RESEARCH-ARTICLE

Beepless: Using Peripheral Interaction in an Intensive Care Setting

MIGUEL CABRAL GUERRA, Eindhoven University of Technology, Eindhoven, Noord-Brabant, Netherlands

DEEDEE KOMMERS, Maxima Medical Center, Veldhoven, Veldhoven, Noord-Brabant, Netherlands

SASKIA BAKKER, Eindhoven University of Technology, Eindhoven, Noord-Brabant, Netherlands

PENGCHENG AN, Eindhoven University of Technology, Eindhoven, Noord-Brabant, Netherlands

CAROLA VAN PUL, Eindhoven University of Technology, Eindhoven, Noord-Brabant, Netherlands

PETER ANDRIESSEN, Maxima Medical Center, Veldhoven, Veldhoven, Noord-Brabant, Netherlands

Published: 18 June 2019

Citation in BibTeX format

DIS '19: Designing Interactive Systems Conference 2019
June 23 - 28, 2019
CA, San Diego, USA

Conference Sponsors:
SIGCHI

DIS '19: Proceedings of the 2019 on Designing Interactive Systems Conference (June 2019)
https://doi.org/10.1145/3322276.3323696
ISBN: 9781450358507

Beepless
Using Peripheral Interaction in an Intensive Care Setting

Miguel Cabral Guerra
[1]Eindhoven University of Technology
Eindhoven, NL
[2]Essense Service Design B.V.
Amsterdam, NL
miguel@essense.eu

Deedee Kommers
Máxima Medisch Centrum
Veldhoven, NL
deedee.kommers@mmc.nl

Saskia Bakker
Eindhoven University of Technology
Eindhoven, NL
s.bakker@tue.nl

Pengcheng An
Eindhoven University of Technology
Eindhoven, NL
p.an@tue.nl

Carola van Pul
[1]Máxima Medisch Centrum
Veldhoven, NL
[2]Eindhoven University of Technology
Eindhoven, NL
c.vanpul@mmc.nl

Peter Andriessen
Máxima Medisch Centrum
Veldhoven, NL
p.andriessen@mmc.nl

ABSTRACT

This pictorial proposes an alternative mode of interaction between nurses and clinical alarm systems and shows how three concepts, developed to interact through the end user’s periphery of attention, can be applied in a clinical setting to improve the workflow of nurses and wellbeing of patients.

Authors Keywords

Peripheral Interaction; Medical Alarm Systems; Clinical Alarms; Alarm Fatigue; Multimodal Interaction User-Centred Design; Interaction Design.

DIS ‘19, June 23–28, 2019, San Diego, CA, USA

ACM 978-1-4503-5850-7 / 19/06 $ 15.00
https://doi.org/10.1145/ 3322276.3323696

INTRODUCTION

Clinical alarms notify healthcare practitioners when a patient’s condition deteriorates or when a medical device is not working properly [11]. In many intensive care units (ICU), including neonatal intensive care units (NICU), nurses are overexposed to such alarm notifications. Due to this excess of alarms, nurses can suffer from alarm fatigue, defined as “the lack of response due to excessive number of alarms resulting in sensory overload and desensitization” [10:269]. In recent years this phenomenon has resulted in a number of preventable deaths, injuries and extended hospital stays [18]. In 2015 alarm hazards were designated the number one technology hazard for the fourth consecutive year by the Emergency Care Research Institute, a non-profit based in the United States of America [11].

Apart from errors in alarm response by practitioners and their associated risks, clinical alarms can also have a big impact on patient wellbeing. A 1997 study conducted in a paediatric ICU found that for every observed hour there were 20 minutes of audible alarms [25]. Another study conducted in a NICU in 2017 found that the number of alarms is variable between patients, and that some infants spend 10% of their time listening to ventilator alarms, just one of many medical devices [23]. Constantly hearing alarm sounds while in a fragile medical condition can have adverse long-term effects. Clinical alarms have been related to Post Traumatic Stress Disorder (PTSD) and sleep deprivation potentially resulting in delirium [26]. For premature infants, excessive auditory stimuli can negatively impact their hearing, heart and respiratory rates, oxygen saturation levels and neurodevelopment [1,9].

According to Cvach, a perfect clinical alarm system is 100% sensitive and 100% specific, meaning it would never miss a critical event and would never notify a practitioner when there is no critical event. However, Cvach explains, most alarm systems sacrifice specificity for the sake of sensitivity. As a result, practitioners receive all critical events in addition to many “false” or non-actionable alarms [11].

Various studies have tried to enhance the specificity of alarms through better sensing technology (video capturing and sensors) and signal analytics (machine learning and predictive monitoring) [4]. Some are trying to solve the ‘false-alarm’ issue and its effects through the use of new architectural layouts, behavioural changes, and best practices [16,30,37]. Others are working on altering the notification sounds of alarms and developing multimodal approaches to alarm notifications (e.g. haptic feedforward and light-based alarms)

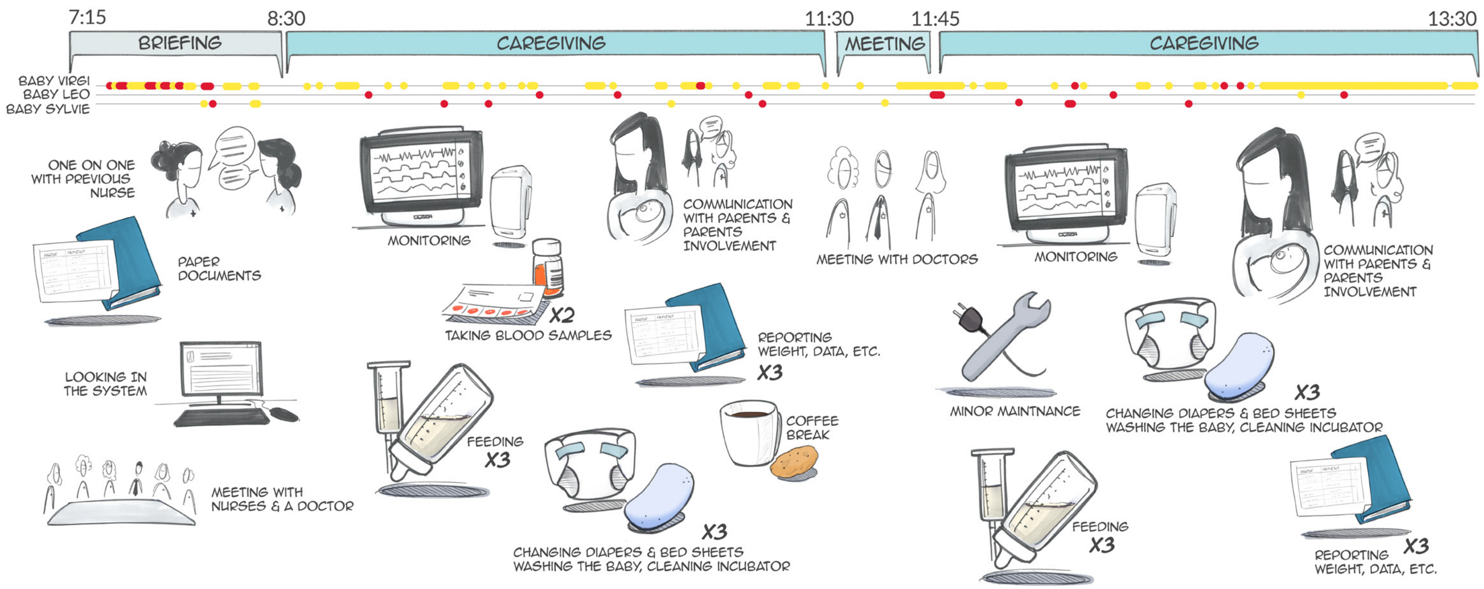


Figure 1. Diagram showing the average morning of a nurse based on two shadowing sessions. The yellow and red dots represent alarms retrieved from three real patients (for privacy reasons the names of these patients have been altered).

[15,21,22,26,27,29,32]. We argue that besides improving accuracy of technology, or conveying alarms in various modalities, this challenge can also be addressed from a more human-centred design perspective, by: (1) making it more effortless and less interrupting for nurses to silence the unnecessary ongoing alarms, and (2) unobtrusively enhancing the nurses' situational awareness about upcoming preventable alarms, so that they can proactively plan or take actions to avoid those alarms.

This pictorial proposes peripheral interaction [6,35,36] as the means to achieve these goals (1,2), since this fields of interaction design have been proven effective in solving similar issues for a different target group of professional practitioners – teachers [2,3]. By doing so, this pictorial contributes novel ways to make Human Computer Interaction (HCI) associated to clinical alarms less burdensome for nurses - a group of users who are already immersed in busy, complex and uncertain situations. Furthermore, our proposed solutions show promise in decreasing the negative impact and overall number of clinical alarms in the NICU context, which could also benefit patients and their families.

Contribution: This pictorial explores how peripheral interactions can be introduced into a neonatal intensive care unit to reduce the occurrence and duration of audible clinical alarms, and offload nurses' alarm-related workflow.

CONTEXTUAL ANALYSIS

This pictorial focuses on alarm systems in the NICU and on nurses as the primary user of the system. This study was conducted in the NICU of Maxima Medical Center, and started with the first author shadowing two nurses for a full shift each, resulting in detailed insights into their busy everyday routines, visualised in Figure 1. At this hospital, nurses in the NICU typically take care of up to three patients per shift, each of whom has their own private room. As such, they need to do a variety of different tasks throughout the day ranging from changing a diaper and replacing a feeding tube to reassuring parents and helping paediatricians with procedures such as lumbar punctures, inserting arterial catheters and intubation. Whilst they are engaged in these tasks, they receive hundreds of clinical alarms on the patient monitors and handheld (mobile) devices per day – of which an estimated 80% are non-actionable or even false, while the other 20% require the nurses' attention [20]. These 20% of alarms are a critical part of patient care and help nurses understand the patients condition and when to intervene. As such, nurses currently serve as the filter that determines whether an alarm is relevant or not. To do so, they need to know their patients' condition and analyse their vital signs. Keeping track of alarms while conducting other caregiving responsibilities requires nurses to multi-task and shift their attention rapidly between different interfaces, stakeholders and contexts, as visualized in Figure 2.

PERIPHERAL INTERACTION

In 1995, researchers predicted that one day we would be surrounded by attention seeking computers and our limited attention would not be able to keep up with this demand [36]. In anticipation these researchers created the concept of Calm Technology, which demands limited attention by residing in the background or 'periphery' of attention and only shifting to the focus of attention when relevant [35]. The vision of

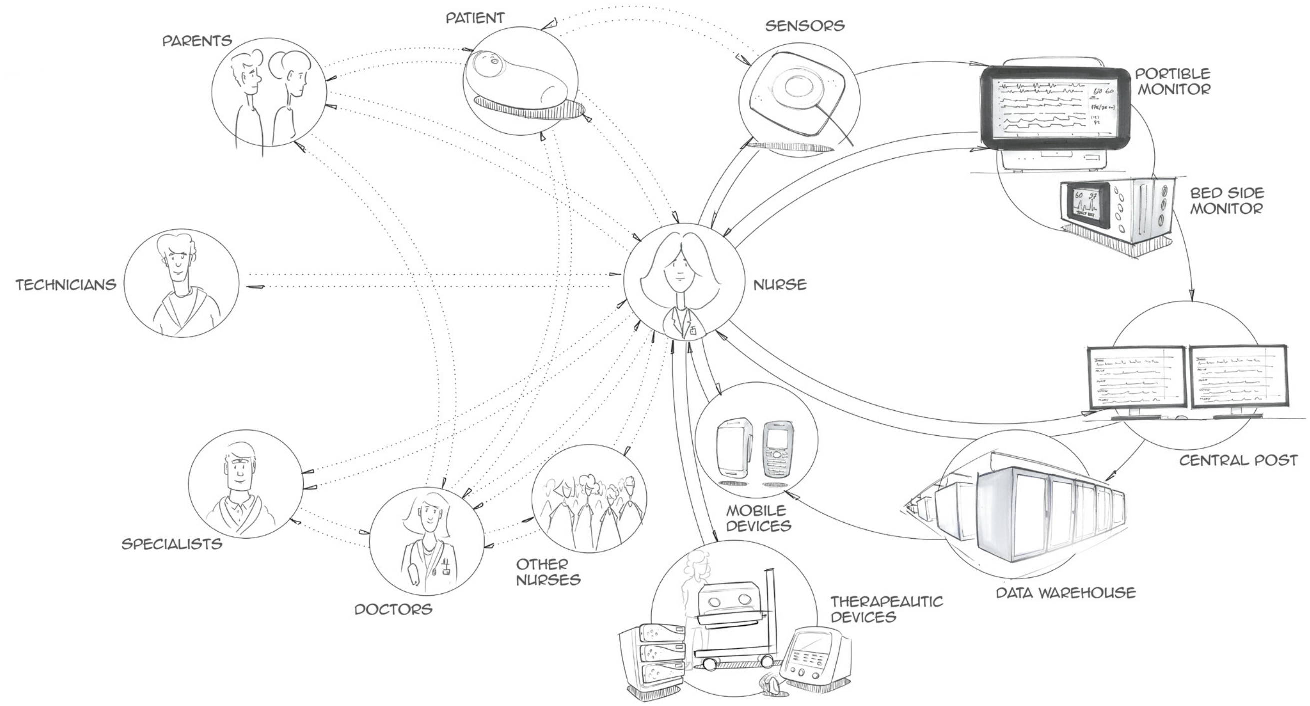


Figure 2. Diagram showing the Human-Computer (continuous strokes) and Human-Human interactions (dotted strokes) a nurse has throughout the day. Note that the number of elements on this diagram can increase with every patient the nurse cares for.

calm technology inspired an abundance of HCI work under terms such as ambient information systems [24], peripheral displays [33], ambient media [19], and more recently peripheral interaction [6], which “encompasses both perceptions of and physical interaction with computing technology shifting between people’s center and periphery of attention”[5:5]. Peripheral interactions do not require as much of the user’s attention, but still allow for intentional and imprecise control over a product/system [7]. This makes peripheral interaction a suitable interaction modality to employ for certain tasks nurses do in their day-to-day work.

In the NICU nurses often need to perform multi-tasking in their nomadic and dynamic workday routines (see Figure 3). These constant transitions require them to repeatedly shift their focus among multiple objects. This helps them keep up with the multiple threads of events unfolding in their complex context, however, it also means that they spend a lot of motor, sensorial and cognitive resources shifting their attention between medical devices, patients and other stakeholders and tools (see Figure 2). This results in sensory overload and alarm fatigue [10]. The concept of calm technology and peripheral interaction is not new to HCI, and has been applied in various domains such as the home environment [38], office work [17]and classrooms [3]. However, limited explorations have been done on how these concepts can be utilised in the high intensity environment of a (N)ICU [12,14,28] and tend to be focused on one-way communication systems (system-to-practitioner) that display patient status.

This pictorial argues for the introduction of peripheral interactions to facilitate nurses’ workflow. Peripheral interactions aim to support users’ computer-related tasks without requiring continuously focused attention from them [6]. Therefore, peripheral interactions can meaningfully enable users’ use of the designed interfaces to become secondary tasks while the users are simultaneously engaged in their primary tasks. We therefore believe that peripheral interaction can be a meaningful approach to offload the workflow of nurses whose work primarily consists of multitasking [31]. As a result, two of our design solutions, a foot-based interface as well as a peripheral lighting device, were inspired by two related design cases in the realm of peripheral interaction, [3] and [2]. These two cases have used similar interaction styles and proved that these two interaction styles are promising to support professionals’ (teachers’) secondary tasks. However, different from [3]and [2], our work addresses the rarely explored context of the NICU, which we believe provides a promising opportunity to contribute new knowledge on designing peripheral interaction.

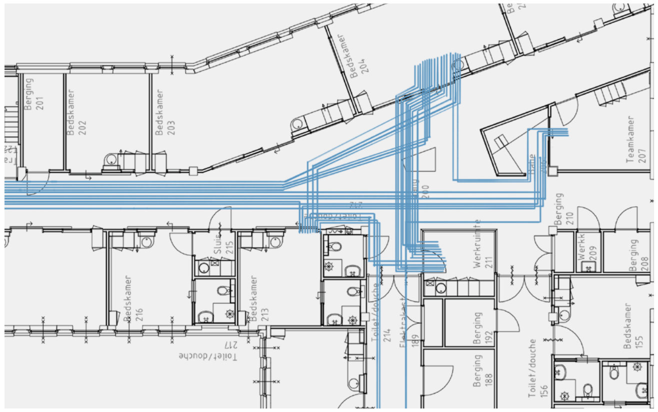


Figure 3. Floorplan showing the rout of a nurse during the first six hours of a morning shift. Note the amount of context changes, between patient rooms, the pharmacy, central post, the medium care unit, the break room and bathroom.

Figure 4. Focus group conducted with seven nurses to validate pain points and early concepts.

Figure 5. Beepless Pedal in a patient room during a usability test.

METHODOLOGY

In this pictorial we present a broad exploration of possible applications of peripheral interactions in the NICU context. We developed three diverse concepts using a user-centred design approach: Beepless Pedal, Beepless Connector and Beepless Indicator. These concepts were validated with users at different stages of the design process and ultimately one concept was introduced in a NICU for a user experience evaluation. In this process there were three particularly noteworthy research and validation points.

The first was an ethnographic study aimed at understanding the NICU context and system of stakeholders and technology. This study consisted of a series of semi-structured interviews with nurses, biomedical engineers, doctors and clinical physicists, two guided tours to two different NICUs (single family room and open bay layout) and two shadowing sessions with NICU nurses for a total of 12 hours. This initial study helped identify areas where peripheral interactions could be applied and potential threats to this application. A brief summary of the insights gathered in this phase can be read in the previous section (see Contextual Analysis), and following section (see Concepts and Findings).

The second was a focus group with seven nurses (see figure 4) aimed at validating the nurses' pain points in interactions with the system and four propositions aimed at solving these pain points, two of which are described in this pictorial. In this focus group, nurses were asked to describe a past situation relating to their workflow (e.g. "Can you recall the last time you had to silence an alarm?"). After a group discussion, they were presented with a concept board and asked whether the presented concept was a viable solution to the previously identified problem.

Lastly, a prototype of one of the concepts was deployed in anonymised hospital for a one-week period (see Figure 5). During this time, the prototype was installed for three non-consecutive days in three different patient rooms. Qualitative data relating to behaviour were gathered by a researcher present in the patient room. At the end of a nurse's test, the same researcher conducted an interview with the nurse who had used the prototype to gather qualitative data regarding perception of the device.

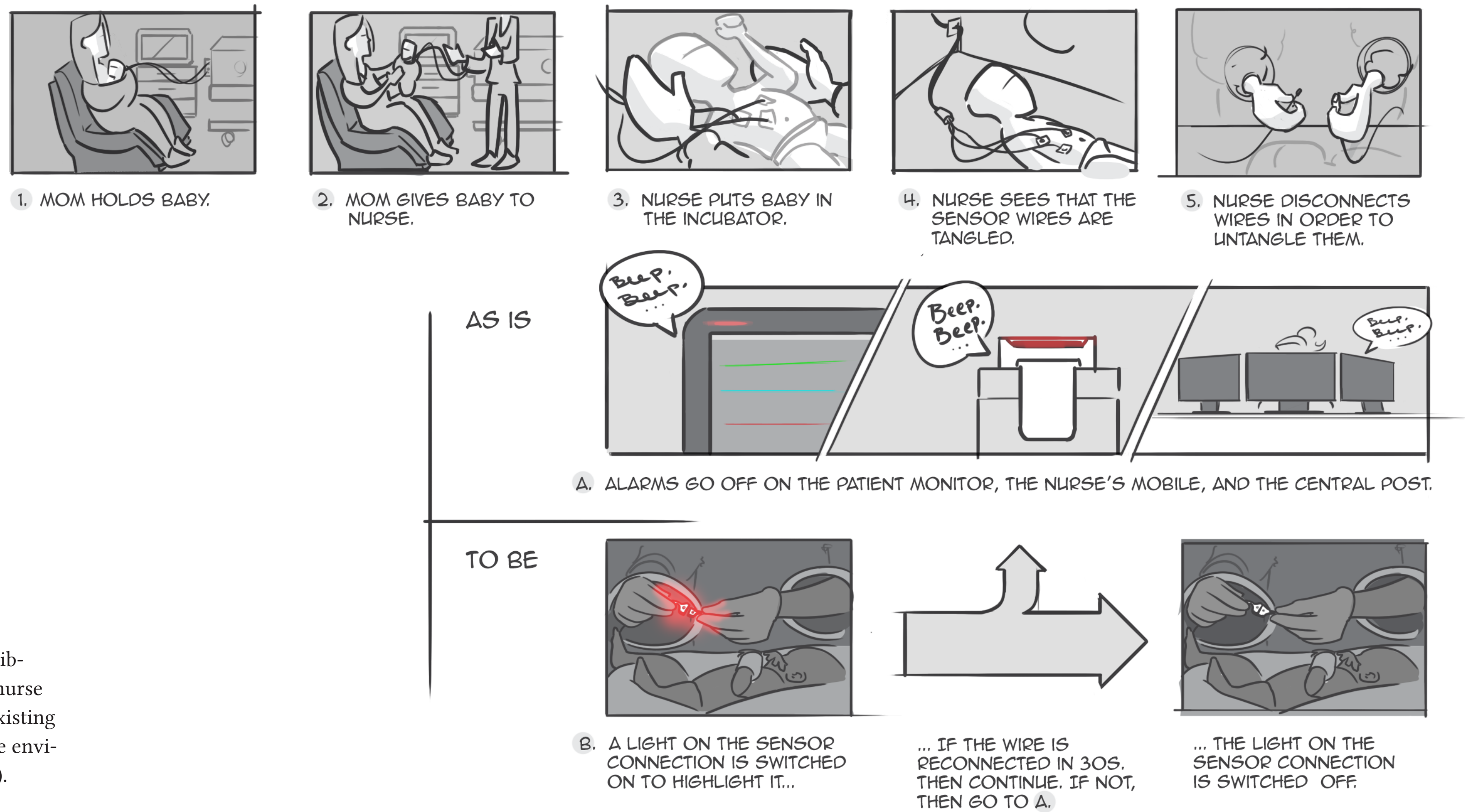


Figure 6. Storyboard describing what happens when a nurse disconnects a wire in the existing situation (or "as is") and the envisioned situation (or "to be").

CONCEPTS AND FINDINGS

Beepless Connector

Context from ethnographic study. During shadowing and interviews, nurses expressed their frustration with alarms triggered by their own regular operations. A common example of this nuisance is depicted in Figure 6: when a nurse moves a patient, sensor wires often become entangled. To solve this issue, nurses are often required to disconnect the sensors for a short period of time. However, when (s)he does so, alarms are triggered communicating 'malfunction' of the sensors through light, sound and a digital notification to the patient monitor, the handheld mobile device and the central post. Building on previous work on silent light-based alarms for patient status [31], we propose a light indicator placed on the sensor connection, which would turn on when the wire is disconnected. If the wire is reconnected within the first 30 seconds the light indicator turns off. Otherwise, alarms similar to the current alarms are triggered (see figure 6). Such an intervention would give nurses augmented feedback and potentially prevent a non-actionable alarm.

Skipped from further validation. Due to safety concerns expressed by the hospital technical team early on in the process, this concept was never developed past the concept board stage. However, in informal communications with nurses and neonatologists they expressed this concept could be useful in the NICU but questioned its effectiveness in paediatric and adult ICUs where patients might (un)willingly disconnect these wires in critical situations.

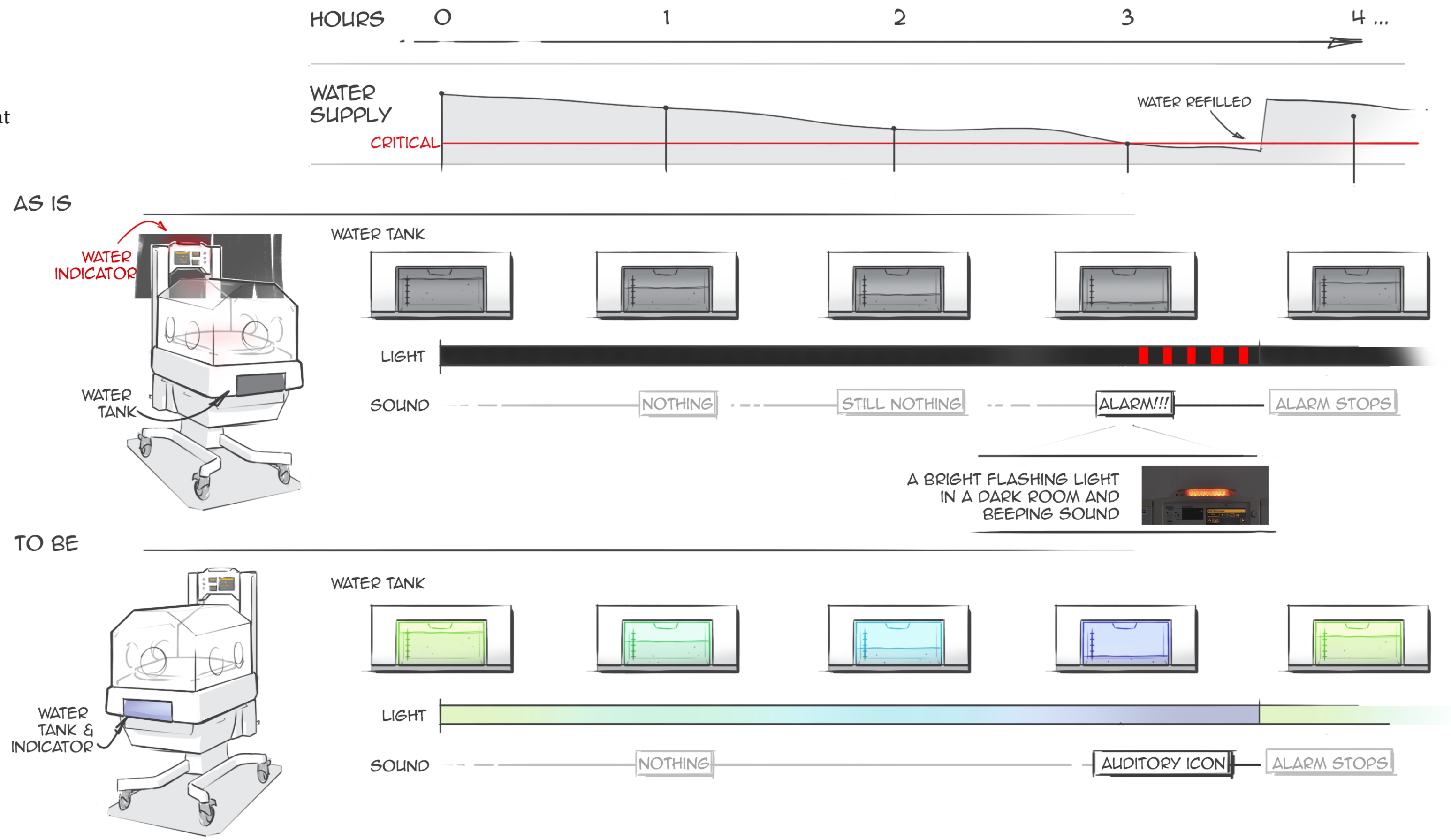


Figure 7. Diagram showing the water supply over time and how this value is communicated to nurses in two scenarios the current scenario (or "as is") and the alternative scenario (or "to be").

Beepless Indicator

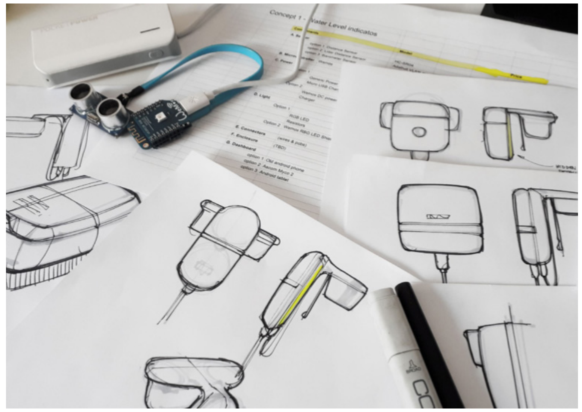
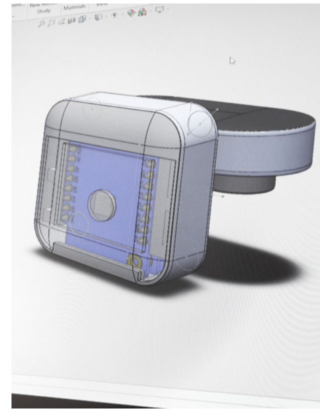
Context from ethnographic study. Based on data from shadowing and interviews, it was revealed that some alarms in the NICU can be prevented if a nurse would be informed by the system about its status, for instance, 'low battery' or 'out of water', remotely and in a timely manner. A good example of such a 'preventable' alarm is the water supply alarm on the incubator's heating and humidifier unit. When the water level drops below a fixed threshold, a big and bright red light on top of the incubator starts flashing and there is a sound alarm every 1-2 seconds. As the incubator is not a high priority alarm and because the incubator is not connected to the alarm system, it can take some time before the nurse sees the alarm and has time to react to it. As a result, patients and families are continuously disturbed and often frightened by this alarm, which may in turn cause stress or anxiety of nurses.

Information design rationale. Inspired by ClassBeacons, a peripheral display that shows a teacher's positional proximity to students over time through a light indicator placed on students' desks [3], a 'water supply indicator' was developed for use on (for instance) incubators (see Figure 7). The Beepless Indicator aims to give nurses feedback about the status of devices through both peripheral and focused interactions. A light indicator is placed in a suitable position, in this case the water tank of the incubator, and this indicator gradually changes colour as the water level decreases. When the water supply is close to reaching a critical situation, the light will start pulsing calmly. If the situation becomes critical, it will intermittently blink, make noise (through an auditory icon) and send the nurse a notification on his/ her handheld device, hereby shifting to the nurse's direct attention. Through this process, these displays of information will be available in the nurses' periphery, and only demand focused attention when an action is urgently required. We expect this would enable nurses to avoid alarms by refilling the water before it reaches a critical level.

Validation in focus group. When asked to recall the last time they had to refill the incubator water tank, nurses described previous experiences when they encountered parents who were new to the NICU frightened and worried about the health of their child. Following the explanation of the proposed solution nurses explained that it could give them better insight into device status and allow them to better plan their interventions and daily tasks.

Concept validation and prototyping. After validation of the perceived value of this concept during the focus group, a prototype of the Beepless Indicator was made consisting of a WIFI connected micro controller, an LED and a detachable ultra-sound distance sensor. This prototype measured the water level in the water tank, changed the light on an LED indicator accordingly and sent the measurement to a mobile application which displayed a gauge chart showing the real time measurement. Due to safety concerns raised during a risk assessment – regarding wireless communication and water damage to the electronics - this prototype was not implemented during the field usability test.

Nonetheless, due to the positive validation results of the design concept, a subsequent study adopted this concept, iterated the prototype, and conducted evaluation in a simulation set-up in a NICU department of anonymized hospital and showed promising results [8].

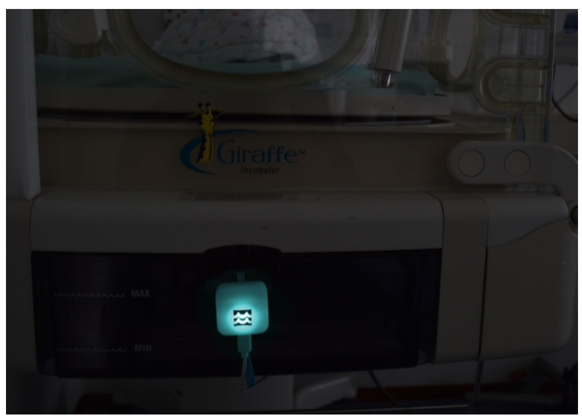



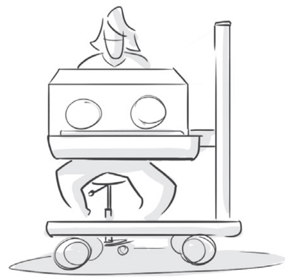
Figure 8-11. Sketches, foam models, CAD files, renders and 3D printed prototypes that gave shape to the final prototype.

Figure 12-13. The beepless indicator, shown here in context, is a two-part prototype where part 1 contains the micro processor and the light indicator and part 2 contains the sensor. The two are connected by a micro-usb cable. This modular approach was chosen to allow future iterations to include other sensors and therefore work with other clinical devices (e.g. ventilator or infusion pump).

Beepless Pedal

Context from ethnographic study. Generally speaking, when a nurse is at the incubator, his/her hands are occupied interacting with the patient; a vulnerable premature infant in a critical health condition. Following the ethnographic study (Figure 1) and literature review, we estimated that 25% of critical alarms happened while the nurse was in the patient's room, close to the incubator [20,32]. These alarms are often triggered by the nurse's actions (e.g. motion artefacts, wire disconnects and patient excitement resulting in a shift in vital signs) and are therefore deemed non-actionable. Yet, if the nurse does not silence these alarms, they will keep sounding and - after 30 seconds or three minutes depending on the type of alarm - escalate to other nurses. Inspired by FeetForward, a foot based HCI for teachers [2], this concept proposes the use of a foot pedal to simplify the alarm silencing procedure from an eight-step (see Figure 14 and 21) interruption-resumption process (which requires the nurse to stop what (s)he is doing), to a four-step, inter-limb, undisturbed process (see Figure 14 and 22).

Validation in focus group and prototyping. Following the focus group where nurses validated the pain points and the proposed solutions, we created multiple prototypes of this concept (see Figures 15-20) through an iterative approach aimed at improving ergonomics and reliability and ensuring the safety of the patient during a future usability tests. Ultimately, we made a minimum viable product (MVP) of the Beepless Pedal to test this concept's usability in the field. This MVP consisted of a foot pedal attached to the incubator (shown in Figure 20) that, when pressed, triggered the mechanical alarm silencing button on the patient monitor remote control using two electrical motors (shown in Figure 16).



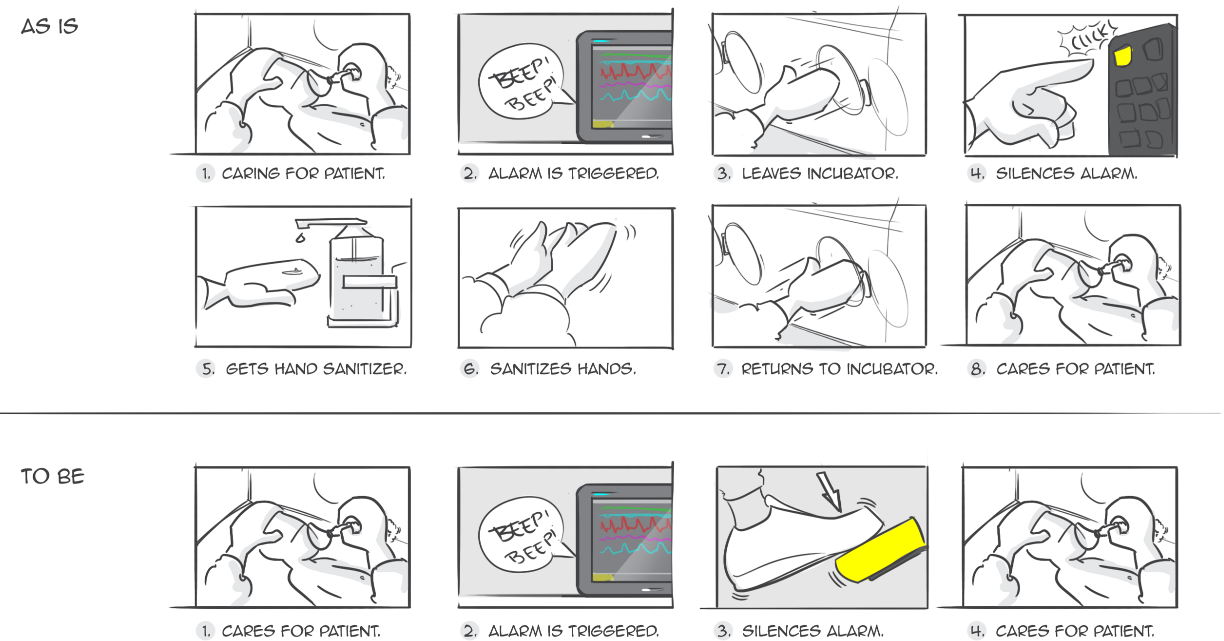


Figure 14. Storyboard illustrating the current situation (or "as is") and the situation with the Beepless Pedal (or "to be").

Validation in field implementation. The implementation of the prototype in the field indicated that the foot pedal was mostly used by nurses when their primary task was patient handling, i.e. manual operations within the incubator. Additionally, they used the foot pedal in other tasks where both hands were occupied and/or sanitized. In contrast, nurses tend to use the existing patient monitor remote control (so not the Beepless Pedal) when walking in and out of the room, or when their primary caregiving task involved operating the patient monitor instead of handling the patient. During the test, nurses often had to search for the foot pedal and during the interviews stated that they still needed to consciously think about using the foot pedal. This finding is in line with previous attempts of introducing peripheral interactions in the workflow of practitioners [2,3]. Regardless of this they felt that if they had time to get accustomed to using the foot pedal, it would be simple enough for them to use it without having to think about it. This finding was also consistent with previous studies [2,3]. Nurses found the product useful, as it allowed them to give uninterrupted care to the patient without having to remove their hands from the incubator to silence alarms.

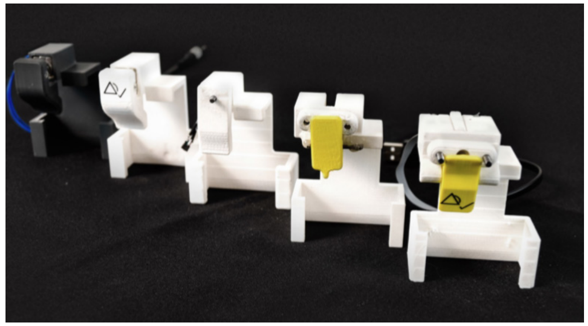
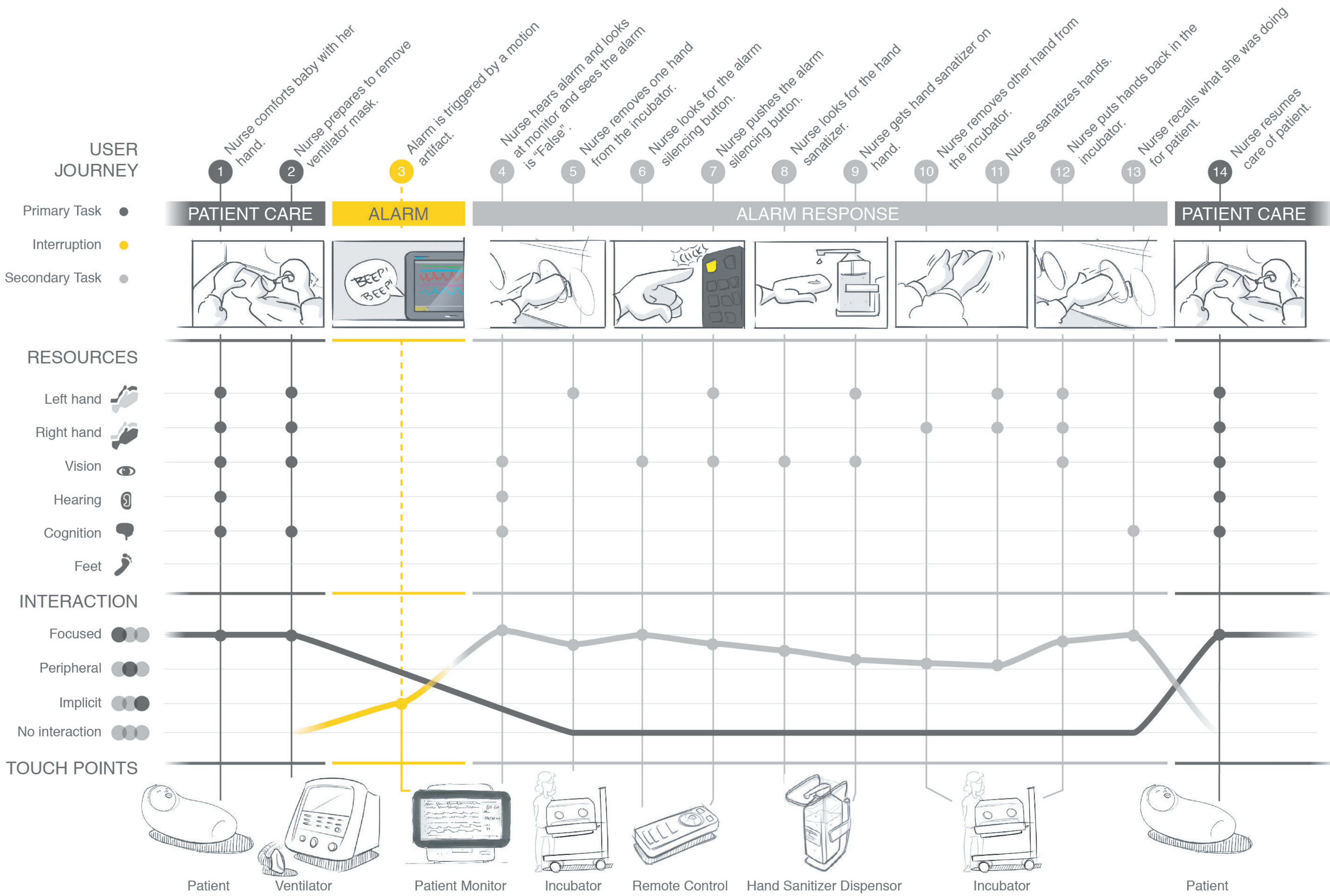


Figure 15-16. Device used to silence patient alarms by pressing the alarm silencing button on the patient monitor remote control. This device was created to bi-pass rigorous medical certifications required for software solutions.

Figure 17-18. Foot pedal iterations changed characteristics like type of feedback, rotation axis, spring tension, positioning in room and size.

Figure 19-20. Final prototype of the beepless pedal in context.


USER JOURNEY
Primary Task
Interruption
Secondary Task
1 Nurse comforts baby with her hand.
2 Nurse prepares to remove ventilator mask.
3 Alarm is triggered by a motion artifact.
4 Nurse hears alarm and looks at monitor and sees the alarm is "False".
5 Nurse removes one hand from the incubator.
6 Nurse looks for the alarm silencing button.
7 Nurse pushes the alarm silencing button.
8 Nurse looks for the hand sanatizer.
9 Nurse gets hand sanatizer on hand.
10 Nurse removes other hand from the incubator.
11 Nurse sanatizes hands.
12 Nurse puts hands back in the incubator.
13 Nurse recalls what she was doing for patient.
14 Nurse resumes care of patient.
PATIENT CARE
ALARM
ALARM RESPONSE
PATIENT CARE
BEEP! BEEP!
CLICK
RESOURCES
Left hand
Right hand
Vision
Hearing
Cognition
Feet
INTERACTION
Focused
Peripheral
Implicit
No interaction
TOUCH POINTS
Patient
Ventilator
Patient Monitor
Incubator
Remote Control
Hand Sanitizer Dispensor
Incubator
Patient

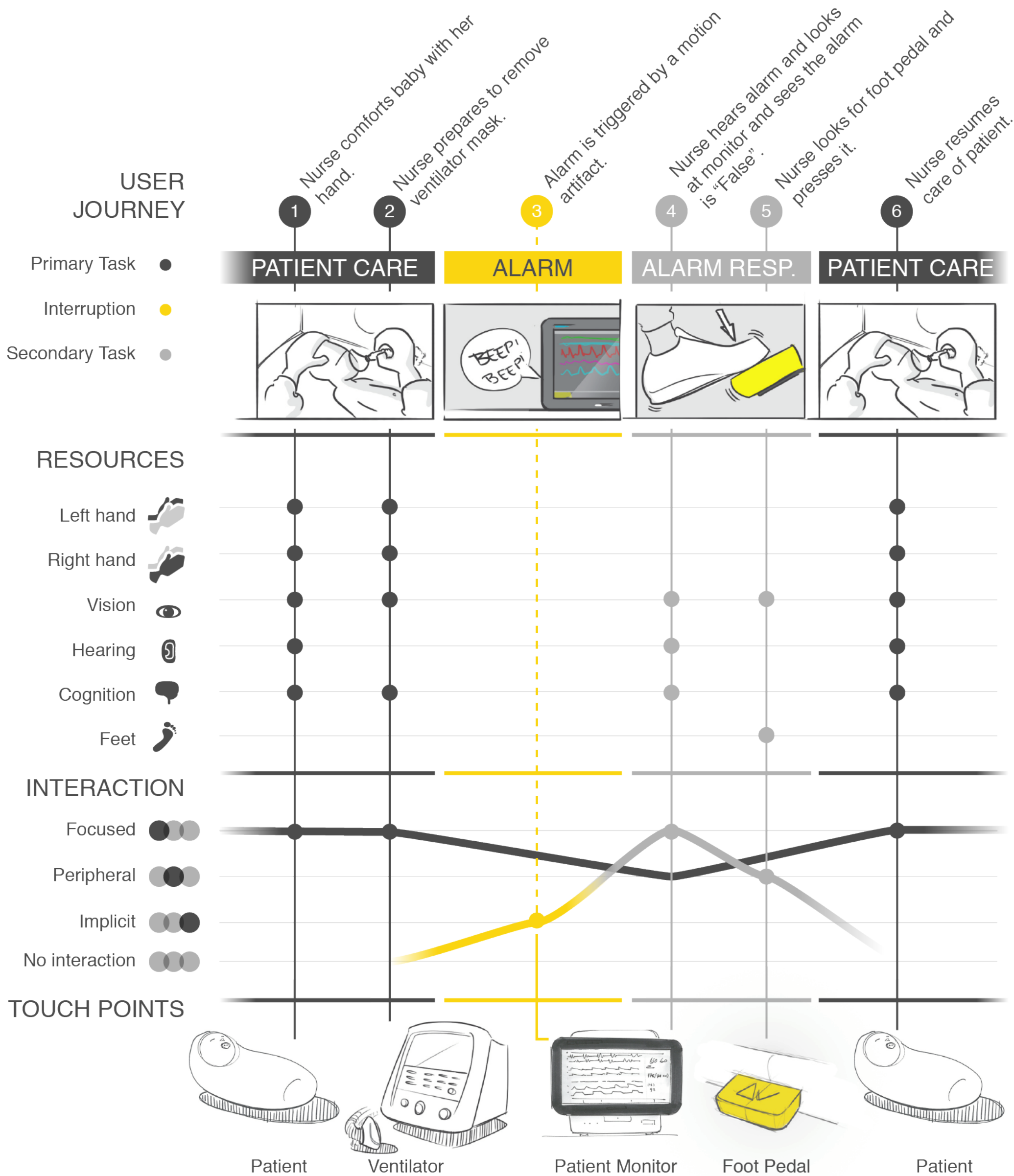


Figure 21 - 22. Detailed description of the interactions between the nurse and the system in two Scenarios: “As is” and “To be”.

The diagrams are divided in four parts the first describes the **user journey**. The last three detail the **resources** needed for interact with each **touch point** and show how much attention is required in each step using the **Interaction**-Attention Continuum [7], which clusters interactions into three categories Focused, Peripheral and Implicit Interactions.

From these diagrams we can see that the “As is” scenario (figure 21) is much more resource heavy and requires nurses to stop the patient care in order to silence alarms. This happens because there is a resource bottle neck where both the primary and secondary task require the same resources at the same time.

In the “To be” scenario (figure 22) we can see that the nurse can silence the alarms without completely stopping patient care. The nurse can do so by shifting the patient to his/her periphery, whilst she focuses on the patient’s vital signs displayed on the patient monitor. Once she is done assessing the clinical alarm she can begin focusing on the patient and silence the alarm through her periphery.

Note that the first scenario takes fourteen steps, whereas the second only requires six. Considering alarms can go off frequently, optimizing this interaction is quite important. This optimization lowers the nurse’s resumption lag and preserves their resources for what is important: Patient Care.

Figure 23. Picture depicting premature infant - Photo by Hush Naidoo, published on Unsplash

DISCUSSION AND CONCLUSION

This pictorial explored different possibilities for the application of peripheral interactions to facilitate the interaction between professional practitioners (nurses) and computer systems (clinical alarm monitoring system and medical devices) in a high intensity scenario (the NICU). Although peripheral interaction, by nature, seems promising in such a professional context, related HCI studies have rarely explored the design of peripheral interaction for supporting nurses’ routines. To bridge this gap spur on more related HCI design research in future, our design exploration identified three possible scenarios where such interactions could be meaningfully leveraged and, to different extents, validated these designs. Beepless Pedal, one of three concepts derived from the scenarios, was introduced in a short-term field implementation with positive results. The Pedal was experienced by the nurses as a meaningful alternative for silencing alarms especially when the nurse’s hands are busy, sanitized or interacting with the patient, i.e. when there is a bottle neck of motor or cognitive resources. This confirms the supplementary values of foot-based interaction to certain HCI scenarios, as generalized in [13]. It also echoes the work in [2], which similarly explored the potential of feet in peripheral interaction. We have also evaluated the design of Beepless Indicator, and demonstrated how augmenting information through ambient displays could unobtrusively offload the practitioners’ cognitive tasks of keeping track of status of multiple devices. This echoes and contextualizes the theory of cognitive offloading [34], and demonstrates that peripheral interaction could be a meaningful paradigm in designing cognitive offloading for busy practitioners, since it conveys information without interrupting the ongoing activities of practitioners. Furthermore, related study in [31] proposes using light-based alarms to reduce the negative influences of auditory alarms on nurses and patients. Building further on this idea, yet adopting the philosophy of calm technology, we use the design of Beepless Indicator as an example to show that light can be used not only for conveying alarming information, but also affording ambient awareness that helps avoid the preventable alarm situations. By doing so, we could further reduce the negative influences of clinical alarms on nurses and patients.

These explorations build on a long line of research into calm technology and peripheral interactions and help us further understand how traditional HCI systems which mostly mean to engage users in their focus of attention can be improved or complemented by intentionally designing some interactions to take place in the periphery of users’ attention. As argued by [6], such peripheral interaction can include both information perception from and bodily interaction with computing systems. Corresponding to this, our explorations also have encompassed both peripheral information perception (Beepless Indicator and Beepless connector), and peripheral physical interaction (Beepless Pedal), through which we want spur on more future HCI designs to broadly explore peripheral interactions for supporting professional routines of nurses. Meanwhile, to be noted, further research is still needed to verify and deepen the findings of this study by increasing the sample size and expanding the time-frame of usability tests or helping normalise contextual factors (e.g. number of alarms per patient, architectural layouts, type of ICU, etc.).

ACKNOWLEDGEMENTS

We thank all the nurses, parents and infants in the NICU who participated and helped coordinate the user research and usability test. Special thanks go to two Maxima Medical Center nuses - Astrid Osagiator and Heidi Van de Mortel. This research is supported by the ALARM Project which is funded by NWO - Toegepaste en Technische Wetenschappen.

REFERENCES

[1] Leslie Altimier and Raylene M. Phillips. 2013. The neonatal integrative developmental care model: seven neuroprotective core measures for family-centered developmental care. Newborn and Infant Nursing Reviews 13, 1: 9–22.

[2] Pengcheng An, Saskia Bakker, and Berry Eggen. 2017. FeetForward: on blending new classroom technologies into secondary school teachers’ routines. Retrieved from https://link.springer.com/chapter/10.1007/978-3-319-67684-5_20

[3] Pengcheng An, Saskia Bakker, Sara Ordanovski, Ruurd Taconis, and Berry Eggen. 2018. Class-Beacons: Designing Distributed Visualization of Teachers’ Physical Proximity in the Classroom.

[4] Shirley Baert. 2017. ALARM - Alarm-Limiting AlgoRithm-based Monitoring. STW. Retrieved December 28, 2017 from http://www.stw.nl/nl/content/alarm-alarm-limiting-algorithm-based-monitoring

[5] Saskia Bakker, Doris Hausen, and Ted Selker (eds.). 2016. Peripheral Interaction - Challenges and Opportunities for HCI in the Periphery of Attention. Springer.

[6] Saskia Bakker, Elise van den Hoven, and Berry Eggen. 2015. Peripheral interaction: characteristics and considerations. Personal and Ubiquitous Computing 19.1: 239–254.

[7] Saskia Bakker and Karin Niemantsverdriet. 2016. The Interaction-Attention Continuum: Considering Various Levels of Human Attention in Interaction Design. International Journal of Design 10, 2. Retrieved May 24, 2018 from https://search.proquest.com/docview/1819560656?pq-origsite=gscholar

[8] Jesper van Bentum, Deedee Kommers, Saskia Bakker, Miguel Cabral Guerra, Carola van Pul, and Peter Adriessen. CheckMates, Helping Nurses Plan Ahead in the Neonatal Intensive Care Unit (Paper under review). Multimodal Technologies and Interaction, Multimodal Medical Alarms.

[9] Pamela Bremmer, Jacqueline F. Byers, and Ermalynn Kiehl. 2003. Noise and the Premature Infant: Physiological Effects and Practice Implications. Journal of Obstetric, Gynecologic, & Neonatal Nursing 32, 4: 447–454. https://doi.org/10.1177/0884217503255009

[10] Maria Cvach. 2012. Monitor Alarm Fatigue: An Integrative Review. Biomedical Instrumentation & Technology 46, 4: 268–277. https://doi.org/10.2345/0899-8205-46.4.268

[11] Maria Cvach and Bradford Winters. 2017. Alarm Fatigue: Review of Evidence and Management Strategies. Retrieved December 5, 2018 from https://www.youtube.com/watch?v=zLpi2lB2Fv0&t=359s

[12] Koelemeijer Dorien. 2016. The Design and Evaluation of Ambient Displays in a Hospital Environment. Malmö University, Malmö , Sweden.

[13] Itiel R. Dror and Stevan Harnad. 2008. Offloading Cognition onto Cognitive Technology. In Cognition Distributed: How Cognitive Technology Extends Our Minds. 1–23.

[14] Jesus Favela, Monica Tentori, Daniela Segura, and Gustavo Berzunza. 2009. Adaptive Awareness of Hospital Patient Information through Multiple Sentient Displays. International Journal of Ambient Computing and Intelligence, 12. https://doi.org/10.4018/jaci.2009010103

[15] Daniel M. Gay-Betton, Parisa Alirezaee, and Jeremy R. Cooperstock and Joseph J. Schlesinger. 2017. HAPTIC: Haptic Anatomical Positioning to Improve Clinical Monitoring. https://doi.org/10.5772/intechopen.71111

[16] D D Harris, M M Shepley, R D White, K J S Kolberg, and J W Harrell. 2006. The impact of single family room design on patients and caregivers. Journal of Perinatology. Retrieved December 28, 2017 from https://www.nature.com/articles/7211583

[17] Doris Hausen, Sebastian Boring, Clara Lueling, Simone Rodestock, and Andreas Butz. 2012. Facilitating State Management in Instant Messaging Systems. In Sixth International Conference on Tangible, Embedded and Embodied Interaction. Retrieved from https://doi.org/10.1145/2148131.2148191

[18] Linda Honan, Marjorie Funk, Michaela Maynard, Deborah Fahs, J. Tobey Clark, and Yadin David. 2015. Nurses’ Perspectives on Clinical Alarms. American Journal of Critical Care 24, 5: 387–395. https://doi.org/10.4037/ajcc2015552

[19] Hiroshi Ishii, Craig Wisneski, Scott Brave, Matt Gorbet, Brygg Ullmer, and Paul Yarin. 1998. ambientROOM: integrating ambient media with architectural space. Retrieved from https://doi.org/10.1145/286498.286652

[20] Rihan Joshi, Heidi van deMortel, Loe Feijs, Peter Adriessen, and Carola van Pul. 2017. The heuristics of nurse responsiveness to critical patient monitor and ventilator alarms in a private room neonatal intensive care unit. PloS one 12, 10. https://doi.org/e0184567

[21] Roman Mars. 2018. Mini-Stories: Volume 4. Retrieved May 13, 2018 from https://99percentinvisible.org/episode/mini-stories-volume-4/2/

[22] Elif Özcan Vieira. Critical Alarms. Deflt Design Labs. Retrieved from https://delftdesignlabs.org/

criticalalarmslab/

[23] Christian F. Poets. 2017. Reducing alarms in the NICU. Archives of Disease in Childhood - Fetal and Neonatal Edition: fetalneonatal-2017-314259. https://doi.org/10.1136/archdischild-2017-314259

[24] Zachary Pousman and John Stasko. 2006. A taxonomy of ambient information systems: four patterns of design. In Proceedings of the working conference on Advanced visual interfaces, 67–74. Retrieved from https://dl.acm.org/citation.cfm?doid=1133265.1133277

[25] Ron Sabar and Ehud Zmora. 1997. Nurses' response to alarms from monitoring systems in NICU. 1027. Pediatric Research 41, S4: 174. https://doi.org/10.1203/00006450-199704001-01046

[26] Joseph Schlesinger, Elizabeth Reynolds, Brittany Sweyer, and Alyna Pradhan. 2017. Frequency-Selective Silencing Device for Digital Filtering of Audible Medical Alarm Sounds to Enhance ICU Patient Recovery. International Conference on Auditory Display (ICAD 2017) 23.

[27] Katharine Schwab. 2018. Hospital sound design can be deadly. FastCo Design. Retrieved from https://www.fastcodesign.com/90171905/hospital-sound-design-can-be-deadly?utm_medium=social&utm_source=facebook.com

[28] Daniela Segura, Jesus Favela, and Monica Tentori. 2009. Sentient Displays in Support of Hospital Work. https://doi.org/10.1007/978-3-540-85867-6

[29] Yuku Sen. 2016. This is the future of hospital sounds. Youtube. Retrieved from https://www.youtube.com/watch?v=RtfPekJcbWI

[30] Mardelle McCuskey Shepley, Debra D. Harris, and Robert White. 2008. Open-Bay and Single-Family Room Neonatal Intensive Care Units: Caregiver Satisfaction and Stress. Environment and Behavior 40, 2: 249–268. https://doi.org/10.1177/0013916507311551

[31] Anette Storesund and Anne McMurray. 2009. Quality of practice in an intensive care unit (ICU): A mini-ethnographic case study. Intensive and Critical Care Nursing 25, 3: 120–127.

[32] Ivo Stuyfzand. 2009. Salient Silent Alarms for the NICU (unpublished). Eindhoven Univerrsity of Technology, Eindhoven.

[33] Matthews Tara, Tye Rattenbury, and Scott Carter. 2007. Defining, designing, and evaluating peripheral displays: an analysis using activity theory. Human-Computer Interaction 22, 1: 221–261.

[34] Eduardo Velloso, Dominik Schmidt, Jason Alexander, Hans Gellersen, and Andreas Bulling. 2015. The Feet in Human--Computer Interaction: A Survey of Foot-Based Interaction. ACM Computing Surveys 48, 2: 1–35.

[35] Mark Weiser and John Seely Brown. 1996. Designing calm technology. PowerGrid Journal: 75–85.

[36] Mark Weiser and John Seely Brown. 1997. The Coming Age of Calm Technology. Beyond Calculation: 75–85.

[37] Marc Wilken. 2016. AlarmRedux. AlarmRedux. Retrieved December 31, 2018 from http://alarmredux.de/en/project-description/

[38] Jan Zekveld, Saskia Bakker, Annemarie Zijlema, and Elise van den Hoven. 2017. Wobble: Shaping Unobtrusive Reminders for Prospective Memories in the Home Context. In Tenth International Conference on Tangible, Embedded, and Embodied Interaction. Retrieved from https://dl.acm.org/citation.cfm?id=3024984&dl=ACM&coll=DL