclude, considering the scenario in the concept where the nurse is standing beside the bed, surrounded by various medical equipment, busy with taking care of patients, the Leap Motion controller has several advantages over Kinect:

- It has a smaller size so it can be placed near the operation field.

- The nurse does not need to step out of the interaction zone(6m2) to stop the system, otherwise the nurse has to drop the patient.

- Hand and finger movements are less tiring than the whole-body movements.

- Its compatible software is more powerful and convenient to use.

- It has a lower cost. (100 euros for the Leap Motion controller, 250 euros for Kinect)

To sum up, based on the above reasons, the Leap Motion controller is chosen for the later prototyping.

While at the concept stage, it is described that the interfaces should be controlled through gestures. However, it is still not defined which gestures to use yet. In this chapter, firstly a few gestures are chosen based on the availability of the software. Then, as the Leap Motion controller is already chosen for prototyping, a user test was done with 8 participants, aiming to find out which gesture has the best performance and highest satisfaction level by users.

7.3 Gesture exploration test

7.3.1 Background

After exploring several software that are compatible with the Leap Motion controller, GameWAVE was chosen for prototyping.

GameWAVE, as a video game and operating system control software compatible with the Leap Motion controller, makes it possible for users to completely control the keyboard and mouse-based video games. GameWAVE tracks both of your hands independently and simultaneously. (Gamewave, 2020) It provides high freedom for users to define their own gestures to control the keyboard. It recognizes over 50 different gestures for each hand. (Julien et al., 2015) It also detects many fine gesture options detailed to fingers, such as 1 finger swiping left and 2 fingers swiping right. Furthermore, it detects gestures from 2 modes: the steering mode, which allows handling of the mouse, such as a left-click or right-click, and the trigger mode, which allows gestures of movement, such as swiping or separating hands or fingers. (see Figure 28)

According to Tauziet's design guidelines for gesture interaction, it is of vital importance to keep simple when you design gesture-based interaction for virtual and augmented reality. (Tauziet, 2020) Furthermore, as Thomas Joos points out, the biggest downside of the gesture controls is a learning curve. Every time you remove UI clutter, the application's learning curve goes up. When more gestures are introduced, more learning tasks are given to the users. (Joos, 2020)

In the concept, there are only two interactive elements, 'silence' and 'forward'. Following the principle of keeping it as simple as possible, the attention is focused on the most common and basic gestures. Considering the availability of GameWAVE, three pairs of gestures were chosen for further study, including swipe left/right, swipe up/down and circle left/right.

7.2 Method

After the gestures were chosen, a user test was organized to investigate the performance of the Leap Motion controller under the context of this project.

Research questions
The research questions are formulated as follows:
- Which gesture has the best performance?
- Which gesture do users feel the most comfortable for interaction?
- Which gesture should be chosen for the design?

7.2.1 Participants
In total, 8 participants were invited to the test. All participants are master students from TU Delft, ranging from 23-26 years old, including 4 males and 4 females.

7.2.2 Apparatus
The Leap Motion controller was connected to the host PC and the system control software Gamewave was used to define the gestures. A mobile phone was used to record the time.

7.2.3 Procedure
Before the test, a brief introduction to the project was given to the test participants. The participants are encouraged to imagine themselves as nurses standing beside the bed in the patient room.
Also, the Leap Motion controller and the working principle (working area, how many fingers to use, etc) are introduced to the participants to help them understand how to use the controller.

After the introduction, the participants are given time to try out the Leap Motion controller and get familiar with the controller until they manage to finish the task successfully 3 times. The test was conducted in the following order: firstly swipe left or right, then swipe up or down, lastly circle left or right. In this test, participants are told to use one hand for interacting. (see Figure 29, 30) vvvvFor each gesture pair, both hands are tested at least three times. For swiping left and right, there are 4 rounds. As there is a time limit in the real context, where after 30 seconds, the Ascom paging system will automatically forward alarms to 5 closest nurses and all nurses after 60 seconds, the design requirement is the interaction should be done within 30 seconds. Thus, a small test was included to test if the time limit has any effect on the performance.

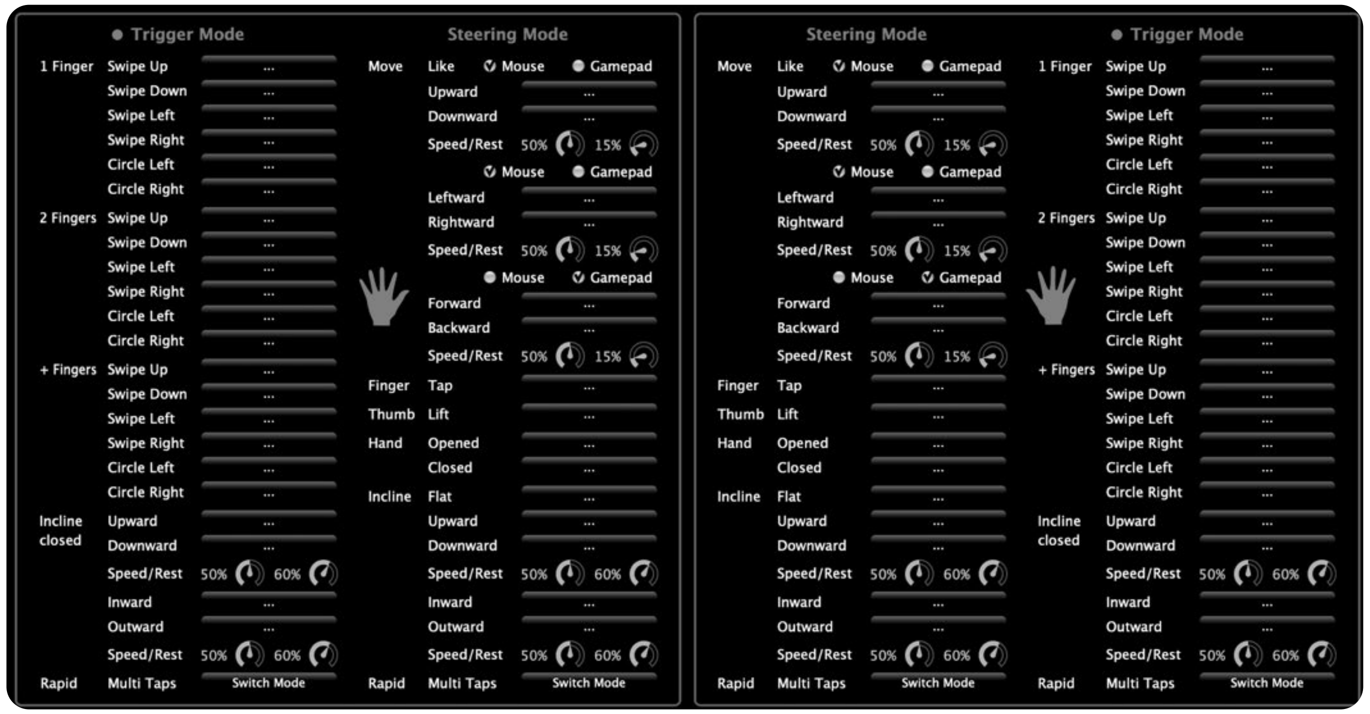


Figure 28. GameWAVE interface

At the end of the test, each participant will be invited to a short interview when they were told to rank the most comfortable gestures.

Stimuli

There are 3 interface prototypes used in this test, respectively designed for 3 different pairs of gestures.

As in real context, after nurses see the alarm information from the display, they have to make decisions of silencing the alarms or forwarding to other nurses. However, participants in this test have no expert knowledge to decide which decision to make, so instructions(icons) were added on the starting page which presents the alarm information. (Figure 31) The participants are told to just follow the instructions of the interface. After the test, the performance of each gesture and the satisfaction level will be analyzed.

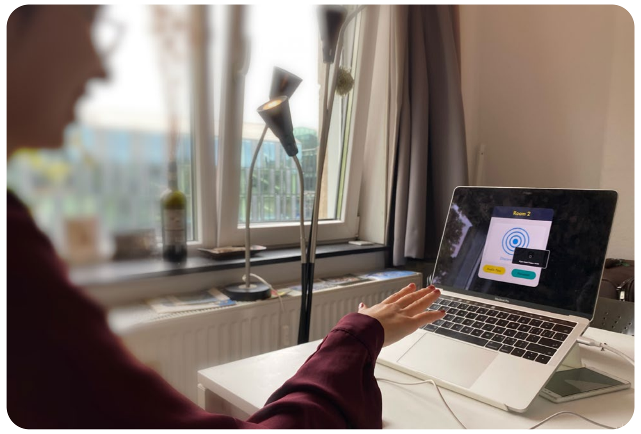


Figure 29. Participant 4 in User test 1

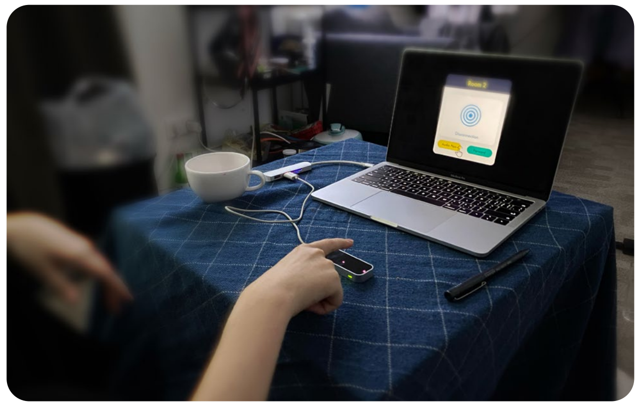


Figure 30. Participant 5 in User test 1

Figure 31. Simple interface prototype used in User test 1

7.3 Result

There are 5 variables in total in this test, gender, hand, gesture, round, and time limit. There are also 5 categories of data collected in the test, including counts of attempts until complete, time consumption, failure, mistake and recognition failure. The data will be firstly analyzed from these aspects. In the end, each gesture is evaluated from three aspects, efficiency, effectiveness and satisfaction level.

Gender

As can be seen from Figure 32, in general, the average time consumption for female participants is 28.9% higher than male participants. Looking into a more detailed graph(Figure 33), it can be found out that except for swiping left, female participants spent more time than male participants when completing the tasks of each gesture. The biggest gap happens on the circle left while the smallest happens when swiping up. As the sample size is small with only 4 female and 4 male participants, it is not sufficient enough to draw a valid conclusion on how gender influences this test. More data would be needed.

Hand type

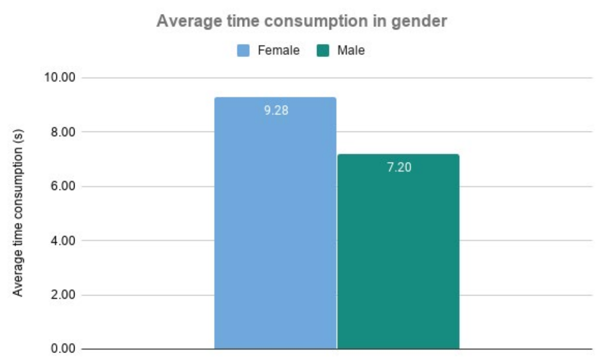


Figure 32. Average time consumption for each gender

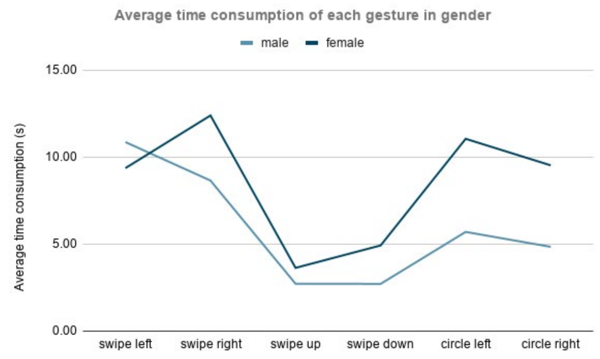


Figure 33. Average time consumption of each gesture for each gender

In general, the average time consumption for the right hand is more than 6 times longer than the left hand. One possible reason could be that all participants start the test with their right hand at the beginning within the rounds of swiping left and right. Looking more detailed into gestures, it can be seen from Figure 34 as well, compared with the other two pairs of gestures, swiping left and right have bigger differences between the average time consumption of two hands. The biggest difference lies in the rounds of swiping right. More tasks they have done, the more familiar they will be with the Leap Motion Controller. Also, for the right hand, more data was collected than the left hand. The right hand completed the task 38 times while the left hand completed 18 times.

Time limit

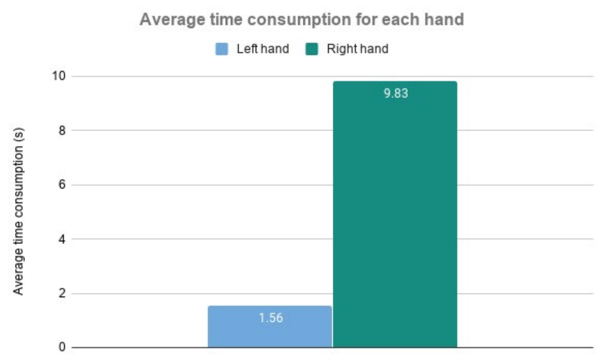


Figure 34. Average time consumption for each hand

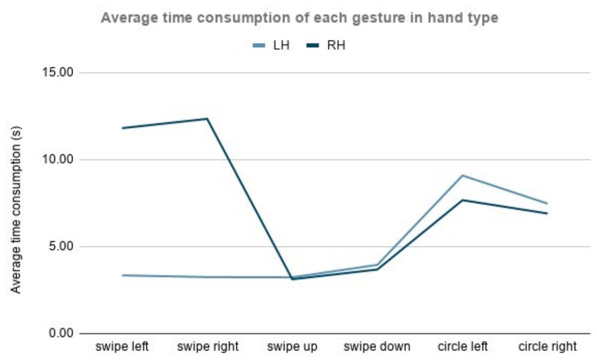


Figure 35. Average time consumption of each gesture for each hand

For swiping left and right, the test included 4 rounds. In each round, the participant has to repeat the task three times. In the first round, there is no time limit. In the following rounds, there are 30 seconds, 20 seconds, and 10 seconds limits for each round.

As can be seen from Figure 36, the average time consumption for 5 participants shows a declining trend while 3 of 8 participants have a longer average time consumption when the time limit decreases. Also, 3 female participants said they can feel the pressure of time limit and then they tried to swipe faster. 2 of these 3 females cause longer time consumption.

Round

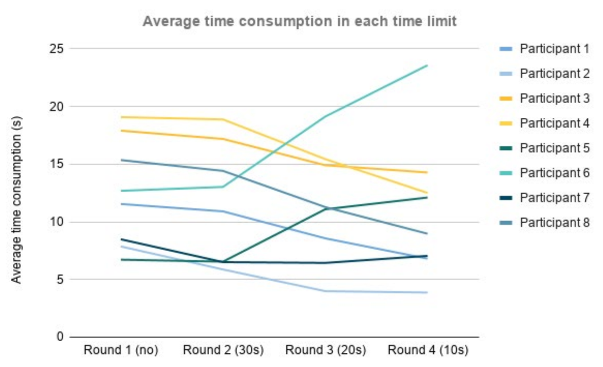


Figure 36. Average time consumption in each time limit

During the test, each participant completed 54 rounds of tasks in total, 30 rounds for swiping left and right, 12 for swiping up and down, 12 for circle left and right. It can be seen from Figure 38, swiping left and right start with higher time consumption compared with the other two pairs of gestures. The possible reason could be the test starts with swiping left and right and considering the influence of the learning process. In the end, all three pairs all end with about 5 seconds for completing each round. In general, the average time consumption shows a trend of decline except for swiping up.

Time consumption

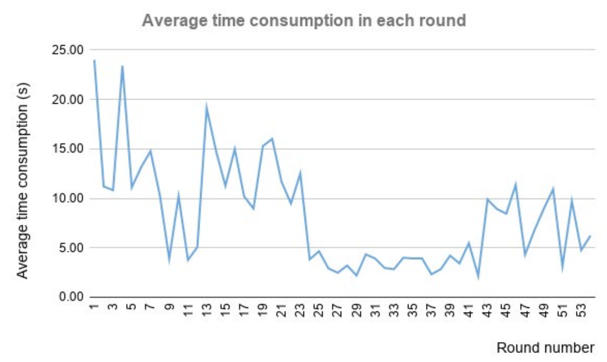


Figure 37. Average time consumption of each pair of gesture

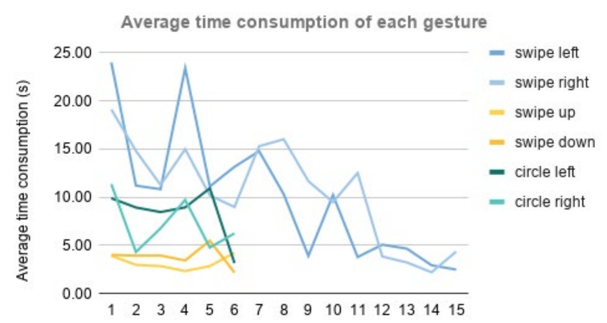


Figure 38. Average time consumption of each gesture

As can be seen from Figure 39, the average time consumption of swiping right is the highest among all six gestures. The average time consumption of swiping left and right pair is the highest while swiping up and down pair takes the least time, 3.5s. Within each pair, the average time consumption is very close, with 0.41s difference for swiping left and right, 0.64s for swiping up and down, 1.19s for circle left and right.

It is found out that during the test, there are three types of errors. The first one

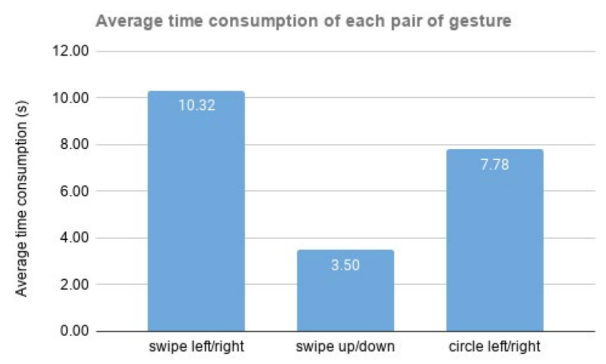


Figure 39. Average time consumption of each pair of gesture

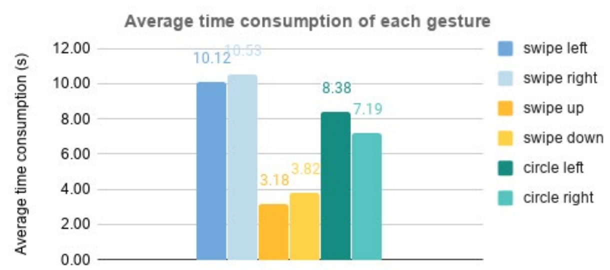


Figure 40. Average time consumption of each gesture

is 'failure', which means the participant failed to finish the task within the time limit. The second one is 'mistake', which means the participant failed to finish the task correctly or lead to a wrong result. This is a very crucial point in the medical context. The third one is 'recognition failure', which means the participant had problems interacting with the Leap Motion controller and the controller failed to recognize the hand.

Failure

Failure means the participant failed to complete the task within the time limit. Among all three pairs, the circle left and right has the highest possibility of failure. 8.33% of the tasks were not completed within the time limit. Swiping left and right has a lower possibility of 7.92%. Looking more detailed into each participant (Figure 43), it can be found all failure in circle left/right was caused by participant 5. However, for swiping left/right, at least 4 participants made the same failure. Thus, participant 5's failure on circle left/right shows the individual influence instead of the universality.

Mistake

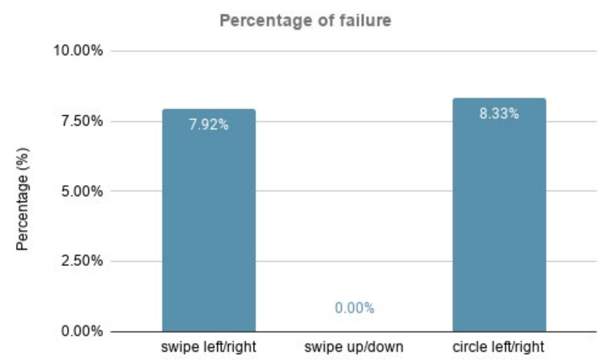


Figure 41. Percentage of failure of each pair of gesture

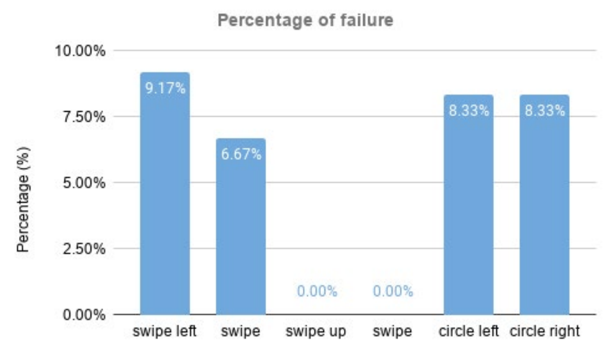


Figure 42. Percentage of failure of each gesture

Figure 43. Percentage of failure of each gesture

As can be seen from Figure 44, swiping left and right has the highest possibility of being mistaken. Among all tasks for swiping left and right, 11.67% lead to misoperations. For swiping up and down, 7.29% of tasks lead to misoperations. Among all tasks for the circle left and right, there are no misoperations. Looking more detailed into each gesture, for swiping right, 17.5% of the tasks result in misoperations. Among all swiping gestures, swiping down has the least possibility of misoperations.

Counts of attempts until complete

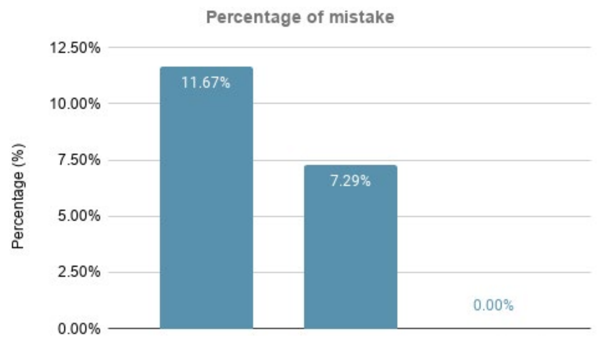


Figure 44. Percentage of mistake of each pair of gesture

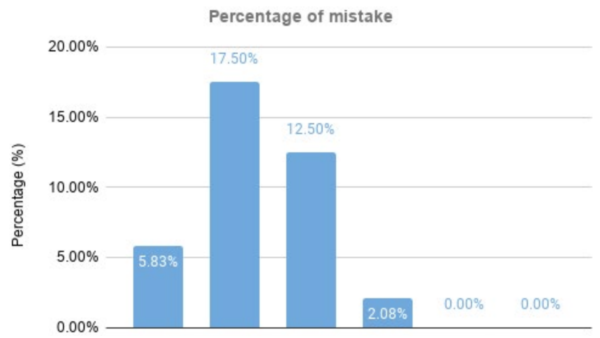


Figure 45. Percentage of mistake of each gesture

It is observed during the test that not all tasks can be done at the first attempt. Sometimes the participants have to make a few attempts before finally completing the task. As can be seen from Figure 46, swiping up/down has the lowest average counts until complete while swiping left/right has the highest average counts of attempts before complete.

Recognition failure

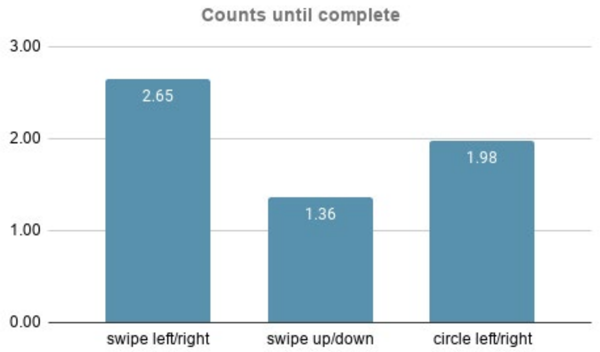


Figure 46. Counts of attempts until complete

As can be seen from Figure 47, swiping up/down has the lowest possibility of recognition failure. The result of swiping left/right and circle left/right are very close.

Satisfaction level

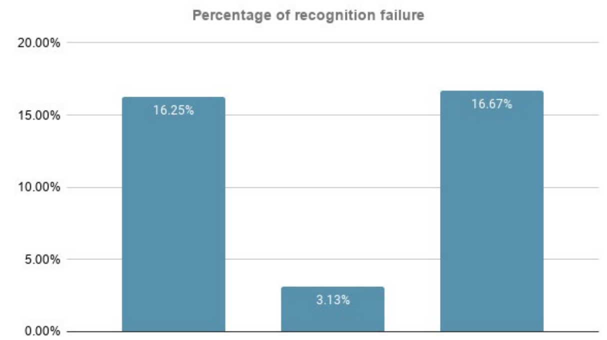


Figure 47. Percentage of recognition failure

As can be seen from Figure 48, participants are most satisfied with the circle left/right. The result of all three gesture pairs are close.

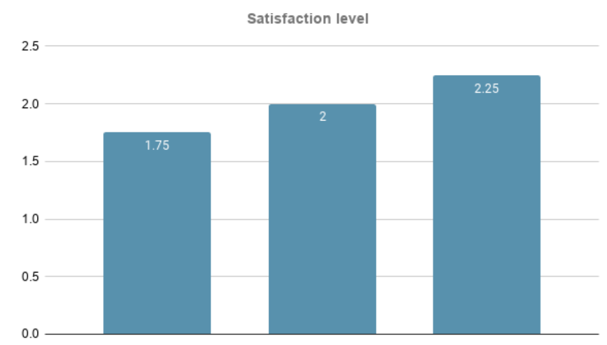


Figure 48. Percentage of recognition failure

7.4 Conclusion

As the goal of the test is to test the performance of completing their pair gesture interaction using the Leap Motion Controller, the performance is evaluated from three aspects, efficiency, effectiveness and satisfaction level.

Efficiency

The average time consumption is used to evaluate efficiency. According to the analysis above, swiping up/down performs best in terms of efficiency.

Effectiveness

By evaluating effectiveness, counts until complete, percentage of mistake, percentage of failure and percentage of recognition failure are taken into consideration. Swiping up/down has no failure to cross the time limit, the lowest average counts until complete and the lowest possibility of recognition failure. Circle left and circle right have the lowest possibility of being mistaken. Since among all four categories, making the least mistake is the most crucial principle, circle left/right has the best performance.

Satisfaction level

From users' perspective, participants are most satisfied with the circle left/right.

To conclude, considering efficiency, effectiveness and satisfaction level, circle left/right has the best performance when conducting gesture interaction with the Leap Motion Controller. Thus, the circle left/right will be chosen to implement in the later design. Moreover, it is obvious that the learning process is very important when using the Leap Motion Controller.

Beside, each user has their own ways of learning new things. It can be observed from the test that the time consumed for each participant to get familiar with the Leap Motion controller and complete three tasks varies a lot from person to person, ranging from 3min to 15 min. Thus, nurses have to go through a training period when they can learn how to use the Leap Motion controller and get familiar with it.

Furthermore, from the perspective of the Leap Motion controller, the settings can be improved. For the next iteration, in the GameWAVE settings, gestures for both hands should be defined for better performance. In this way, the recognition failure can be reduced and the time consumption for completing the interaction can be shortened.

7.5 Discussion

The test lasts from 20 min to 40 min per participant, depending on how participants perform when completing the tasks. During the test, the participants repeated those gestures in a very frequent way, one by one, at least 30 times for each gesture. Some participants are becoming more and more tired as the test goes. However, in the real context, nurses will not deal with the virtual interaction continuously, one after one.

For participant 5, compared with swiping down, swiping up is more likely to be recognized correctly. According to the observation, the reason could be that for swiping up, the hand starts from one point and directly goes up, however, for swiping down, the participant tends to first raise his hand to one point and then go down which result in being recognized as swiping up. For participant 2, swiping up is very easy to be recognized mistakenly as swiping down.

Participant 1 described the gesture circle left and right is not natural and too complicated. Swiping up/down is the most intuitive for him. One of the possible reasons could be that in the interface, the visuals of ‘Silence’ and ‘Forward’ are placed in a horizontal way.

As the ranking of satisfaction level was done in the end, the result can be connected to the performance of gestures. For example, during the test of participant 3, swiping up and down has the best performance in terms of efficiency and effectiveness. And participant 3 ranked swiping up and down as the most satisfied gesture pair.

It is found out that it is not easy for the leap motion controller to differentiate between the left hand and the right hand accurately. The controller is more likely to recognize the right hand when the hand is placed on the right side of the controller. Otherwise, the hand would be very likely to be recognized as the left hand. And this results in the longer consumed time to complete the task.

8 | AR Interface Design

In this chapter, the last sub-goal in this project, interface design will be developed, tested and improved. The interface design guidelines will be presented firstly, followed by design explanation. The test process and findings will be presented as well.

AR INTERFACE DESIGN

When conducting Gesture Exploration User Test, a simple interface prototype was made for the simulation in the test. As the test focuses not on the interface but the interaction between the user and the Leap Motion controller, not much effort has been put into the interface design.
In this chapter, the goal is to define the interface design principles and complete the interface design.

8.1 Interface design guidelines

These design guidelines are formed based on the human-factors principles for designing and implementing decision support alerts and recommendations provided by Phansalkar et al. Ten user interface design guidelines established by Jakob Nielsen and Rolf Molich and human interface guidelines from Apple are also studied.

8.1.1 Distinction

1 According to Alert philosophy introduced by Phansalkar et al., a distinction should be made between alerts related to medications versus those that relate to system errors. For example, for infusion pumps, the visual features for technical alarms such as a low battery or no AC power supply should be distinguished from those for empty pump alarms.

8.1.2 Prioritization

2 The alarm information should be prioritized. This can be coded using the signal word, color, shape, position on the screen, and other indicators known to influence urgency.

8.1.3 Consistency

3 The interface design should be consistent. According to the ten user interface design guidelines established by Jakob Nielsen and Rolf Molich, in the interfaces, both the graphic elements and terminology should be maintained across similar platforms. For example, an icon that represents one category or concept should not represent a different concept when used on a different screen which might cause confusion.

8.1.4 Simple

4 The content of the interface should be reduced to only necessary components for the current tasks, whilst providing clearly visible and unambiguous means of navigating to other content.

8.1.5 Feedback

5 The interface should provide the necessary feedback. According to David Hogue's core principles for user interaction design, good interaction design provides feedback as it provides comfort and a sense of security. It gives the user a signal that they (or the product) have succeeded or failed at performing a task. (Natoli, 2020)

6 The interface should minimize the user's memory load. According to Nielson's 'recognition rather than recall' principle, the user should not have to remember information from one part to the next or during the interaction process. This can be done by keeping reminding users of the information during the interaction process. For example, important information can be included in the next interface or the following interfaces.

8.1.6 Textual information

7 Interface text should be kept clear and concise. People absorb short, direct text quickly and easily and don't appreciate being forced to read long passages to accomplish a task.

8 A mixture of upper and lower case lettering is easier to read than the upper case only. (Poulton,1967)

9 Identify interactive elements appropriately. People should be able to tell at a glance what an element does. When labeling buttons and other interactive elements, use action verbs, such as Connect, Send, and Add.

8.1.7 Use of icon

10 The icons used in should be high-simplified and recognizable. Icons can help represent information visually but too many details can make an icon confusing or unreadable.

8.1.8 Use of color

11 Dark text on a light background is easier to read than light text on a dark background. (Snyder et al., 1990)

12 The number of colors used should be kept below ten. Otherwise, it may be difficult for users to remember each color's meaning and can be confusing.

13 Besides indicating priority level, color can be used in other ways to code visual alerts and make them less confusable. For example, visual alerts can also be color-coded by response required, or by their function.

8.1.9 Placement and layout

14 Alert information should be placed in the visual field in the order of importance. For example, information of high importance should be placed in the stationery field while the less important information should be placed in the eye and head field.

8.2 Interface Design

Based on the user interface guidelines described in the previous chapter, the simple prototype used for User test 1 was developed. In this section, the interface design is presented and explained in detail, and the whole interaction flows as well.

8.2.1 Equipment

Firstly, at the equipment level, different visuals are designed for different medical devices including infusion pumps, patient monitors, and ventilators. The visuals match the appearance or functions of the devices themselves. The infusion pump was visualized with a column of pumps while the patient monitor is symbolized by a heart and ventilator by a lung. (Figure 49)

8.2.2 Priority level

Within this design, the priority level is color-coded. There are already three priority levels in the current medical system, low, medium, and high. Apart from these three priority levels, yellow is introduced to represent reminding alarms. In total, there are four colors used for priority levels: blue for low priority or technical alarms, orange for medium priority alarms, red for high priority and life-threatening alarms, and yellow for reminding alarms. Reminding alarms are now only implemented for infusion pumps.

8.2.3 Type of alarms

For different equipment, there are different types of alarms. There are two types of alarms for infusion pumps, technical alarms like low battery or battery empty and infusion-related alarms like occlusion, air bubble, end of infusion. Each of these alarms is matched with their own icons for a better explanation. Battery-related technical alarms are visualized by an icon of battery while a syringe visualizes medication-related alarms. (Figure 50) The visuals are more detailed in differences when indicating the empty battery, and the battery is running out in 5 minutes.

Figure 49. Visuals of different priority alarms for infusion pumps, patient monitors and ventilators

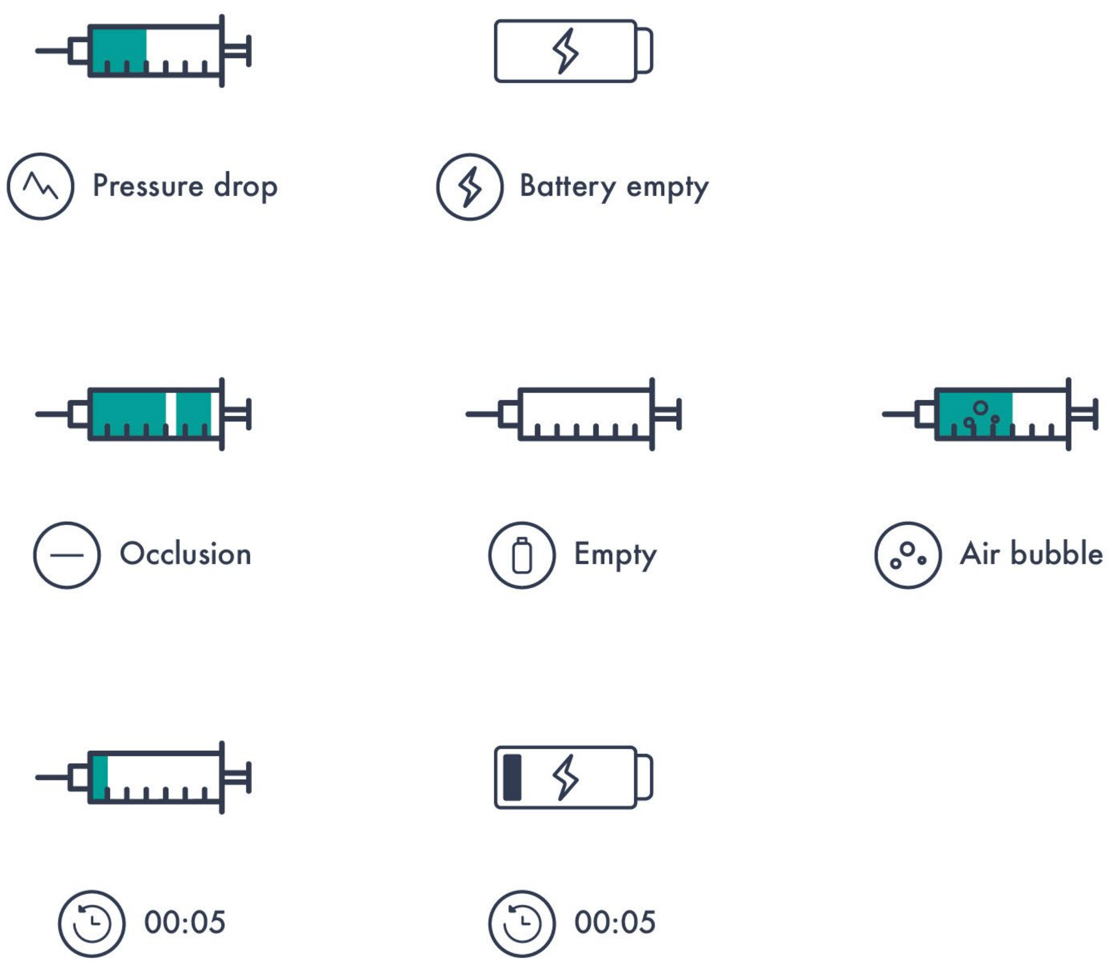


Figure 50. Visuals of different types of alarms for infusion pumps

8.2.4 Starting Page

Importance level

The interface is designed in three parts. The top part includes the basic information of the patient such as the name and the gender and system-related information like the time. According to the Design Guideline 14, important information should be placed at the stationery field while the less important information can be placed in the eye or head field. The patient information including gender and name helps nurses to recall the condition of the patient. However, alarm information is more important in this short notification interaction. Thus the alarm information is placed in the middle, taking up the biggest space. Interactive elements ‘silence’ and ‘forward’ are placed at the bottom.

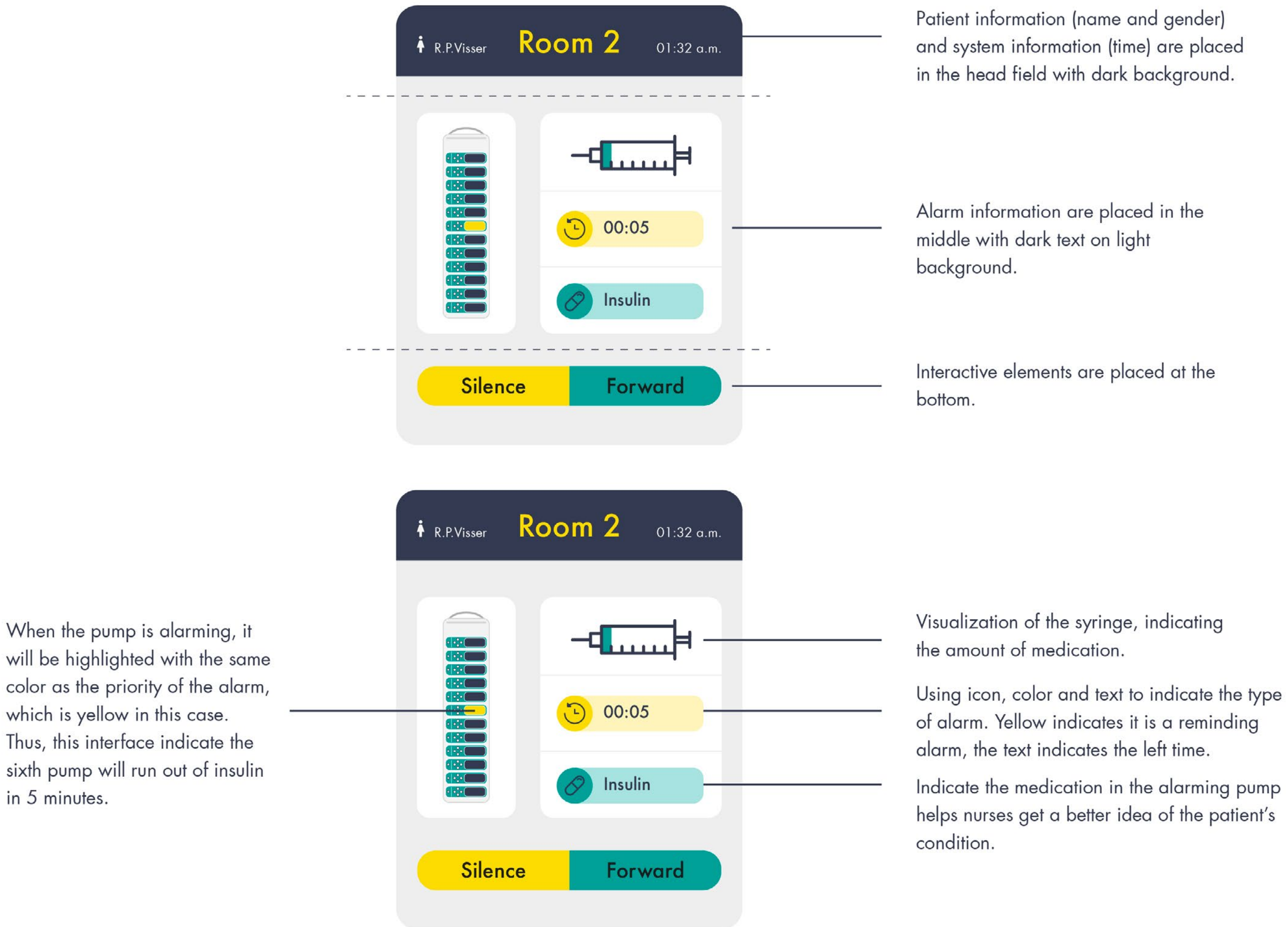
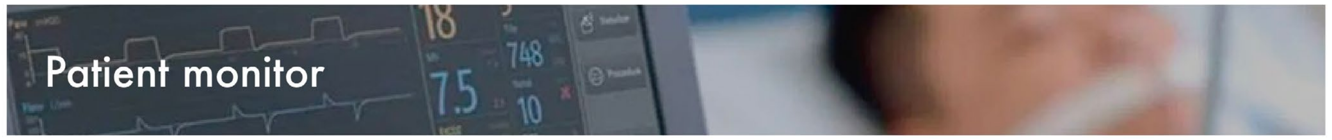


Figure 51. Interfaces of reminding alarms for infusion pumps



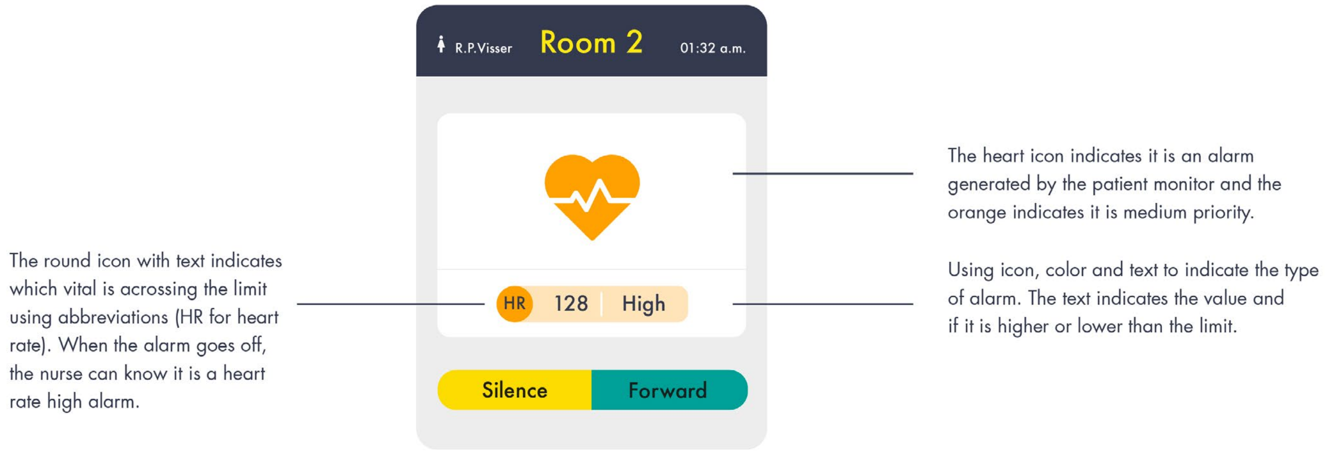


Figure 48. Interfaces of medium priority alarms for patient monitors

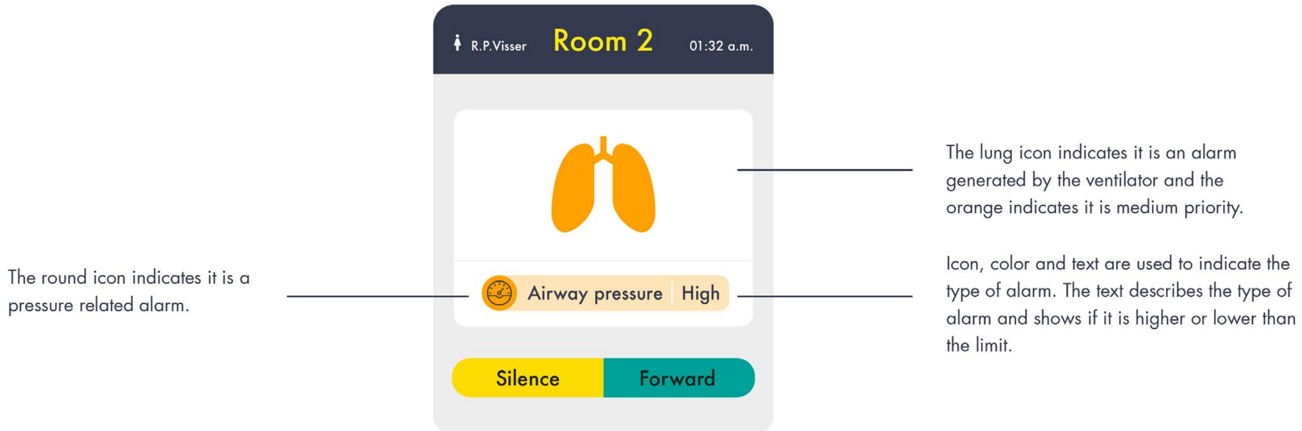


Figure 52. Interfaces of medium priority alarms for ventilators

Consistency

The interfaces for all three equipment follow a consistent design style according to the Design Guideline 3. The interface uses consistent elements, layout, and combination of color, icon, and text to maintain a consistent style. The interface of infusion pumps has a slight difference with those of patient monitors and ventilators in the layout as there exist different needs of content for different equipment. (Figure 53)

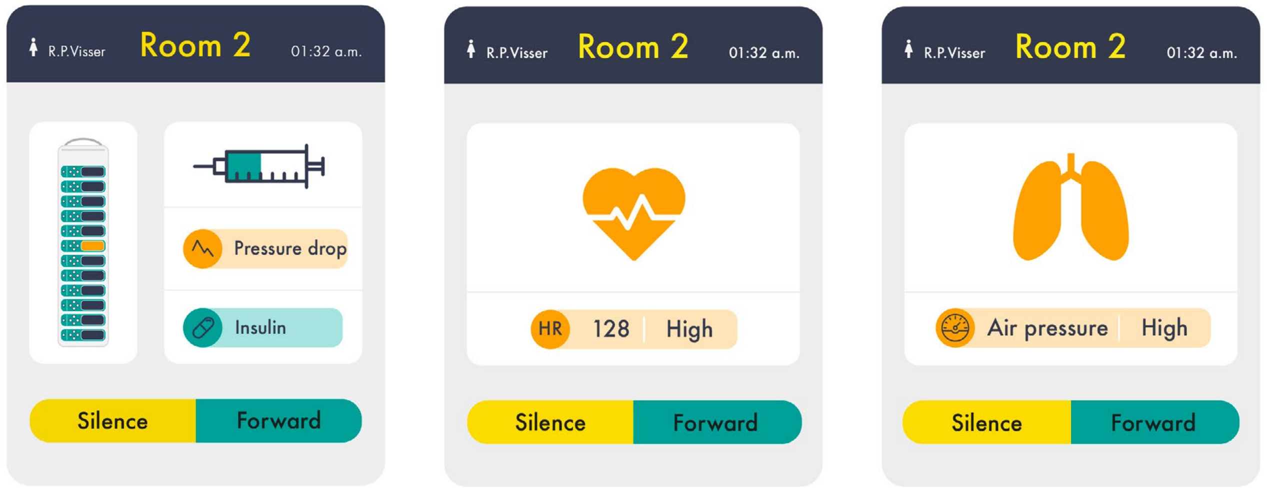


Figure 53. Interfaces of medium priority alarms for infusion pumps, patient monitors and ventilators

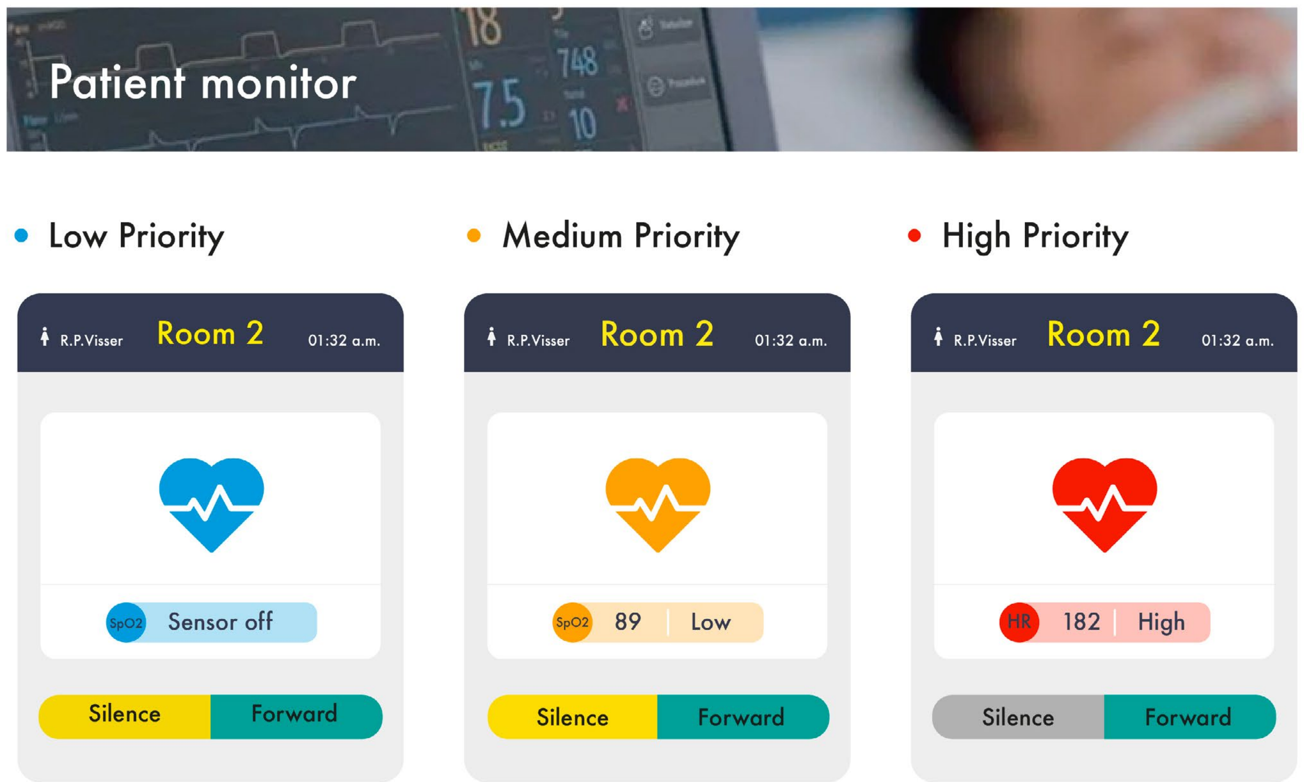


Figure 54. Interfaces of different priority alarms for patient monitor

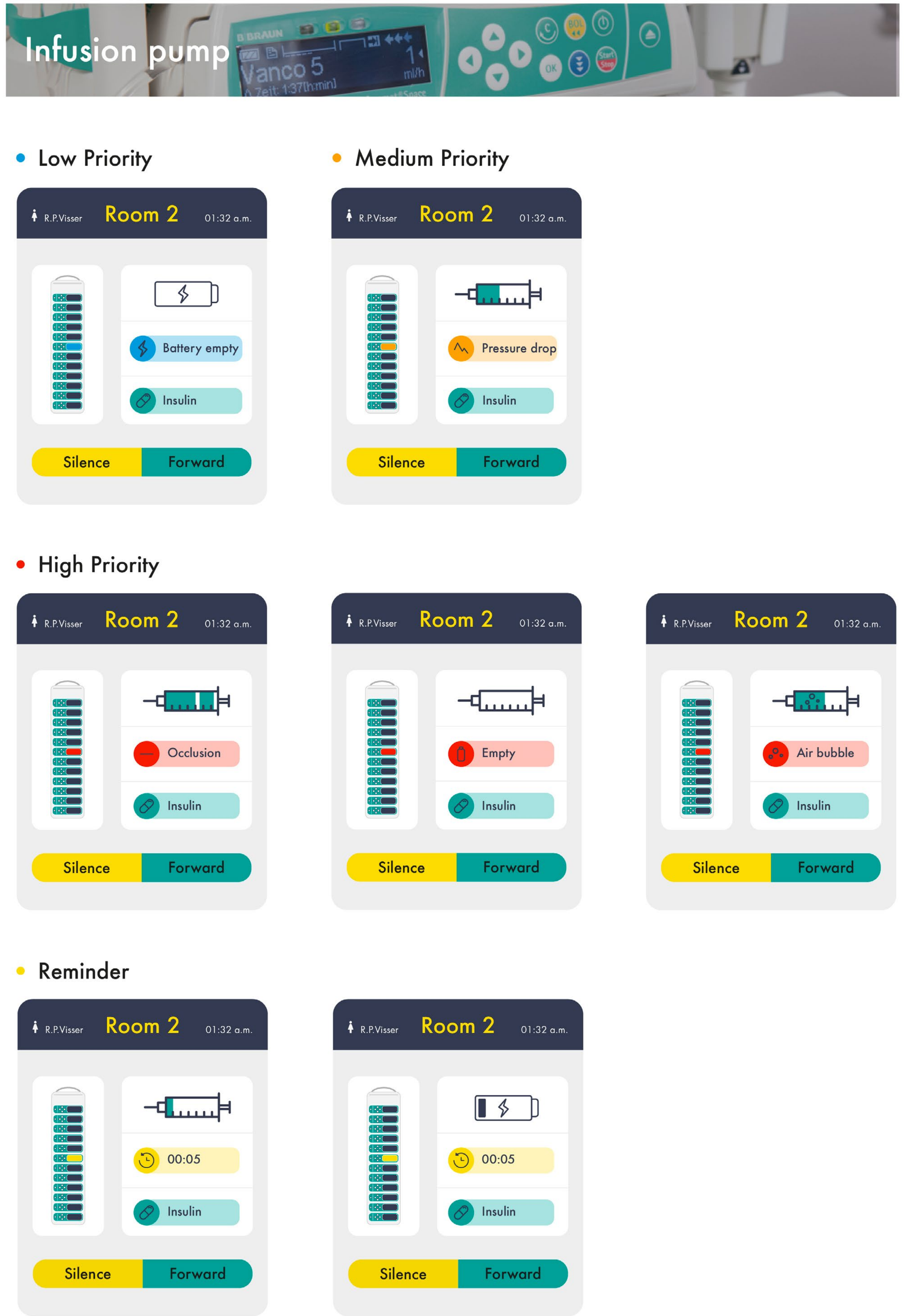


Figure 55. Interfaces of different priority alarms for infusion pumps

8.2.5 Interaction flow

When an alarm goes off, the starting page will show on the patient window first. When the nurse chooses to silence the alarm, the first page will show on the window, indicating the alarm is successfully silenced. When the nurse chooses to forward the alarm, the six interfaces on the right will show on the patient window to give nurses real-time feedback of the nurse that replied to the alarm. According to **Design Guideline 5**, giving appropriate feedback helps give nurses a sense of security by informing them if they complete the task successfully or not, especially critical alarms. By informing what is happening now at the invisible place which is the other patient room in this case, it helps raise the awareness of nurses.

Animation elements

Animations are added at each page for the most important information to help attract the user's attention. There are two types of animation used in the interface. Popping and gradient animation are used to indicate longer processing action such as 'Forwarding'. Blinking animation is used to quickly indicate the result such as the nurse's arrival or the alarm is silenced.

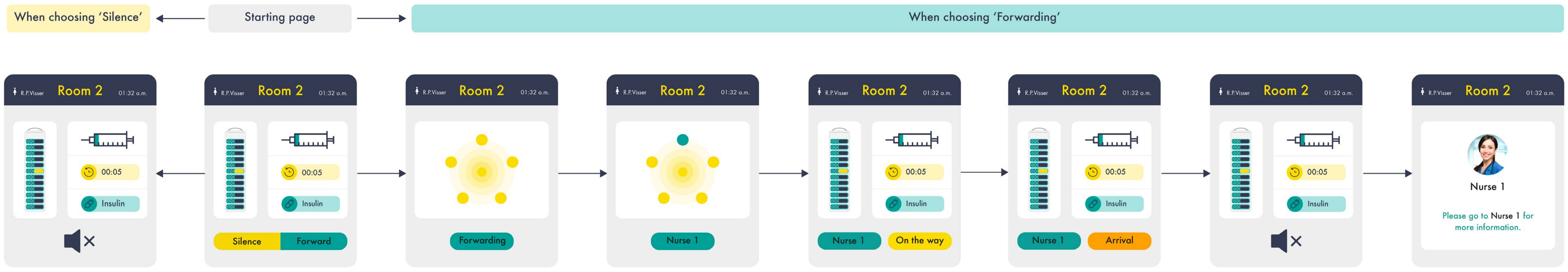


Figure 56. Interaction flow for infusion pumps

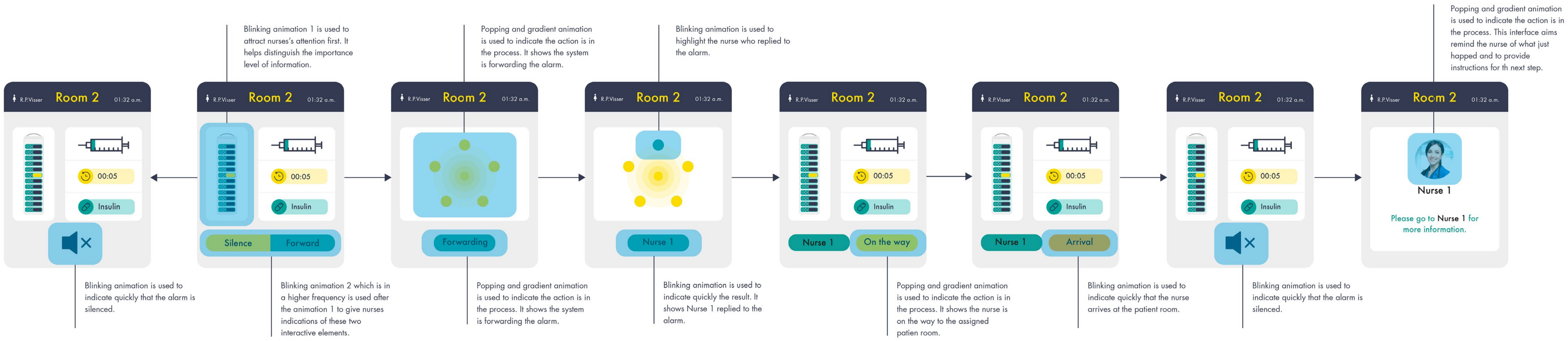


Figure 57. Animation explanation for the interaction flow

8.3 Interface test

In this section, a user test has been conducted to gather feedback on the design presented previously. Firstly, an overview of the testing process will be presented and then based on the results, the interface design went through an iteration and the final interface design was presented, followed by an explanation to the whole system.

8.3.1 Background

The design described previously was first presented to the supervisory team before this test. The design was discussed with the supervisory team and the supervisory team provided advice from experienced designers' perspectives. There are too much blinking animations in the interfaces which are unnecessary. Blinking animations intended to attract nurses' attention, however, apart from the starting page, there is no need to attract nurses' attention later. Thus, the modifications as seen in Figure 58 were made before the test.

After the interfaces were developed, a test was planned to gather feedback on the interface design. Due to the effect of pandemic, the nurses were busy with the increasing COVID cases, the test was turned into a remote test rather than a face-to-face interview. Thus, all the content was made and presented in the form of videos for the user test. The goal of this test is to gather feedback on the interface design, focusing on finding out if the interface can meet the related design requirements stated in the LoR.

Research quesions

The research questions are formulated as follows:

Do the interfaces meet LoR and how can they be improved?

To answer the main research question, the following sub-questions were formulated:

- If the source of the alarm can be recognized(infusion pump, patient monitor or ventilator)
- If the interfaces are easy to understand.
- If the nurses can quickly find the specific information that they needed to know.
- If the interfaces contain enough information that you need to know when responding to alarms.
- How can the interfaces be improved?

8.3.2 Method

As the interfaces include animations and had to be presented to the nurses online, the interfaces were made into videos. Three simulation videos were prepared, including the whole interaction flow for infusion pump alarms, patient monitor alarms and ventilator alarms. Compared with interviews, questionnaires are more efficient and can provide a more quantitative result. Not intending to occupy too much time from ICU nurses during this period, a questionnaire is better for a quick check.To answer the research questions, the questionnaire includes four single choice questions. Apart from checking if the interfaces meet the design requirements, it is also important to know how to improve. Thus, three open questions were included to ask the nurses about the missing information if applicable or if there is anything that can be added. The questionnaire can be seen in Appendix E.

Procedure

The nurses are asked to watch an introduction video first which gives an introduction to the project and the concept. In the end, the goal of this test is explained. Then, nurses are asked to watch three videos, Simulation 1, 2 and 3. After each simulation video, nurses are asked to fill in the related questions in the questionnaire. Each test took 10-15 minutes.

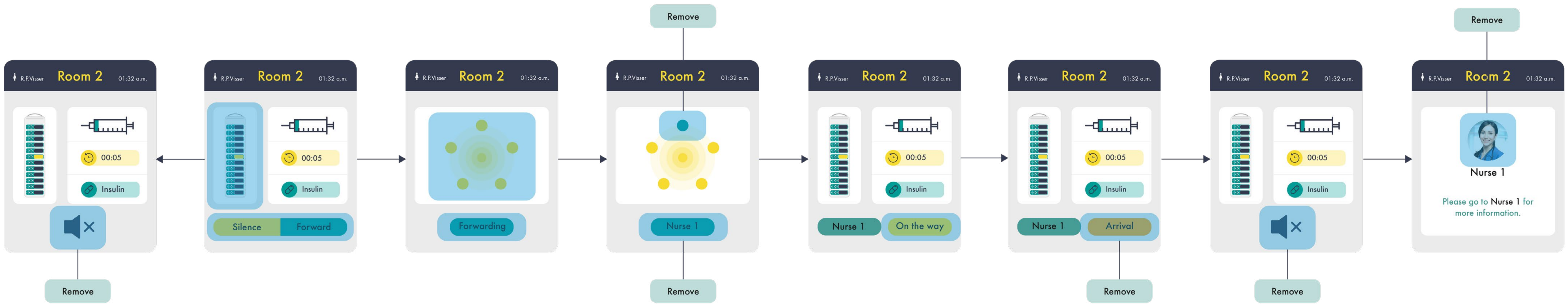


Figure 58. Animation changes for the interaction flow

8.3.3 Result

In total, 11 responses were received. The result regarding each equipment will be explained below respectively from quantitative and qualitative perspectives.

Quantitative result

In this section, the answers from the single questions will be presented. (Figure 59) With these answers, the researcher can get an overall view of how nurses perceive the interfaces.

Infusion pump

For infusion pumps, all 11 respondents can recognize the interface indicates an alarm from the infusion pump. They agree that the interfaces are easy to understand. Only one respondent cannot quickly find the specific information he/she needed. Two respondents think there is information missing.

Patient monitor

For patient monitors, there are 2 respondents who failed to recognize the source of the alarm. All respondents agree that the interfaces are easy to understand. 9 out of 11 can quickly find the specific information they need to know. 5 respondents think there is some information missing.

Ventilator

For ventilators, there is one respondent who failed to recognize the source of the alarm. All respondents agree that the interfaces are easy to understand. 10 out of 11 can quickly find the specific information they need to know. Three respondents think there is some information missing.

Figure 59. Quantitative result from the questionnaire

Qualitative result
In this section, the answers from the open questions will be presented. With these answers, the researcher can get a better understanding of what information is missing. Meanwhile, these answers also revealed the nurses' needs for the information when responding to alarms. The result will be presented separately for each equipment.

Infusion pump

1 Other parameters
For infusion pumps, two respondents mentioned that they need other parameters from other equipment, for example, BP and HR from patient monitors are needed when dealing with norepinephrine alarms.

"For example, norepinephrine, you would want to know the speed and or dosage and BP\HR in order to know if you want to solve the problem yourself or if you let a colleague handle it."

"There could be another reason why the pump alarms, for example, high pressure. Is this also presented on the screen?"

2 Communication with the helping nurse
The respondent mentioned it is necessary for them to communicate with the helping nurses and give instructions.

"It would be handy I think to have such a device but I think it is only complete if you can directly communicate with the helping nurse. So then you can give instructions for example change the dosage if necessary, because that might be a thing you want to do and is something you forget if someone else has handled the empty syringe for you."

3 Other comments
Apart from the missing information, two respondents gave advice regarding the details in the interfaces. One mentioned that the last page which reminds the nurse of the helping nurse is unnecessary to know. The other respondent suggested that the empty pump alarm should be reminded earlier.

"Which nurse is attending to the alarm is not important to know for me."

"I know it's an example but alarming just 5 min before the pump is empty is 'too late'."

Patient monitor

When asked about patient monitor interfaces, almost half of the respondents think there is information missing. The detailed description from the open questions were taken a deep look to know what information is missing. To conclude, there are mainly three different types of missing information.

1 Set limits
Two respondents suggested that the set limits could be added as they are important for them to make comparisons with the current values. As the pre-set limits vary from patient to patient based on their own conditions, nurses might not always remember the limits. Thus, instead of requiring nurses to remember the limits, it will be easier for them to present the set limits together with the current values.

"Is there a possibility to see what the set limits are?"

2 Other parameters
Beside the set limits of one specific parameter, four respondents mentioned that they also need other parameters, for example, respiratory rate, SpO2, ECG curve, etc.

"Only high is not enough information, you also need to know what kind of rhythm it is.

"Heartbeat combined with other parameters"

"To know if the alarm is correct, you need: HF, RR, SAT, ECG curve, etc."

"If info from the monitor or the monitor itself could be displayed, that would be more helpful."

"I would want to know the BP and maybe see the ecg so I can see if it's an artefact or not. If it's an artefact it could be the patient is restless or delirious. A camera would come in handy by that time. Or the patient is in pain or is bleeding. More info via BP is necessary to see if I can silence the alarm for a while or to get help from someone else."

3 Video connection
Apart from the interfaces, the respondents highlighted the importance of the clinical look at the patients. The patient's movement is important for them to make the judgments if the alarm is artefact. Several respondents suggested introducing the video connection into the system. This can be taken into consideration in further development.

"I don't see the movements of the patient. When the heartbeat on the monitor is "moving", the patient is moving. Only the figure 128 is not enough."

"Clinical look: a video link to monitor, pump and patient. If you don't have this information, you can never say for sure what is going on.(maybe the patient is moving or the patient is shivering, rhythm changes?)"

"You really have to be able to take a clinical look at your patient, this is best when you sit in the Niche and you can see your patient, monitor, ventilation, pumps at a glance."

Ventilator

1 Other parameters
Same as the patient monitors, four respondents mentioned that more parameters need to be included in the interfaces of ventilators.

"Just tidal volume is no sufficient parameter."

"more parameters"

"For the breath minute volume, is the patient awake? Moving?"

"You would want to know the Minute Volume and the question is when is this

alarm being forwarded by this system. If the patient has one VT under the lower limit it is not a problem, but when it is ongoing then there is something that matters."

2 Communication with the helping nurse

One respondent had concerns that the helping nurse might handle the patient in a different way as he/she will. and proposed a solution to have a short conversation. This concern is not especially for ventilators but a common concern for all equipment. This needs also to be implemented and can be researched later.

> *"My concern is that I forward alarms to my colleagues and then they take actions that I would not have taken because I have more info than they have because it's my patient. For a colleague to handle my patient, I would want to give instructions beforehand. For example my ventilated patient is waking up. If my colleague does not know that, he would interpret that maybe differently. A short conversation with me could make the difference."*

> *"Is there a possibility to communicate with the attending nurse? An intercom system which turns on if a helping nurse is in the room. So info about the alarm and the patient can be quickly exchanged."*

3 Video connection

Two respondents mentioned that the clinical look is needed and a video of the patient can help as nurses have to check the movement of the patient and if they are coughing.

> *"you need your clinical view, video connection."*

> *"All ventilation curves required, observation of the chest with video of the patient and noise from the room: (is the patient coughing? / is there mucus in the breathing tubes?)"*

8.3.4 Conclusion

Answer to research questions:
All repspondents can recognize the source of the alarm from the infusion pump interfaces. One cannot recognize the ventilator alarm, and two for the patient monitor. In general, the majority of the respondents have no troubles recognizing the right equipment from the interfaces.

All respondents think the interfaces are easy to understand.

The majority of the respondents can quickly find the needed information.

Patient monitor interface has the biggest problem as almost half respondents think there is information missing.

Set limits

Other parameters
(from the same equipment or from other equipment)

Communication with the helping nurse

Video connection

Overall, the results are very insightful. From the quantitative analysis, a general idea of the design' s feasibility was collected. Nurses are most satisfied with the interfaces designed for infusion pumps. There are more doubts about the interface designed for patient monitors, mainly because of different kinds of missing information. This result attracts the research's attention to interfaces for these two equipment and more improvement should be made for them. Looking at the qualitative analysis, it is found that there are four different levels of needs regarding the alarm information.

Moreover, it can be seen there are also different needs regarding different equipment. For example, the need of communicating with the helping nurses is mentioned for all three equipment while video connection is only mentioned for patient monitors and ventilators, not for infusion pumps.

Furthermore, by encouraging nurses to think about this project, the answers also reveal some current issues in the ICU workflows. For example, there are nurses asking what if all nurses are busy and no one is responding. This is not a question especially for this design but also an existing problem in current ICUs.

To conclude, the interface design is on the right track, but still some improvements can be made based on the four different kinds of needs.

8.3.5 Discussion

As the planned interview had to be conducted in the form of questionnaires, it is more difficult to get qualitative results since some of participants did not answer the open questions. And it is not possible to ask more detailed questions regarding their answers.

The nurses have more doubts regarding patient monitors. One possible reason could be among all equipment, patient monitors are the most well-developed one. The current patient monitors can fulfill most needs and nurses are familiar with them. These provide examples that the nurse can compare with when looking at the proposed interfaces. However, for the infusion pumps, there are no such interfaces on the equipment now. This might have influences on the nurses' expectations of infusion pump interfaces. Although there are many comments collected about the missing information, there are still over half of the nurses holding the idea that the provided information is enough. The reason for this difference between nurses was not found out in this research. Each nurse has their own ways of monitoring their patients and it might be affected by their working experience. In this test, the profiles of the nurses were not included, thus it is not possible to analyze more in detail if the working experience has any effect on the information they need.

8.4 Final design

Based on the result from User test 2, the interface design was improved and presented as follows. Due to the time limit in this project, only the first one and part of the second need were met among all four needs defined from the User test 2. The other needs will be stated in the recommendations for further development.

8.4.1 Interfaces

In this section, the final interfaces(Figure 60, 61, 62) are presented and the improvements are explained. Not much was changed about the infusion pumps except the reminding time starts from 10 minutes instead of the previous 5 minutes. For patient monitors, the set limits were added, thus nurses can have a quick check of the pre-set limits and current values. Also, other parameters are added. In total, there are 5 vitals presented, including HR, RR, SpO2, NBP, and Temperature. For ventilators, more parameters were added as well, including MinVol, VTE, Ppeak, Oxygen. Also, the HR is also added based on the nurse's needs.

8.4.2 System

This project is not only designing an interactive display for alarm information presentation, but a whole system. As to make it possible to present the alarm information and enable the interaction functions, the concept is supported by many equipment and services. A detailed system blueprint is shown in Figure 63. It explained how the system works from both the frontstage and the backstage. And the supporting services are also listed.

Among all supporting services, apart from those that were mentioned before like the manufacturers, equipment, sensors and software, there is also another important supporting services, which is Ultimo.

Ultimo, developed by a group of earlier students at the CAL was included in the whole system. The Ultimo system can sense if the nurse is inside the patient room by tracking the nurses' labels on their clothes. Thus, the system can be activated only when the nurse is inside the patient room. Also, when the helping nurses walks into the room, the system knows that the helping nurse arrives and gives feedback to the nurse who 'forward' the alarm.

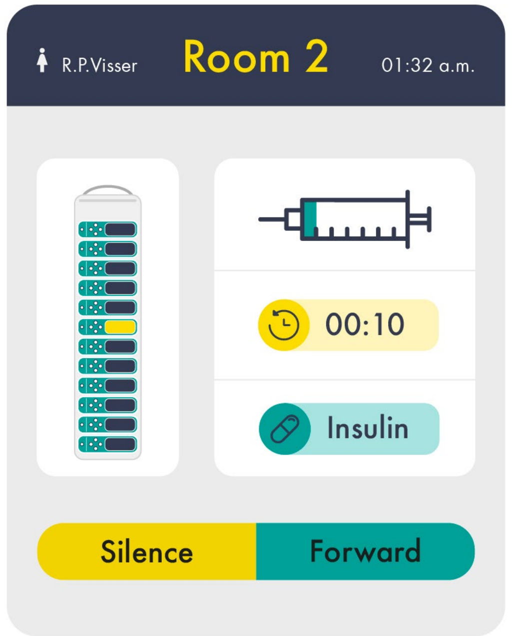


Figure 60. Final interface of infusion pumps

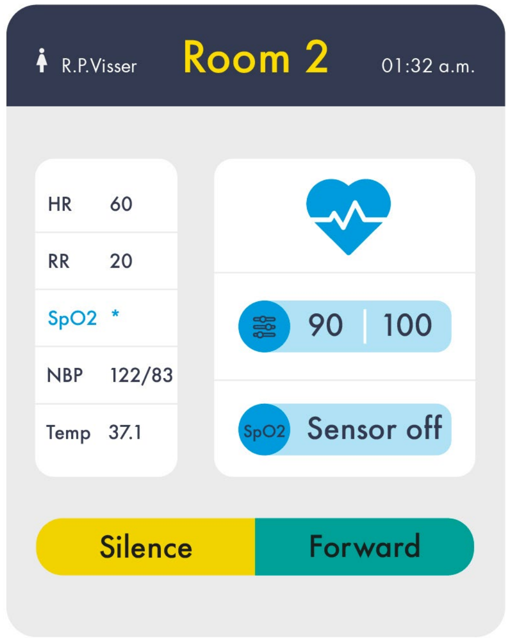


Figure 61. Final interface of patient monitors

Figure 62. Final interface of ventilators

System service blueprint

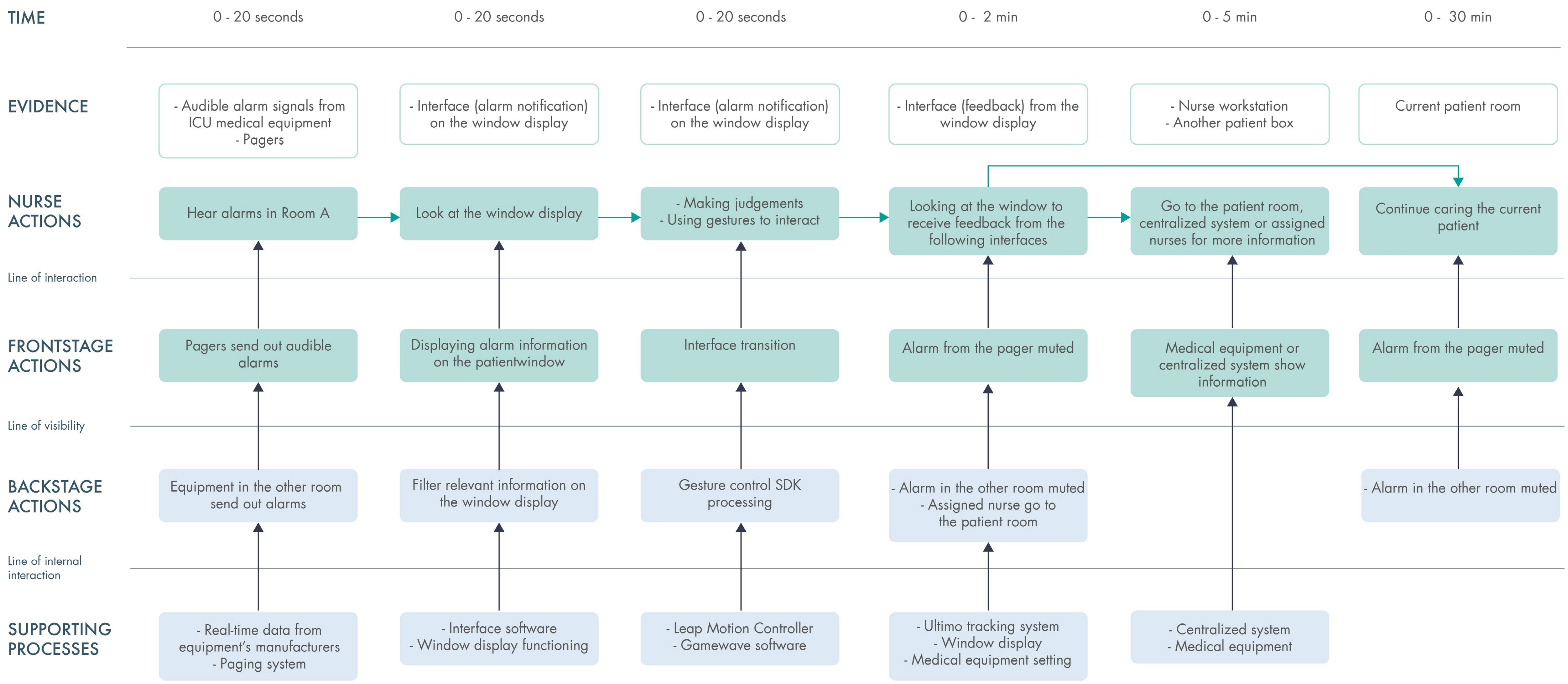


Figure 63. System service blueprint

8.4.3 Scenarios

In this section, the scenarios of the design implemented in the context are presented in visuals. There are two scenarios demonstrating respectively when choosing to 'silence' and 'forward' alarms.

Scenario 1 - 'Silence'

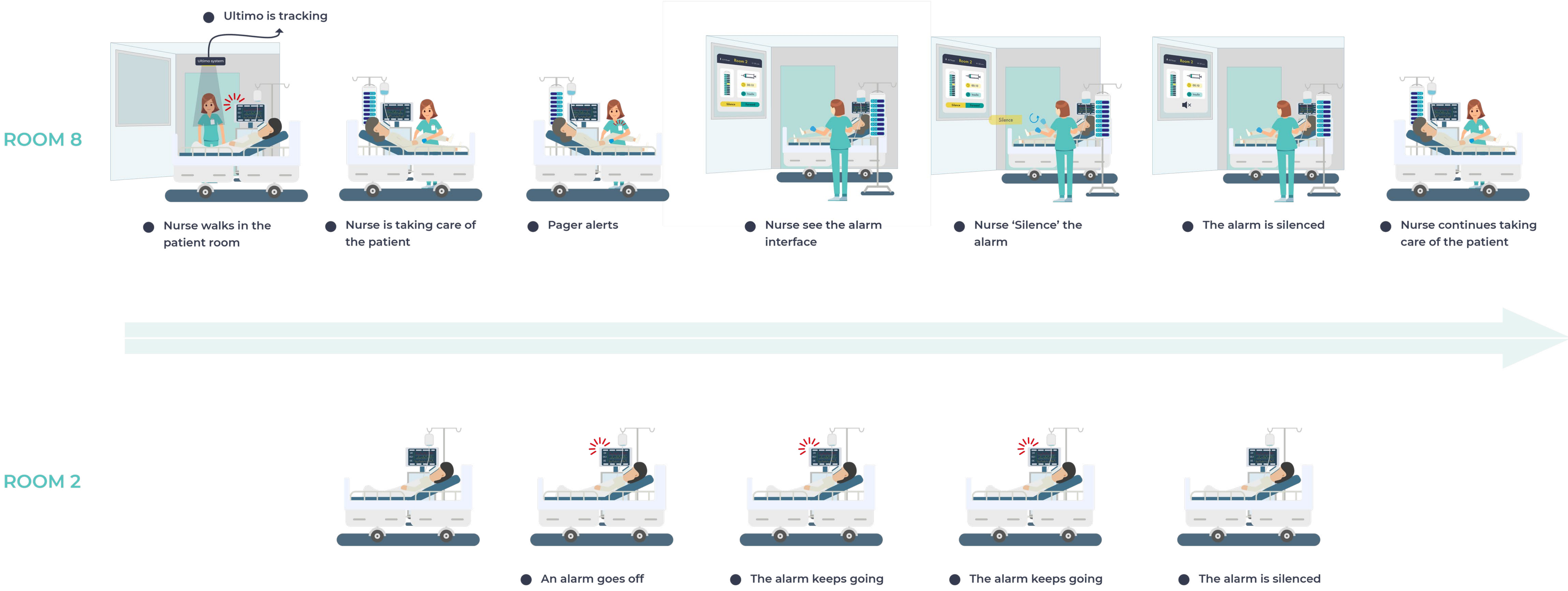


Figure 64. Scenario 1

Scenario 2 - 'Forward'

① The helping nurse can go to the patient room to check direclty.

② The helping nurse can go to the nearest workstation to check the central patient monitor and have a clinical look through the window. Then, if necessary, she can go inside the room to check the patient.

③ When the helping nurse is sitting in front of the workstation, she can directly check the central patient monitor and have a clinical look through the window. Then, if necessary, she can go inside the room to check the patient.

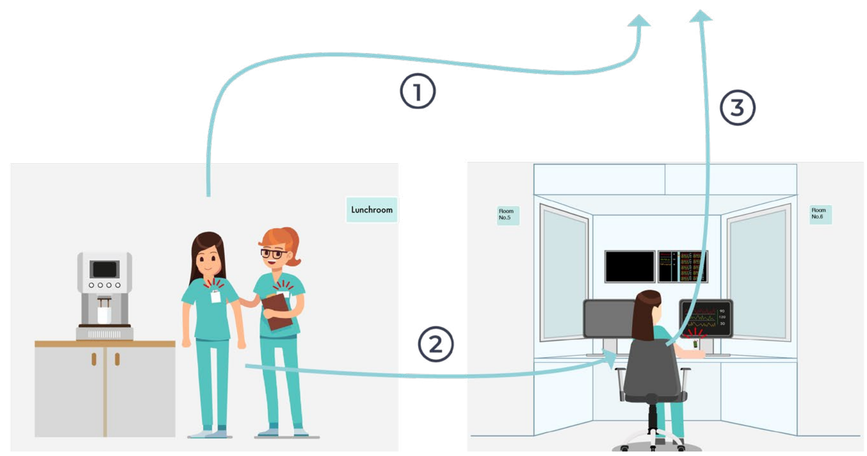


Figure 65. Scenario 2

8.5 Integration

In this section, the final interface design in integrated with the gesture control sensor, and the transparent display.

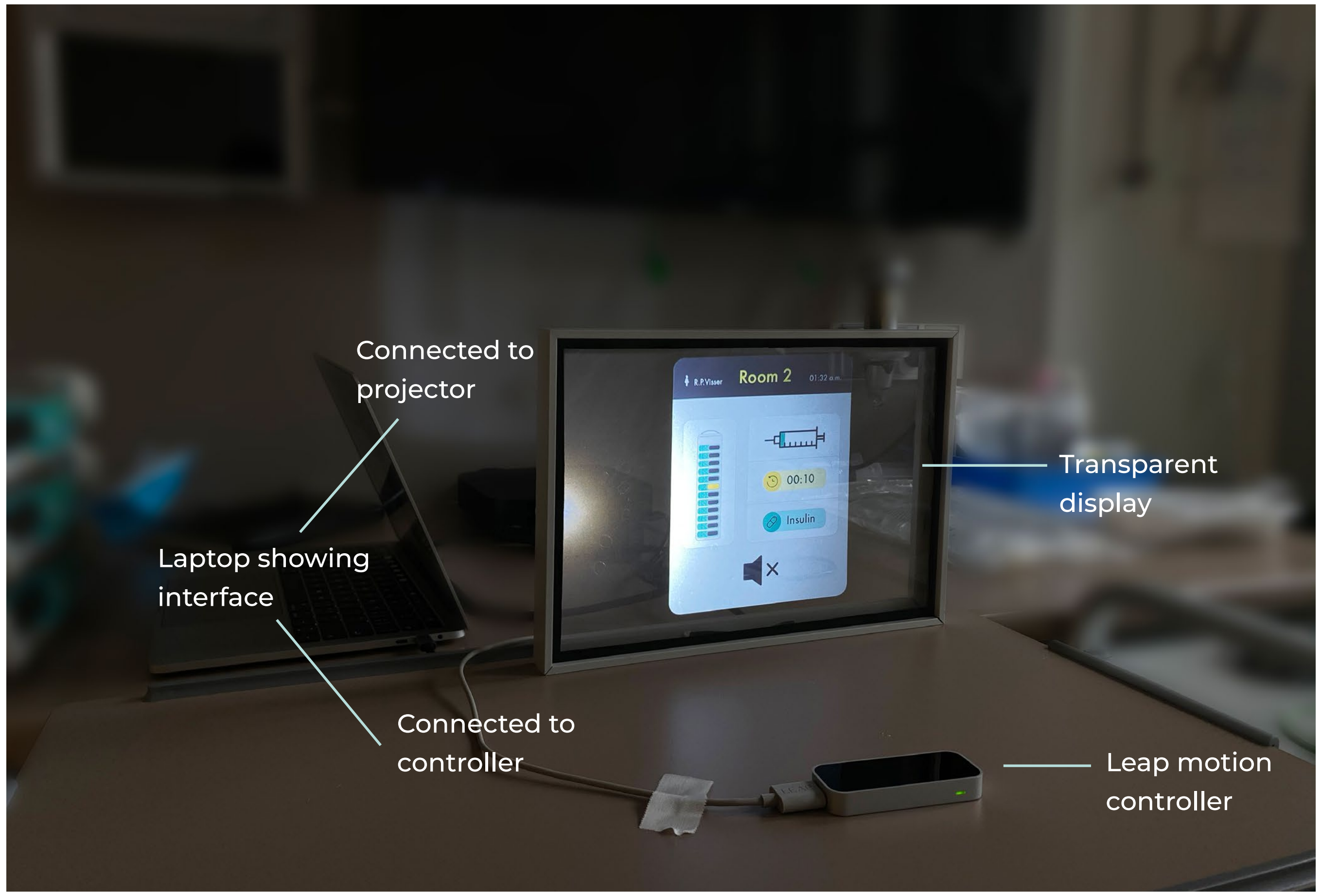


Figure 66. Integrated prototype

9 | Design Evaluation

In this chapter, the integrated prototype is evaluated by an ICU technician expert and four ICU nurses in the EMC. First, the chapter starts with an overview of the interview process. Then, a summary of the nurses' experience and thoughts of the design is presented. To conclude, this chapter provides recommendations based on the points of view from all interviewees.

DESIGN EVALUATION

9.1 Background

After testing with the technology part and interface part separately, the design has already gone through two iterations. After two separate iterations, the interface, projection, gesture control are combined into an integrated prototype. However, how the end users, ICU nurses experience the design is still unknown. Therefore, ICU nurses from EMC were invited to share their experiences and thoughts on the overall view of the final concept. This evaluation aims to give insights into how users experience the design. The conclusions are essential for giving insights of the current design and also giving recommendations to improve the design later.

Research questions

The main research question during this usability test is formulated as follows:

What are the ICU nurses' thoughts on the final design in terms of usability?

To answer this question, a few sub-questions were formulated as follows:

- How many attempts do they need to execute the tasks?
- Can the nurses execute the tasks within 30 seconds?
- How do the participants experience the design based on AttrakDiff attributes?

9.2 Method

The design and prototype were presented to the technician and nurses in ICU at EMC. The AttrakDiff questionnaires, as one of the most recognized UX evaluation questionnaires, were used to evaluate the final design. During the test, the technician and nurses are encouraged to 'think out loud'. By sharing their thoughts freely throughout the whole test, very insightful results were collected. Moreover, a short interview was conducted with each participant to discuss their thoughts and concerns of implementing the design in ICUs in the future. Furthermore, while the nurses were interacting with the prototype, observation is also a useful tool. Among all the sub-questions, the first two sub-questions can be answered from the observation results.

Partcipant	Gender	Role	Working experience	Night shift
1	Male	ICU technician	Worked as nurses for more than 8 years	No
2	Male	ICU staff nurse	Worked as nurses for 15 years	No
3	Female	ICU staff nurse	Worked as nurses for 40 years	No
4	Male	ICU nurse	Worked as nurses for 3 years	Yes
5	Female	ICU nurse	Worked as nurses for 8 years	Yes

Figure 67. Profile of participants

9.2.1 Participant

In total, five ICU staff are invited in the evaluation test, including one technician, two nurses and two staff nurses. Inviting ICU staff working at different positions, makes it possible to gather feedback from different perspectives. Nurses can provide feedback based on their nursing experience. Apart from nurses, the technician who has nursing experience as well can provide feedback not only from a nursing perspective, but also from an engineer who is experienced at the implementation. The profile information about all participants is described in Figure 67. The 2 ICU nurses work during night shift. Both staff nurses have more than 15 years of nursing experience but are not working during the night shift now.

9.2.2 AttrakDiff questionnaire

Based on the context of this project, the following three attributes were chosen for nurses to evaluate:

Complicated - Simple
Ugly - Attractive
Impractical - Practical

9.2.3 Procedure

The evaluation interview took place in an empty patient room on the 6th floor ICU at EMC. The nurses are invited to the test room one by one. Each test took about 10-15 min, depending on the available time of the nurses. Among all nurses, 3 nurses filled in the earlier questionnaire so they already know about this project. However, there are 2 nurses who were totally new with this project. Thus, the test starts with an introduction video (2min). In the video, the design was explained from the found problem, design goal and concept. For those who already know about the project, a brief introduction was given together with the video, to recall their memory of the project. For the other two nurses, the video was played at a slower speed together with the explanation at the same time. Thus, the design was explained more in detail and more clearly. After the introduction, the prototype was presented to the nurses. Due to the nurses' tight schedule, there is no training time for the gesture control. Instead, a demonstration was shown to the nurses. After the researcher's demonstration, the nurses were asked to try out the prototype themselves. Afterwards, the nurses were asked to scale the experience from three attributes.

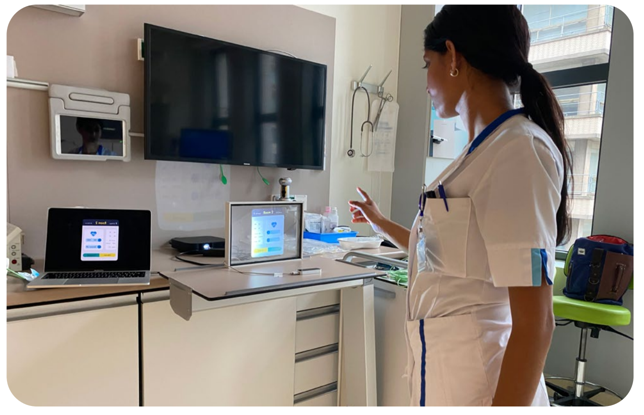


Figure 68. Participant trying the prototype

9.3 Result

9.3.1 Observation

According to the observation during the test, even though without the training period, all participants in the test were able to execute the task within 30 seconds with less than 5 attempts.

9.3.2 Quantitative analysis

The first participant joined the interview but didn't take part in the scaling part. For the quantitative analysis, the scores from four nurses were visualized in Figure 69. The average score is also highlighted in yellow. It can be seen from the figure, in general the nurses perceive the design more to be simple, attractive and practical. The average scores for the three attributes are the same.

9.3.3 Qualitative analysis

As the method 'think loud' was used in the evaluation test, the participants are able to speak out their thoughts throughout the test. Thus, a lot of information was collected for the qualitative analysis. The insights are presented as follows.

Alarm silencing

"For how long is the alarm silenced?"
A nurse had doubts about this and the question was discussed during the evaluation test. For silencing alarms, there is always a timer. After you silenced it, every 2 minutes, the alarms go off again. The only solution to silence the alarm is to fix the problem. Otherwise, the alarm should always reactivate every 2 minutes.

"Silencing alarms forever is illegal."

Red alarm

For red alarms, you should not be able to forward but you can silence them. Silencing red alarms for 2 minutes is fine. It can be an artifact. You can silence it if it is an artifact. When nurses are outside the patient room and the red alarms go off, the nurses will check the central patient monitor and look through the patient window. They will not act if they think nothing is wrong.

"70% of red alarms are artifacts."

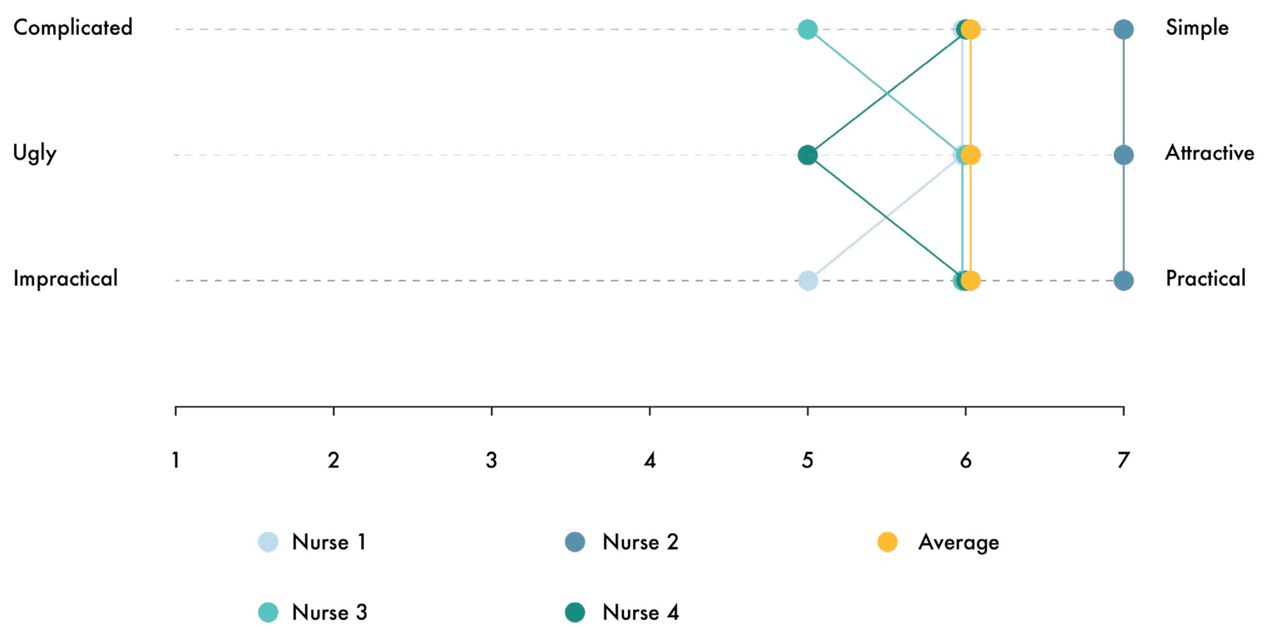


Figure 69. Result of AttrakDiff

Gestures

One nurse had concerns that the chosen gestures of the circle left and circle right look alike. In this case, using similar gestures might confuse nurses. After a few minutes, the nurse might forget which gesture they used. If the gestures are totally different, it will be easier to remember.

"They are too similiar."

Implementation of sensor

The sensor cannot be placed on the bed because when nurses transmit patients, they also move the beds. It is possible for them to forget there is something connected to the bed. Then the sensor or the wire might be broken. Looking around the current ICU patient room, the most possible solution is to place the sensor from the ceiling or on the wall.

"In general, everything you put on the bed that needs power can break."

The connection between pagers and nurses

One concern mentioned by the nurse is how the system knows which nurse is taking care of the specific patient. This reveals one keypoint that pagers are connected to each room instead of each nurse. Every room has a pager. So one nurse might have a few pagers when they are taking care of several patients.

"How do you know it's my patient?"

Alarms at the same time

Another question asked by the nurses is what if two or more alarms go off at the same time. This concern is not especially for the presented concept. It also exists in the current context with the pager system. Now the nurses have a few pagers with them but when several alarms go off at the same time, they also have to check the pagers one by one. In the proposed concept, the alarm information is presented and handled individually.

"This does not happen a lot, but what if a few alarms go off at the same time?"

9.4 Conclusion

To conclude, after the design is presented to nurses and the nurses tried the prototype, the nurses liked the idea in general. However, the nurses also mentioned a few detailed points in the whole system that haven't been considered in this project yet. These points will also be stated in the recommendations.

9.5 Discussion

Based on the discussion regarding the implementation of the sensor, the most possible solution is to place the sensor from the ceiling or on the wall instead of the bed. In this case, to implement in a larger area, sensors that have a larger sensing area should be considered.

Moreover, an assumption was made that each nurse has a pager and the pager knows which patient the nurse is taking care of. However, from the interviews, it turnt out that the pager is related to each room but not to each nurse. This is a new point in this project which hasn't been considered yet.

As the later two nurses were busy with their work, they did not have enough time to go through all three interfaces on by one. So the discussion is more in general other than detailed into the interfaces. While it is not possible to directly project interfaces on the patient window, it might have an influence on the nurses' perception of the design.

9.6 Last modifications

The insights collected from the final evaluation with nurses reveals the possible direction for the further development. Recommendations will be described in detail in the next chapter. Before that, some quick modifications are made and presented in this section.

Based on the discussion on the red alarms, the relevant interface is modified. (Figure 70) To keep consistent with other interfaces, the option is kept but recolored. With making the 'forward' option grey, it helps indicate the option is not available in the system.

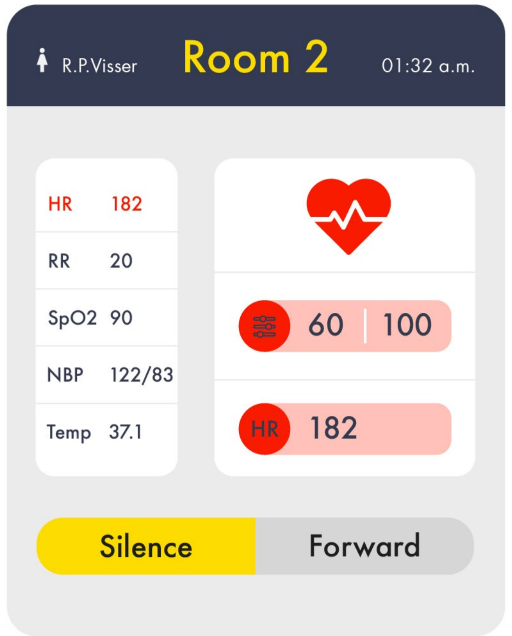


Figure 70. Interface for red alarms

9.7 Recommendations

In this section, based on the insights from the design evaluation, recommendations are given for further developing possibilities. The recommendations are stated in four categories. The first three parts correspond to the three main parts in this project, transparent display, gesture control and interface. In the end, recommendations for the whole system are also included.

9.7.1 Transparent display

There are doubts about implementing projectors in the ICUs. There are mainly two reasons, firstly, the projector also causes noise. Secondly, it is not user friendly when the nurse is facing towards the project as the light from the project shines toward the eyes. This project focuses on the patient window. However, there are also other possibilities to implement the system. For example, a closer step could be firstly implementing the interface system on the TV in ICUs.

9.7.2 Gesture control

Regarding the nurse's doubt that chosen gestures are alike which might be confusing, different pairs of gestures could be investigated in the future. For example, hold the full palm for 'silence', swiping for 'forward'.

In this project, the scenario is narrowed down to the nursing standing beside the bed. In the future, a bigger scenario could be researched which is anywhere inside the patient room. In this case, nurses can be supported anywhere inside the room. Then, the design is not only focusing on a small area near the bedside but in a much bigger area. Thus, other technology possibilities might be found.

9.7.3 Interface

Based on the nurse's response from the questionnaire, ECG curve is also an important when judging if the alarms are artefacts. However, the researcher had concerns of adding too much information might increase the time nurse spend on the interface. Then, the interface will not be a quick notification any more. Within the time limit of this project, the research cannot be done so it is not implemented. Thus, it is recommended to further investigate on this topic.

9.7.4 The whole system

Based on the discussion on "how the system knows which nurse is taking care of the patient", it is now known that the pager is connected to the room, the patient instead of nurses. Thus, for further development, Ultimo tracking system can be used not only for tracking nurses' labels to know if they walk into the room, it can also be used for tracking pagers. In this way, when nurse walk in the patient room with pagers which are connected with other rooms, the system gets to know the room information based on the pagers.

Regarding the nurse's concern about what if two or more alarms go off at the same time, "Should more gestures be introduced? Or should the interfaces be presented one by one? Based on what order?" These could be interesting questions to research on in the future.

Moreover, there remain two needs from nurses are not fulfilled for monitoring patients remotely. One is the communication when nurse can give their colleagues instructions before they act on their patients. Another is video connection where they can take a clinical look on the patients.

10 | Project Conclusion

This chapter gives a conclusion to this whole project. The research question defined at the beginning of the project will be answered. Then, the value this project can bring to the context is discussed. Moreover, the limitations of the project are described and in the end, a future vision of the design is discussed.

PROJECT CONCLUSION

10.1 Answer to design question

The project aims to find the answer to the research question formed at the beginning of this project, “What possibilities are there to use Augmented Reality to visualize the alarms in ICUs?” Throughout the project, after conducting the context research, user research, technology research, two user tests and the final design evaluation, the answer has been found.

Based on the context research and user research, the project was narrowed down to focus on the night shift and then nurses' need and design opportunities were discovered. It has been found that the biggest support that nurses need regarding alarms is the information from room to room. This lead to the proposed concept that supports nurses with alarm information from other rooms and help them respond using gesture control. Afterwards, through three iterations, the final design was evaluated by 5 ICU staff (including one technician and 4 nurses). With the final design, the nurses are able to get real-time alarm information when they are in another room and remotely deal with the alarm right away.

10.2 Project value

Information transmission between rooms

The biggest value this design can bring to the ICUs is that it enables the transmission of the alarm information between rooms. This information transmission is not a one-way transmission but a bidirectional transmission. It not only presents the nurses with the alarm information they need, but also enables them to handle it remotely. It helps raise the nurses’ awareness of the alarms while they are not on site.

The use of patient window

Moreover, this project explored the possibilities of introducing a new use of the patient window, not only for exploring another futuristic example of Augmented Reality applications but really going into a different direction which haven’t been researched on yet.

This project presents a new possibility of implementing Augmented Reality in ICUs apart from the traditional AR glasses or wearables. Without adding devices onto nurses and other ICU staff, this project makes use of the current patient window. As a larger display, the patient window has advantages over the traditional monitors. It has more potential than what is shown in this project.

Noise reduction

By presenting nurses the alarm information in time and making it possible for them to respond right away, the design might have the potential of reducing the alarm noise in the ICU patient rooms.
In the current context, when the pager sends out alarms and the nurse does not respond right away, the alarms continue and after 30 seconds, it will send out to 5 closest nurses and after 60 seconds, it will automatically send out alarms to all nurses in the unit. This system is designed for safety purposes but meanwhile causes more noise in the ICUs. The design helps nurses respond to non-actionable alarms right away and by silencing them directly within 30 seconds, the chances of other nurses getting the alarms decrease.

10.3 Limitations

Monitoring critical patients is complicated work and each nurse has their own way of doing this. It is hard to formulate a common standard of the needed information for alarm response. Different nurses might interpret the alarms in different ways and might handle them differently. The number of nurses involved in the tests are limited. More nurses are needed for gathering more feedback and discovering their needs better.

For the purpose of patient safety and data privacy, devices need to comply with rules and regulations imposed by national and international regularity agencies. (Ozcan et al., 2018) Due to the limitations of the current protocol and manufacturers, the concept is designed for a future context, where real-time alarm data can be retrieved from the manufacturers. Also, the whole system includes many supporting subsystems, including Ultimo tracking system, datastream from all medical equipment, the paging system, etc. And it is not possible to make it fully functioned within the time of this project. As it can not be tested fully-functioned and completely in the context, if it can help reduce the alarm noise remains unknown. Also, to what extent the sensor can work in the real context cannot be tested and is unknown.

This project has achieved the initial stage in this research direction and is a good start to use Augmented Reality to support the ICU workflows. But there remains still a lot of space for further improvement.

10.4 Future vision

Near the end of the project, in August 2020, Chinese company Xiaomi launched the world's first mass-produced transparent TV with a price of around 6100 Euros. Even though the price is still high for TVs and displays, compared with the price of 17332 Euros from LG's transparent TV in 2017, it is much cheaper. It can be seen that the transparent display is still being explored by companies and manufacturers these years. From only for exhibitions a few years ago to mass production these days, transparent displays are still a trend and the price is declining. It is not groundless to imagine that transparent displays will be much cheaper and more common in our daily life in the future. Replacing the patient window with transparent displays in the ICUs, the projector can be avoided.

Figure 71. Xiaomi 55 inch Transparent TV

REFLECTION

Looking back on this half year, I met difficulties, changed plans, went back and forth but I believe I have learnt a lot and enjoyed the journey.

Being affected by the pandemic, I lacked much context information from the beginning as it was not possible to visit the hospital and communicate with nurses. In the first two months, I struggled a lot finding a clear direction and it took longer to find a direction to go on. Thus, the project didn't go as planned. I felt upset at the beginning, but with the support from my supervisory team, I started to gradually enjoy being flexible with my plans and enjoy this special experience.

Being the first time in a medisign project, I started with totally no idea of ICUs. The most difficult part in the project for me is the interface part. To be specific, it is about what alarm information should be included in the interfaces. As I have no medical background and have little knowledge about the medical equipment, the most difficult part for me is to get to know about those medical equipment, which vitals are monitored, and which alarms are there, detailed into alarms like high airway pressure or low tidal volume. Not knowing the information the alarms indicate, I was struggling to find a way to design the interfaces. Without being able to spend time in ICUs to see the equipment myself, the way I used is to watch videos from YouTube which introduce those equipment and explain about the related alarms. But sometimes, I went too far into the detailed settings and parameters of the equipment and got myself confused and lost. To simply display the screen of a patient monitor is also a solution. And it is what nurses already adapted to and familiar with. But I was struggling to balance between giving a short and quick notification and at the same time containing enough information. This really requires talking deeply with nurses who have medical expertise. It would be better if a co-creation session could be organized.

Moreover, I started the project with many assumptions and also carried some through the project. Many ideas and knowledge regarding ICU workflows were based on assumptions. But through the project, with all interviews with nurses, expert interviews, I gradually gained more knowledge about ICU workflows and more and more assumptions were answered.

This project prompted me to think about the role of design in a more specialized context, the medical context. Design process is never linear. And sometimes, the solution is not obvious and straightforward. In this project, due to the medical context, the design is very related to the current protocol and regulations. We envisioned reducing non-actionable alarms to help achieve silent patient rooms. However, reducing non-actionable alarms is not easy due to all the limitations of the current protocols and alarm management. This made me start to think how design can fit and help under all these limitations. Even though we cannot change the protocol, the alarm management and just silence the alarms from the root, can design still play a role to help improve the experience? I think I found the answer. In this project, instead of silencing the alarms directly from the equipment, the solution is to reduce the noise caused by alarms through enabling nurses to respond to the alarms and shortening the time of alarms going. It is not an obvious answer but an interesting direction to go, from my perspective.

Looking back to the whole project, there still remain things that can be improved, not only from the project management but also project approach. I was too narrowed down at the beginning and eager to confirm the initial idea while I ignored chances to explore other possibilities. Otherwise, the design might end up totally different. For those who are interested in this topic, more possibilities can be explored. Also, there are also some interesting research points that cannot fit in the time scope. For example, what about if the chosen gestures are not a pair but two totally different gestures? This could be a very interesting point to research.

Working on an ICU topic during this pandemic is not easy but I believe it will be an unforgettable experience. I really appreciate the opportunity to work on this project and I hope the outcome of this project can be helpful for those who have interest to develop further.

ACKNOWLEDGEMENTS

In this section, I would like to express my gratitude to everyone that I will mention below for contributing in this project and supporting me through this graduation project. This pandemic not only affects the way we work but also puts invisible stress on every of us. It's a difficult time for everyone. Thank you for being so supportive and enthusiastic even during this special time. Without any of you, I couldn't have reached the progress so far and enjoyed this project during these half years.

To my graduation committee
First of all, I would like to express my gratitude to the chair of my project, Elif. Thank you for your effort and enthusiasm during this project . While I was struggling with the project at the beginning, your idea of having weekly meetings was helpful to connect and share the progress every week. Apart from the weekly meetings, you also helped a lot contacting experts. Secondly, I would like to thank my amazing mentor Meng, who gave me extraordinary support throughout the project. You are always willing to help and give advice when I'm stuck or lost in the project. Apart from the project related topic, we also talked about life And both of you give quick responses to emails when I need help. It was very helpful and efficient. To both of you, thank you for the trust, the enthusiasm, and the effort you gave to this project.

To Teus, and all other experts
Firstly, I would like to express my greatest thanks to Teus van Dam, from EMC. Without your effort, this project wouldn't achieve the current progress. Thank you for arranging all the meetings with nurses, sending out the questionnaires. Also, you always responded quickly to my emails and never hesitate to share your opinions during our conversations. Thank you for your help and effort throughout the whole project. Moreover, I would like to thank Ryan Forde, Leo Groenendaal, Nico Kalden and Andreas Walden for sharing your opinions and giving advice from your expertise in the expert interviews.

To all participants in the user tests
First of all, I would like to thank all nurses from EMC who participated in the tests, including 10 nurses who helped with the questionnaires. Even though it was not possible to have interviews face to face and the test had to be in the form of questionnaires, you provided very insightful information and helped the project to improve. Thank you for sharing with me your opinions and helping me improve the concept. Moreover, I would like to thank Martijn, Cootje, Vincent and Sunaina for participating in my final evaluation and provided a lot of insights for later improvement. Lastly, I would like to thank all participants in User test 1, Yuchen, Yanjie, Yaqi, Yingda, Ruoxi, Xiaochen, Jianghui, Jizhou. Thank you for your time and help.

To my friends
To my friends in Delft, thank you for always encouraging, inspiring and helping me while I was struggling with the project. We had dinner together, ran together, watched TV shows together, and laughed together. While we were all stuck at home during the COVID time, I feel very lucky and grateful to have you guys by my side. Thank you for all the happiness you brought to me and accompanying me along this half year.

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Appendix

APPENDIX A. PROJECT BRIEF

How Augmented Reality can help represent alarm in Intensive Care Units — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 16 - 03 - 2020 — 27 - 08 - 2020 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

This graduation project focuses on exploring the technological possibilities of replacing auditory alarms in Intensive Care Units (ICU) with specific visual information to achieve silence in the patient room in ICUs while still informing clinical staff regarding the patient status.

The main stakeholders in this project are ICU patients and nurses. Patients staying in ICUs are usually critically ill and need to be monitored and mechanically supported. Those patients are in need of monitoring devices that collect data regarding heart rate, blood pressure, and of organ support devices such as mechanical ventilators to assist breathing. Nurses working in ICU are those who monitor the status of patients and react to alarms that result as the telemetric function of these devices. In the Dutch ICUs, nurses sit in front of a desk located between two patient rooms and the patients' vitals are shown through the monitor on the desk. With the windows in the wall, they can look through into the patient room. (Figure 1)

Nearly every device in ICU is outfitted with an alarm, like infusion pumps, ventilators, bedside monitors tracking blood pressure, heart activity and even beds are alarmed for detecting fall movement. Those auditory alarms intended to keep patients safe by alerting nurses to tackle potential problems and emergencies. However, those medical alarms can produce sound levels in ICU between 70 dB and 90 dB which are much higher than 35 dB during the day and 30 dB during night recommended by WHO. Even in an empty patient room, the background sound level in ICUs could reach 30 dB. As the sound level is often above the recommended level, sleep deprivation is a common phenomenon for patients in ICU which can lead to many negative effects, such as altered blood pressure and heart rate increasing, slower healing and increased length of stay and even delirium. Therefore, the negative effect of medical alarms on patient experience should be improved without hindering nurses' need for medical information.

Moreover, current audible alarms are not informative enough. As a result, not knowing which equipment is sending the alarm costs time for nurses who try to find out the exact equipment that requires attention. This is where Augmented Reality (AR) could help. With adding specific input into the real-world context instead of replacing the real-world, AR can keep users contextualized and more informed. In this graduation project the opportunities with AR will be explored in the context of audible alarms.

This graduation project is a collaboration between TU Delft Critical Alarms Lab (CAL) and Adult ICU Department of Erasmus Medical Center Rotterdam (EMC) from where many relevant research has been done and can be helpful resources to get better understanding of the context of this project. Also, collaborating with EMC brings opportunity to conduct research with the target group and evaluate the result of the project. For the implementation of the AR, the VR Zone, a lab located in the TU library that explores the use of VR/AR, is also available for support.

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introduction (continued): space for images

image / figure 1: ICU environment in Erasmus Medical Center

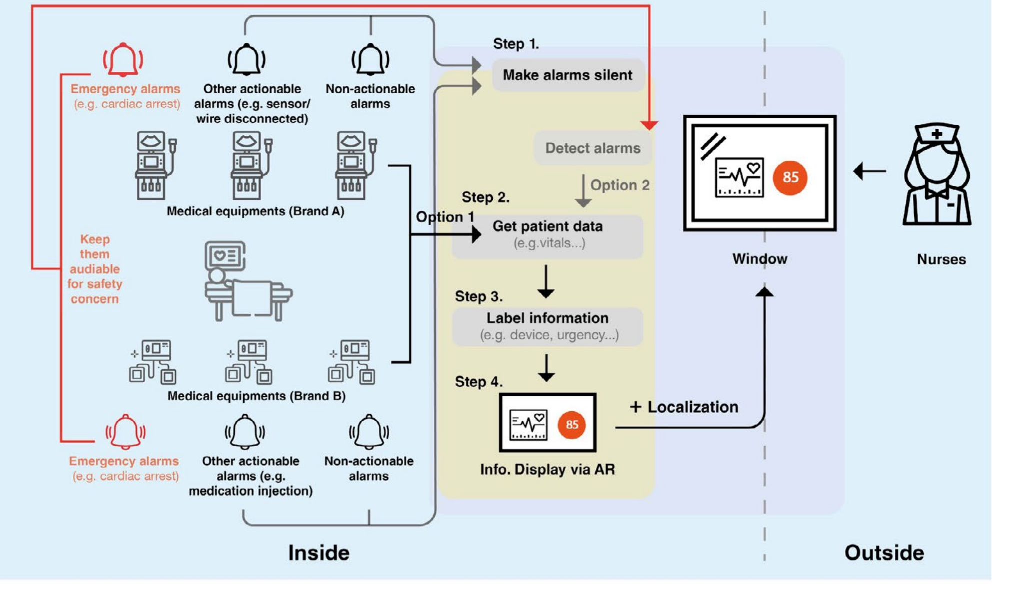


image / figure 2: An overview of the system

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

As the medical equipments in ICUs are made from different brands and have different communication protocols, they do not follow the same principle and even the alarms are designed in different ways. For example, alarms sound in different ways and some alarms are not informative enough. It adds difficulty for nurses to directly distinguish different types of alarms and the urgency levels to react effectively. Thus, how to make all equipments communicate in the same way is an issue to be solved in this project.

Besides, localization of alarms is desirable output for informing nurses of more specific information regarding the source of alarms. However, the location of each equipment might change in different care activities and vary from one room to another. So how to locate the alarming equipment in real-time needs to be studied for displaying more accurate information.

Also, to achieve a seamless and real-time display, the transparent window between the patient and the nurse will be used as the screen instead of any electronic device (iPad, monitor, etc) or wearables for complying wit infection prevention protocols. However, their usual viewpoints need to be sensed for displaying information in the right place. This is also a challenge in this project.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

This project will explore on how audible alarms generated by different medical equipments in the patient room of ICUs can be displayed visually on the window via Augmented Reality. The end result will be a system which can fetch specific patient data that are required for nurses to monitor patients, label those data and then displays visualized information on the window using AR.

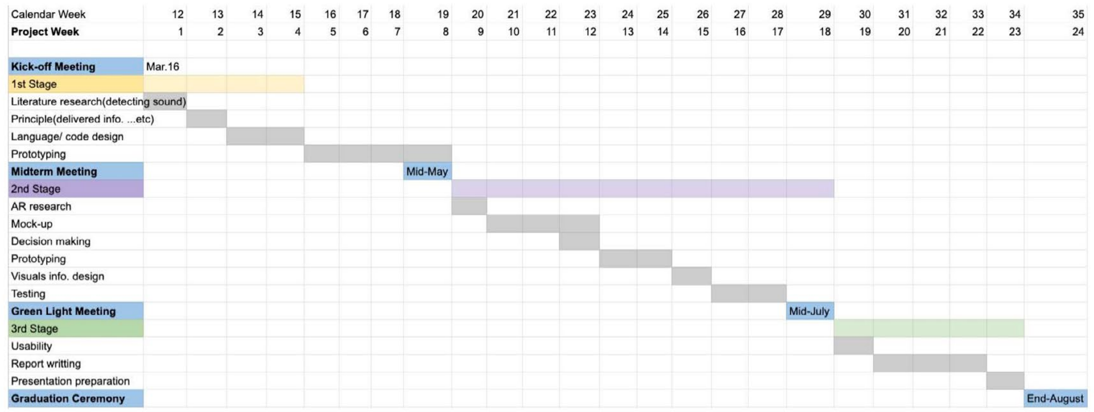
An overview of the system can be seen in Figure 2. This system includes 4 steps. In step 1, alarms except emergency alarms will be set silent. In step 2, there are two possibilities to get the patient data. Option 1 is to get data directly from the equipment. If Option 1 doesn't work, Option 2 could be tried to get data from detected alarms. The minimum expectation is to use simulated data stream for later stage. If Option 1 could work, alarms (except emergency alarms) could be eliminated in this mode. In step 3, the principle or a method to label the information need to be studied.
In step 4, specific information should be displayed via AR on the window. Firstly, research will be conducted on what information need to be delivered. Then, those information will be visualized by using visual information design principles (e.g. iconicity, concreteness, complexity, etc.). The outcome should be able to allow nurses easily and quickly understand the visual information that represents the main purpose of audible alarms. Lastly, as the focus of this project is AR exploration and implementation, a feasible solution of AR should be found to help display those specific visual information representing alarms on the window in a real-time and seamless way.

For now, some equipments have a privacy mode when some alarms are silent by percentage. In the future, it would be suggested that all producers could add another mode (e.g. night mode, silent mode, etc.) to their equipments so that the end result of this project could help achieve silent patient rooms in ICU.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 16 - 3 - 2020 27 - 8 - 2020 end date



*The planning includes 7 public holidays in days. The planning of this project includes three main stages, the configuring the system, adjusting it to the context, and final evaluation. The first stage should be achieved by midterm and the other two after.

In the first stage, the focus is on the basic principle and structure of the system, together with the hardware part. A research will be conducted on what information should be delivered (device, urgency level, specific information, location in the room, etc.). Besides, how to fetch patient data and then label those data, and lastly to visually display the information will be studied and prototyped. Collected alarm samples could be used, and the display could be the laptop or any other screen for this stage. Consultations with sound experts will be scheduled to get knowledge about processing sound data. The outcome will be evaluated by relevant technical experts.

In the second stage, the basic system achieved in the first stage will be further developed within the context of the ICU. All alarm samples will be encoded to become silent but informative and their functions in the Augmented Reality will be implemented. Different forms of Augmented Reality will be explored for finding the best fit for the ICU context and nurse work flow (e.g., head-up display). The opinion of nurses, expert and manufactures will be gathered through interviews (e.g.,engineers from Philips and Dräger Patient Monitoring Systems). This could be preferably in the context of ICU but will depend on the COVID-19 situation. In that case, online interviews and demos will be opted for.

I am aiming at the final evaluation to be conducted by nurses. Whether AR could help nurses react better in ICU context could be figured out by test if possible. However, this will also depend on the status of the COVID-19 crisis. Again, an online usability test can be provided instead.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

From my projects in the MSc programme, I have learnt a lot and gained a deeper understanding of the design process and design methods. Since I did a project of designing for deaf-blind runners where I experienced doing user research with the special group, I have become more and more interested in design for healthcare and well-being. Also, as the target group is deaf-blind runner, our group used sound data to create a more intuitive tactile experience which involves a sound analysis. Later, I collected speech data for speech emotion recognition experiment for another project. Thus, I gained interest in sound related design and would like to dive more into it.

During this project, I want to dive into a few specific subjects which I am mostly interested in and eager to improve:

• Obtaining depth knowledge about sound related research/ design:
During this project, I want to get more knowledge about sound from academic aspect and also more importantly, learn more about how to deal with sound data and how sound can be used for design.

• Getting a deeper understanding about Augmented reality and the implementation
I'm always interested in implementing new technology into design and I believe new technologies can help design go further. AR has been a trendy technology which I'm quite interested in and this project is a good chance for me to experience the design of AR.

• Project management
Good management can help lead to good result but also need more effort and experience in management which I would like to improve during this five months. I learnt a lot about planning in the last year, and now it's time to put into practice.

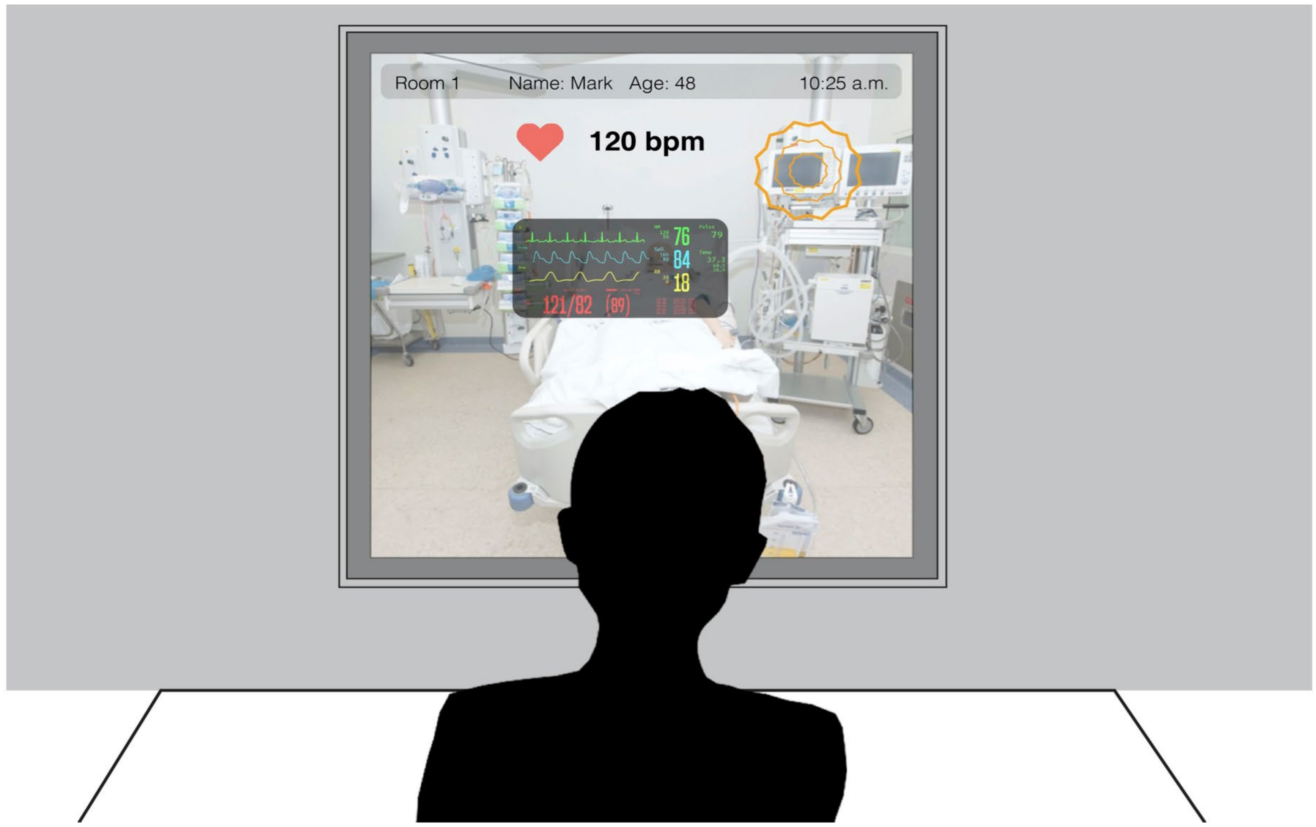
FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Initials & Name S. Yan Student number 4895991

Title of Project How Augmented Reality can help represent alarm in Intensive Care Units

APPENDIX B. EXPERT INTERVIEW 1.0



Patient Monitor alarm

Question list:

Technical related:

1) What system is used in the ICU of EMC to get data from all equipment? How does the system work? Is it possible to get data from the system to use in my project? (Considering getting real-time data for display on window)

2) Camera might be used to scan the equipment or any Image. Is it possible or an issue?

3)What's the size of the ICU in EMC? What's the size of the window?

4) As the equipment might move due to care activity, to what extent will it be moved? Just in a small field or big changes?

Interaction related:

1) What information would be useful/needed for nurses to deal with alarms?

- What's the difference between the needed information about different alarms regarding this?
- Is there any information missing in current concept?
- What extra info. could be added as well? Maybe overview status of other rooms or...?

2) Regarding the hierarchy of the alarms, how do nurses recognize different alarms?

- For example, the ventilator, how do nurses know it's a high-pressure alarm or low-pressure alarm?
- Does every alarm have urgency level?

3)As the limited time for the project, if not all alarms could be taken into consideration, does it make sense to only put these four in the scope? (patient monitors, mechanical ventilators, continuous renal replacement therapy machines, and infusion pumps)

Brief Insights

1. According to Teus, those devices in ICU patient room won't be moved around a lot, mostly in fixed places. But it does happen that sometimes the equipment like ventilator will be moved out of the room but when it returns, it will be put back in a similar place. Considering this fact, there will be no need to use cameras for real-time update footage of equipment. Places could be fixed in design.
2. He wouldn't bother much if the blinking graphic is shown at the ventilator's place or not which means showing info. at equipment's place is not necessary.
3. About the detailed graphics, for the patient monitor doesn't matter much because nurses can see the information from the monitor on their desk. However, nurses would like to see the detail information about other machines from outside, according to Teus.
4. Teus agrees on limiting the scope to only four equipments: patient monitor, ventilator, infusion pump and replacement machine.
5. **Value of the project**

Teus was very honest about the value of this project. He didn't see this project as a solid need in current ICU but more conceptual.

Also, Teus had a bit worry about replacing the audible alarms with visualisation as nurses not sit in front of the window all the time. They will walk around a lot or maybe at the nurse station. Furthermore, alarms have different sounds so nurses could differentiate, there should be something similar for visualisations, like colours, etc.

Other information of current ICU:

A case: 12 patient unit, 950 alarms in total a day.

Among those alarms:

approx. 25 life threatening alarm

approx. 250 technical alarm, 80% of those are because of sensor off

approx. 670 limit variation (like heart rate go beyond limit...etc)

Questions & Answers:

Technical related:

1) What system is used in the ICU of EMC to get data from all equipment? How does the system work? Is it possible to get data from the system to use in my project? (Considering getting real-time data for display on window)

A: All medical devices are connected either by cable or network to the paging system to get data. Paging company get all the data.

To be honest, in real case, what would be easy to achieve is Room number and time.

2) Camera and projector might be used to scan the equipment or any Image. Is it possible or an issue?

A: Considering the privacy issue, camera could be hard to go, especially for user test in the real case. However, if to only test with student fellows or volunteers, it would be fine.

For back projection, the picture is reversed, should take into consideration as well.

3)What's the size of the ICU in EMC? What's the size of the window?

A: The size of the one patient ICU is approx. 4×4m (need further check)

The size of the window is approx. 1×1m (need further check)

There's a shutter on the window of current ICU, cannot be used for projection in the real case. (which means hard to test in real ICU)

APPENDIX C. EXPERT INTERVIEWS 2.0

MEETING AGENDA

Date: June 4th Time: 2.00 p.m.- 3.00 p.m. Location: Skype

Participants: Andreas Walden (Philips), Shu Yan (TU Delft)

Goals: *To get more insights on the problems of current workflow in ICUs and the real needs when dealing with alarms.*

1. Project introduction

Time: 5 minutes

Purpose: share background information

2. Discussion: Information flow in ICUs

Time: 30 minutes

Purpose: Nurses in ICUs get information in many ways, such as from the central patient monitoring system, pager, documentation sheet, etc. The purpose is to find out the problems and needs of ICU staff regarding current workflow, and possibilities to apply better data visualization in ICUs.

- What is the daily routine of ICU nurse? (walking around, not in the same place)
- How are nurses and caregivers interacting with alarms in ICUs? What are their approaches? (Pager, patient monitor and other support devices, health record?)
- What is the problem of the current workflow in ICUs when dealing with alarms?
- What could be the ideal workflow to help nurses and caregivers to deal with alarms?
- How are ICU staff dealing with alarms of different priority? (false alarm/ yellow alarm and technical alarm)
- Do nurse assign tasks for responses to different alarms?
- What information to be displayed on the window(nurses could see from outside) would be helpful when alarms go off?

3. Discussion on the current concept

Time: 10 minutes

Purpose: Get feedback on current idea

Expert information

1. Teus van Dam: Expert user EHR HiX Thorax Center, worked as nurses for more than 8 years, later work on research and IT projects (27years bij EMC)

Ryan Forde: Senior Staff Clinical Engineer at Dräger

2. Leo Groenendaal: Manager medische technologie (37years bij EMC)

Nico Kalden: Projectmanager infusion pumps & drug libraries bij EMC

3. Andreas Walden: UX/UI designer in Philips

Gathered information

- How are nurses and caregivers interacting with alarms in ICUs? What are their approaches? (Pager, patient monitor, and other support devices, health record?)

A: **Paging system**

For patient monitor, they can get detailed information from the pager. It is not possible for other equipment.

M**onitors on wheels, show EHR (patient data)**

Nurses are moving around.

Only nurses are dealing with alarms, no other staff. Nurses don't always sit in front of the workstation, they might be in the patient room, at the bedside, washing patients, giving medication, etc. They might also be in the cafe room, in the medication room, talking in the corridor.

There are monitors in the cafe room, medication room where nurses can check for the patient's condition. If alarms went off when the nurses are in the cafe room, they will hear the alarm from the pager which indicates the information of the alarm. And they can see from the monitors to check first.

- What could be the ideal information flow to help nurses and caregivers to complete tasks more efficiently?
- How are ICU staff dealing with alarms of different priorities? (false alarm/ yellow alarm and technical alarm)

A: When alarms go off, nurses will silence the alarms first.

Red alarm: run to patient

Yellow alarm: e.g. infusion pump pre-alarm: medication will be empty in 10 min.

Nurses go inside the patient room, check if the medication is really going empty. Go to the medication room get a new medication, go back, and give new medication, instead of waiting for the high priority alarm.

- Do nurse assign tasks for responses to different alarms?

They decide themselves, register in the system, they can have a buddy.

Discussion on the initial idea:

A: Nurses are very busy and will not sit in front of the patient window most of the time. The initial idea of presenting alarm information from the outside will not help much.

Difficulties

Reducing alarm fatigue:

It's not about switch off the alarms, the issue is to reduce alarms from the beginning.

Nurses have to be trained to use the devices to set limits according to patient's condition.

Manufacturers don't allow switch off alarms. The hospital is also developing relevant functions in the system.

Trends in hospital:

Nurses are working more and more digitally, like the Hix system.

APPENDIX D. NURSE INTERVIEW SCRIPTS

Transcripts:

During the night, you have fewer patient flows, fewer interactions, fewer nurses, then there are less noise because nurses create noise, moving patients create noise, people create noise.

- Nurses are very busy during the day, but how do ICU nurses work at night? What are their tasks? Where are they? Where do they stay?

They give medication, they do checks at least every 2 hours. They do checks inside the patient room, it's a must. you can see all the visuals on the monitor but they have to see the patients face to face. If the patient is critical, they have to spend more time in the patient room, and more often, like every hour. For stable patients, each check lasts about 10 minutes, but for critical patients, it might take up to half an hour.

Do they close doors at night?

Most doors are closed, but if the patient is awake, nurses prefer to leave the door open so they can hear the patient better if they are a little bit confused, or trying to get off the bed.

Apart from being inside the patient room, they are in the medication room to get medication, to help colleagues, otherwise, they are sitting in front of the workstations.

you don't have to pick up staff, they have to transport patients, at night shift, they spend more time sitting in front of the station, during the daytime, they have to give much more medication.

- What's the difference between work in ICU during day and night?

During night shift, apart from fewer patient flows, there are far fewer people, not only nurses but also nurse helpers, family, physicians in general, all the examination, all tests like x-ray, social work, the visitors, people there at night could be only 10 per cent of the day.

For nurses themselves, there are not many differences, no examination, only the basic care, look at the patient, check the patient, turning patient around, that part does the same, but a few procedures like getting rid of needles, that's you typically do during the daytime, you try to prevent doing it at night.

- Do alarms go off more often at night or less than during the day?

Typically, during the night shift, there are far fewer alarms, they might ring longer because you don't respond right away. if you don't touch and nurse the patient, you have fewer alarms. if the physicians don't examine the patient, if their relatives are not there, there are fewer alarms.

There exist emergency cases, but far less than examining patients and nursing patients.

are more likely to be not stable just after the surgery, more alarms than during the night. Patient has surgeries only during the day, they

fewer ECG artifact alarms at night

6 a.m. nurses take blood sample, that gives alarms if nurse don't do it correctly.

- How often do they interact with the patient and also with other nurses?

Each nurse is responsible for 2 patients.

they check together, starting from 12p.m., 2a.m., 4a.m, 6a.m,

medication time: normally twice, 12pm, 6am

Some patients are supported by more devices. Some patients have also continuous medication.

Interaction between nurses:

about 9-10 nurses work at night. There are 2 different kinds of patients: 1)patients are not critically ill, they just need extra care, one nurse can do 3-4 this kind of patients if needed. 2) if you have patients those are critically ill, then every 2 hours you have to start nurse these patients, you cannot do it yourselves, you need help.

They speak to each other and call from pagers.

On the 4th floor, it is more predictable. On the 6th floor, it is more unpredictable. Normally, patients are not admitted at night. But there are exceptions. For example, you might have plenty of time at 8 p.m., and 2 hours later, you have 3 new admissions. In this department, the amount of admission is very high. It's a little bit between ER and ICU, some patients might just come from ER or immediately from the street because of some accidents.

You have always kept some rooms empty. If all patient rooms are full, the physicians have to call other hospitals and some patients will be transported to other hospitals. For these 16 units, around 2 patient rooms will be kept empty.

- How can nurses be supported at night? What do they need? What are the different needs of nurses between the day and night shift?

The biggest support would be: If the nurses are inside the patient room and busy there, they want to check other patients' condition.

The biggest problem: If you are not sitting in front of the workstation, you are somewhere else. How do you know if your colleague need help or patient need care? When alarms go off, you can see from pager that it's Room 12, heart rate 120. But how do you know if the alarms are true and if any colleague is going there? 50% might be false alarms.

5 years ago, there was a central station in the pharmacy room, cost about 40,000 dollars. In the old concept, you have only one central station in one unit. But now, you have 8 central stations, they already spent much money on this.

It's a big unit, 100 meters hall. It's more difficult than on 4th floor. They have units that are much smaller, it's much easier.

If patients in room 1 and 2 are very ill, patients in 3 and 4 and very ill, then nurses for room 1-4 can only take one from this and another a simple one.

For example, room 2 and 3 are empty, you will have patients in 1 and 4. If you have a patient in room 1 and room 12, it takes you time to run to the other one. plan 2 hard patients together

8 a.m. all the rooms are busy, 10-12, many patients can go to the general ward, they have to go to the general ward because new patients have to come in, this is the busiest time here. A number of patients have to be prepared to transport to other rooms. Then nurse helpers have 2 hours to clean everything, from 12-6, new patients start to come in slowly one after another. Some patients who come in at 12 might already leave at 9 p.m.

- If alarms go off at night, how are nurses responding? What are their approaches? (Pager, patient monitor and other support devices, health record?) Do they need to go inside the patient room?

They look at the screen, see if it is real or not real, and try to silence the alarms, they can do it remotely or they might go into the patient room, from the central station, you can click 'audio pause'. As soon as the alarms go, nurses also get from their pagers, but the information is rather limited. It says heart rate high/low, just text.

When you are inside the room, nursing the patient with gloves on, your pager is in your pocket, you cannot see the information. You can see from the patient monitor, a small text showing that in Room X something is going on. When you implement pagers, the number of alarms can be double. Not only the device generate alarms, but also the pagers. And what is worse, when one nurse cannot answer the pager right away, the system sends alarms to 5 closest nurses after 30 sec, and after 60 sec, it sends to all nurses' pagers. One example, within 60 seconds, 15 pagers go off. It's a myth that it is safer.

> "If I'm nursing one patient, I think my patient is more important, I cannot drop my patient, I hope someone else could take care of it, but I have no way to communicate with them, I don't know if someone is going there."

If you are in the medication room or lunchroom, and alarms go off, you have to go to the nurse station to check if it is true. You can go to any nurse station. It doesn't matter which one. All nurse station has access to all patients' condition.

For devices except patient monitor, all therapy devices, you always have to go inside to silence the alarms. I will not feel comfortable if you can silence a ventilator alarm without showing what is really going on. For infusion pump, it might be possible because might not be so critical.

Nowadays, it is forbidden to disable the speaker of devices or completely turn the volume down. In the future, there will be a new protocol. It basically means the ventilator is connected to a system, the system can know if you are online or alive. Then it's allowed to disable the volume from the ventilator. Then Ascon sends alarms to pagers, without having a sound in the patient room. As soon as the ventilator cannot find a device which is taking care of sending alarms, then the ventilator will not allow to turn off the volume. "I can turn off the volume of patient monitor 100 per cent. as long as the patient monitor sees a network which makes a sound. As soon as the patient monitor detects I'm not on network, then the volume goes on"

- How are ICU staff dealing with alarms of different priority at night? (non-actionable alarms/ yellow alarm and technical alarm)

They all have different tones. Without seeing the pager, nurses can distinguish all alarms.

At least ten devices, each device itself, there are different sounds, e.g. patient monitor has 4 different sounds. if you have a new sound in ICU, all nurses will be confused: "What is this? What is going on?"

take the patient monitor, if they hear the alarm, they all look at it. If it's blue alarm, nobody looks at it. red alarms don't last long. Yellow and blue alarms can last minutes. Nobody cares. They silence them all or is over. if the blue alarms go very frequently, they can ignore it.

- What could be the ideal workflow to help nurses to deal with alarms at night?

There's no difference with the day.

- How do they use the patient window now?

close the shutter for privacy. They see through it a lot. if the patient is moving.

- What information would like to see on it? **What kind of information is important at night? Are they different from the daytime?** What information to be displayed from outside would be helpful when alarms go off? What information are they missing?

For infusion pump, you don't know which pump. only info. it says is: blocked, empty, but it doesn't tell you which one with which drug. for some therapy devices, you don't know something is going wrong but do not know which and how.

> better information from room to room is needed.

- Besides muting alarm, is there any other ways to reduce the interferences of the patient during the night?

Reducing alarms can only be done on the device level.

50-80% nurses don't do it correctly. should silence the alarm first then do the approach.

Wait a minute, increase the waiting time before the sound goes off.

Nurses go in as less as possible during night shift. day: 60 per cent, evening: 30 per cent, night: 10 per cent

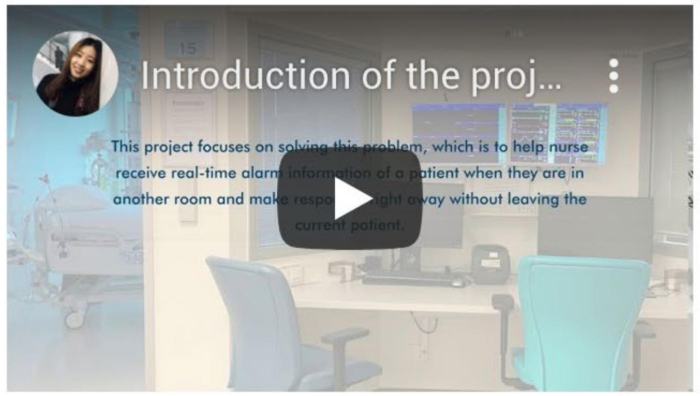
Brightness: 80 per cent night: 40 per cent

APPENDIX E. QUESTIONNAIRE

User test on ICU alarm display interface

Hi, my name is Shu Yan and I'm a master student from TU Delft. I'm now working on my graduation project. The topic is to help nurses receive a patient's real-time alarm information when nurses are in another patient room and make responses right away without leaving the current patient. This test aims to get feedback on the interfaces of the concept.
There are 3 simulations in the video which include interfaces designed for 3 medical equipment, including patient monitor, ventilator and infusion pump.
Please watch the attached video of simulations first, and then finish the following questionnaire. Thank you very much for your time!

The following video gives an introduction to the project and this test.



Next

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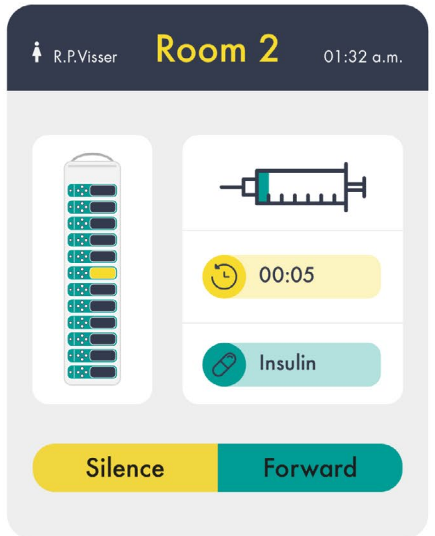
User test on ICU alarm display interface

Simulation 1

Please watch the video of Simulation 1 and then finish the following questions.

Simulation 1 Video Link: https://youtu.be/69_VzN1UQwM

Simulation 1



Can you recognise it is an alarm from the infusion pump?

- Yes
- No
- Not sure

Are the interfaces easy to understand?

- Yes
- No

Can you quickly find the specific information that you needed to know?

- Yes
- No

Do the interfaces contain enough information that you need to know when responding to alarms?

- Yes
- No, some information is missing

If some information is missing, please describe it:

Your answer

Is there anything else could be added?

Your answer

Do you have any other advice for improvement?

Your answer

Back Next

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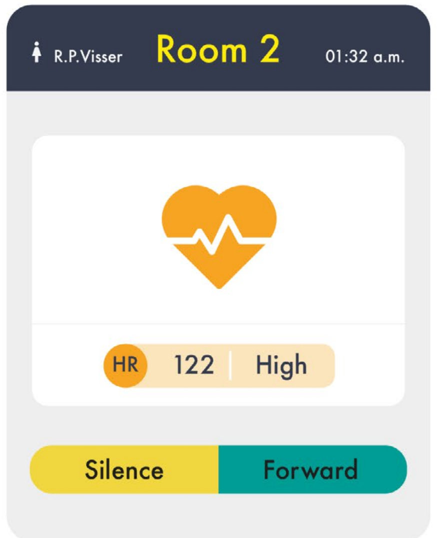
User test on ICU alarm display interface

Simulation 2

Please watch the video of Simulation 2 and then finish the following questions.

Simulation 2 Video Link: https://youtu.be/nSKAaRB84YM

Simulation 2



Can you recognise it is an alarm from the patient monitor?

- ◯ Yes
- ◯ No
- ◯ Not sure

Are the interfaces easy to understand?

- ◯ Yes
- ◯ No

Can you quickly find the specific information that you needed to know?

- ◯ Yes
- ◯ No

Do the interfaces contain enough information that you need to know when responding to alarms?

- ◯ Yes
- ◯ No, some information is missing

If some information is missing, please describe it:

Your answer

Is there anything else could be added?

Your answer

Do you have any other advice for improvement?

Your answer

Back | Next

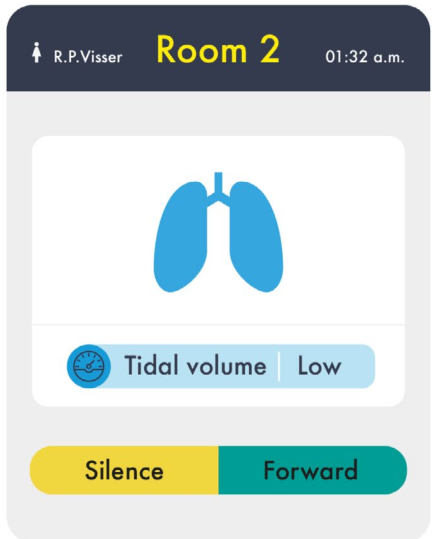
User test on ICU alarm display interface

Simulation 3

Please watch the video of Simulation 3 and then finish the following questions.

Simulation 3 Video Link: https://youtu.be/G2WVVcfPdwc

Simulation 3



Can you recognise it is an alarm from the ventilator?

- ◯ Yes
- ◯ No
- ◯ Not sure

Are the interfaces easy to understand?

- ◯ Yes
- ◯ No

Can you quickly find the specific information that you needed to know?

- ◯ Yes
- ◯ No

Do the interfaces contain enough information that you need to know when responding to alarms?

- ◯ Yes
- ◯ No, some information is missing

If some information is missing, please describe it:

Your answer

Is there anything else could be added?

Your answer

Do you have any other advice for improvement?

Your answer

Back | Submit

11 responses

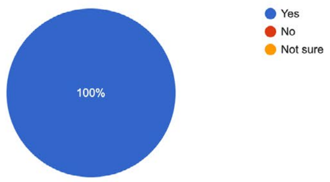
Accepting responses

Summary | Question | Individual

Simulation 1

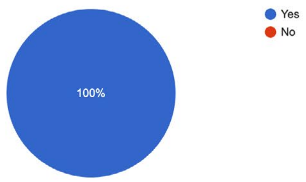
Can you recognise it is an alarm from the infusion pump?

11 responses



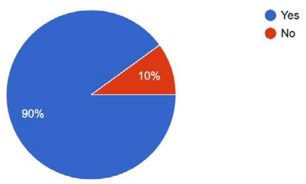
Are the interfaces easy to understand?

11 responses



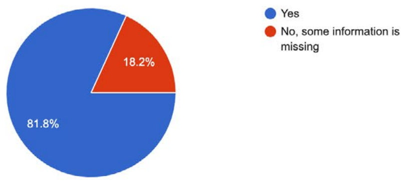
Can you quickly find the specific information that you needed to know?

10 responses



Do the interfaces contain enough information that you need to know when responding to alarms?

11 responses



If some information is missing, please describe it:

5 responses

heb een video verbinding van de pomp nodig of het alarm terecht is. (vals alarm?) knik in de lijn?

which nurse is attending to the alarm (really with photograph?) is not important to know for me.

I know its an example but alarming just 5 min before pump is empty is ' too late'

It's somewhat unclear what forward mean;

I see how long it takes to the next alarm when the syringe is completely empty, but maybe in case of, for example norepinefrine, you would want to know the speed and or dosage and BP\HR in order to know if you want to solve the problem yourself or if you let a colleague handle it. Do I touch the window to forward or to silence? And is there a vocal connection?

Is there anything else could be added?

7 responses

there could be another reason why the pump alarms, for example high pressure. is this also presented on the screen?

No

zie boven

no

what would help is showing info for all pumps how long before its empty; however this might me more something for pump vendor

In addition I would recommend to add a state;=> Mute which means you are reminded in X min again

It would be handy I think to have such a device but I think it is only complete if you can directly communicate with the helping nurse. So then you can give instructions for example change the dosage if neccessary, because that might be a thing you want to

Do you have any other advice for improvement?

3 responses

No

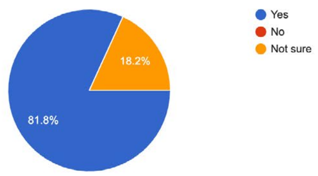
I dont remember I recognised the purpose of the picture on the left. with the 12 blocks.

Is it a projection or is it something build in the window? Maybe it could be an portable device to be placed where ever it is handy for the nurse.

Simulation 2

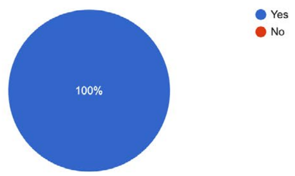
Can you recognise it is an alarm from the patient monitor?

11 responses



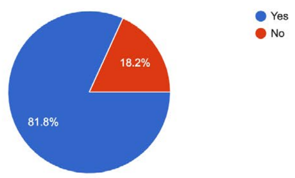
Are the interfaces easy to understand?

11 responses



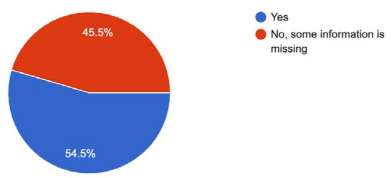
Can you quickly find the specific information that you needed to know?

11 responses



Do the interfaces contain enough information that you need to know when responding to alarms?

11 responses



If some information is missing, please describe it:

6 responses

Only high is not enough information, you need also to know what kind of rythm it is.

Maybe more specific information about what is going on with the heartfreq. Is the freq. above the alarm limits? Is it a asystole? A Asystole is much more worse and requires immediate action. A higher heart freq. may can wait for a moment.

1) je wilt weten of het alarm klopt (terecht alarm)
2) hiervoor heb je nodig: HF, RR, SAT,ECG curve enz.
3) Klinische blik: een video verbinding naar:
-monitor, pompen, patient
Als je deze gegeven niet hebt kun je nooit met zekerheid zeggen wat er aan de hand is. (misschien beweegt de patiënt?, rilt de patiënt, Ritme verandering??)

i dont see the movements of the patient. when the heartbeat on the monitor is "moving"the patient is moving. only the figure 128 is not enough

PLS use color which are known to nurses so in thuis case Blue-Yellow and RED

Is there anything else could be added?

2 responses

the set limits

So if info from the monitor or the monitor itself could be displayed, that would be more helpfull

Do you have any other advice for improvement?

5 responses

is there a possibility to see what the set limits are

Je moet echt een klinische blik kunnen werpen op je patient, dit gaat het beste als je in de Nis zit en je in 1 oog opslag je patient,monitor, beademing,pompen kan zien.

heartbeat combined with other parameters

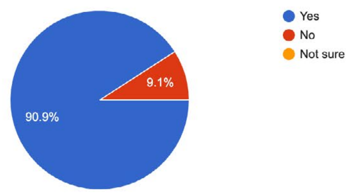
See the above, for better advice I would want to know if you are bound to a kind of device or if you have lots of ways to make the information known. Overall I think I would likes some more vital signs to be displayed when the alarm goes off. And a camera would also be awesome!

what is, if all the other nurses are busy?

Simulation 3

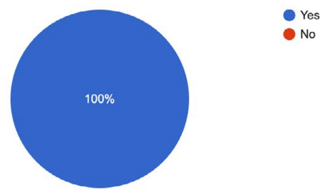
Can you recognise it is an alarm from the ventilator?

11 responses



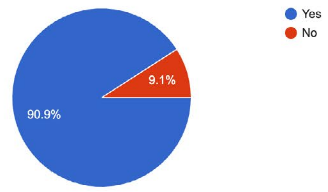
Are the interfaces easy to understand?

11 responses



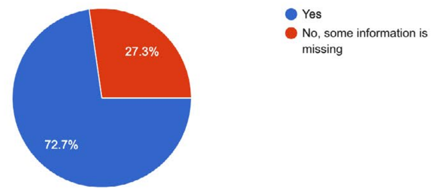
Can you quickly find the specific information that you needed to know?

11 responses



Do the interfaces contain enough information that you need to know when responding to alarms?

11 responses



If some information is missing, please describe it:

5 responses

How much time does it takes before you know that nurse 1 is really helping your patient? and do you have to wait if nurse 1 is reacting before the alarm goes to nurse 2 and so on?

je hebt je klinische blik nodig,
zie vorige slide: video verbinding
toevoeging: alle curves van de beademing nodig+observatie van de thorax met video van de patient+geluid van de kamer: (hoest de patient?/zit er slijm in de beademingsslangen?)

just tidal volume is no sufficient parameter. I will need more to know what's the matter..

same as earlier follow color codes alarm

You would want to know the Minute Volume and the question is when is this alarm being forwarded by this system. If the patient has one VT under the lower limit it is not a problem, but when it is ongoing then there is something the matter.

Is there anything else could be added?

3 responses

-

like breahte minutevolume, is the patient awake? moving?

My concern is that I forward alarms to my colleagues and then they take actions and that that are actions I would not have taken because I have more info than they have because its my patient. For a colleage to handle my patient I would want to give instructions before hand. For example my ventilated patient is waking up. If my collegea does not know that, he would interpret that maybe differently. A short conversation with me could make the difference.

Do you have any other advice for improvement?

4 responses

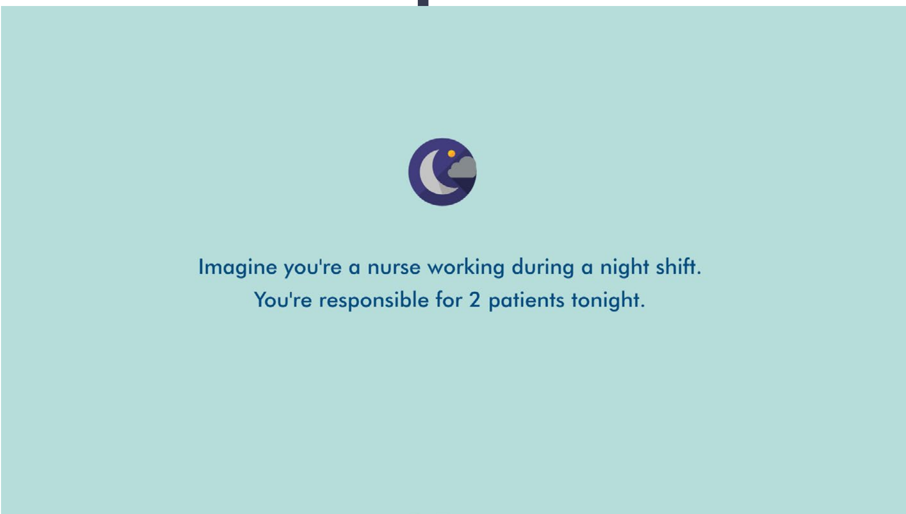
-

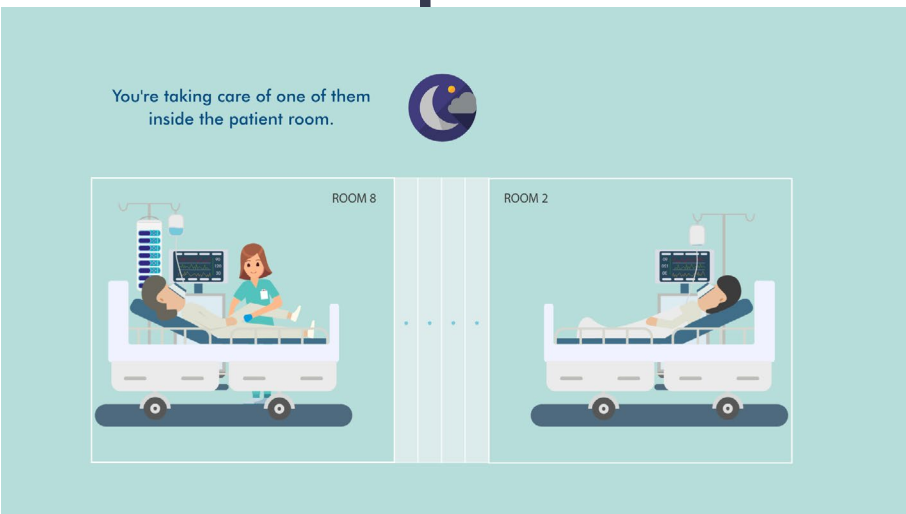
more parameters

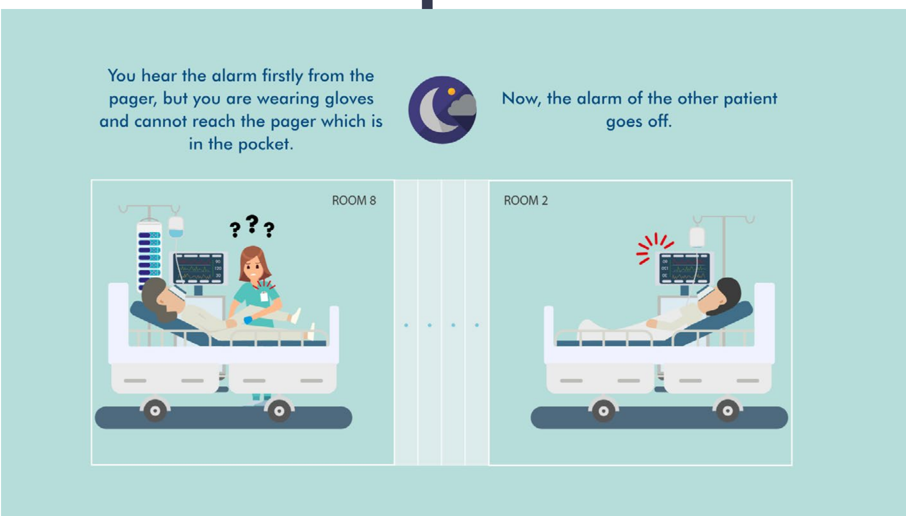
So a possibility to communicate with the attending nurse. An intercom system which turns on if a helping nurse is in the room. So info about the alarm and the patient can be quickly exchanged.

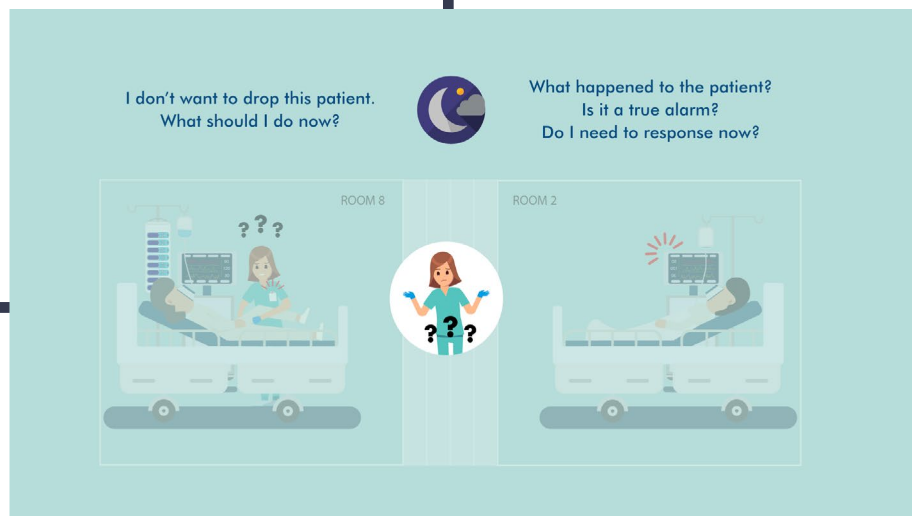
what is, if all the other nurses are busy? What is the next step?

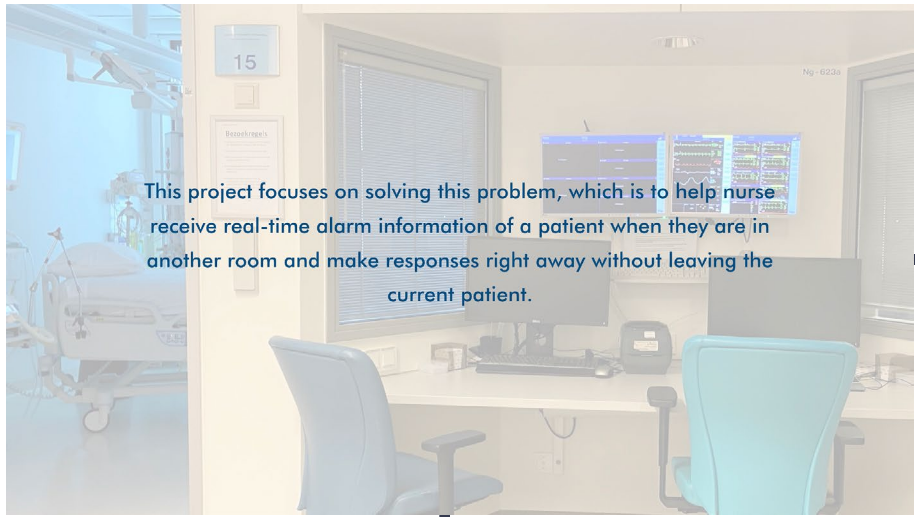
APPENDIX F. INTRODUCTION VIDEO IN THE QUESTIONNAIRE

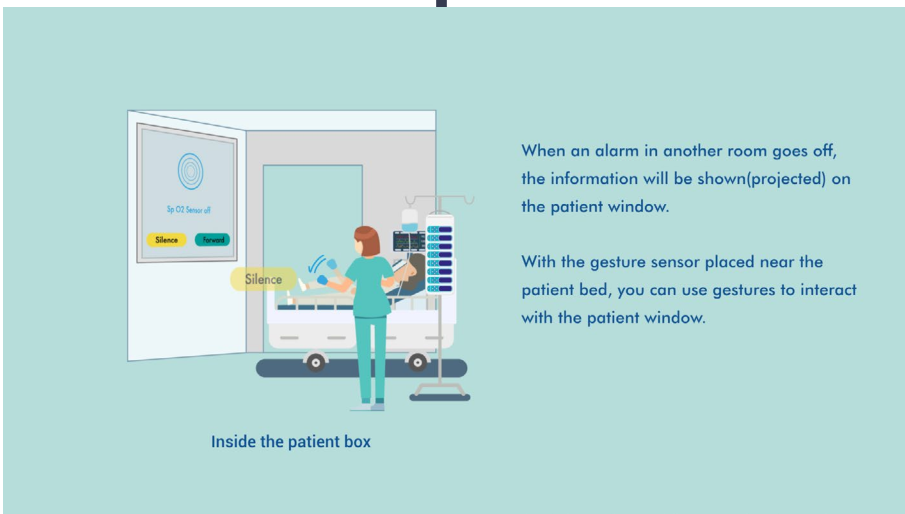


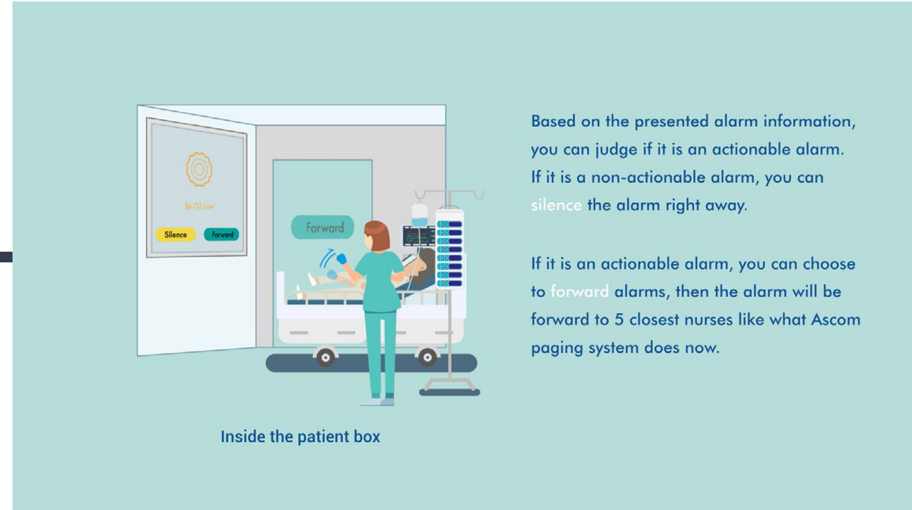












Above is an introduction of this project.
Here starts the test part.

This test aims to get feedback on the interfaces of the concept.
There are 3 simulation videos which include interfaces designed for 3 medical equipment, including patient monitor, ventilator and infusion pump.
Please watch video of simulations first, and then finish the attached questionnaire.

Thank you very much for your help.

APPENDIX G. SIMULATION VIDEO IN THE QUESTIONNAIRE