Requirements for a Novel Interaction Device for Patients in Intensive Care

Jan Patrick Kopetz[1], Börge Kordts[2], Adrienne Henkel[3], Nicole Jochems[1]

Institute for Multimedia and Interactive Systems, University of Lübeck[1]
Institute of Telematics, University of Lübeck[2]
Institute of Social Medicine and Epidemiology, University of Lübeck[3]

kopetz@imis.uni-luebeck.de, kordts@itm.uni-luebeck.de, adrienne.henkel@uksh.de,
jochems@imis.uni-luebeck.de

Abstract

Due to the obstruction of verbal communication, mechanically ventilated patients in intensive care units often cannot impart their basic needs. Possible consequences are a prolonged healing process, delirium, and other complications. To overcome the communication barrier, we provide a specialized solution to support communication in intensive care. Since patients bound to the bed are not able to use traditional devices efficiently, we develop a novel interaction device tailored to the intensive care context.

In this paper, we present key requirements for the device, which are relevant to the interaction itself. These requirements resulted from a human-centered design process consisting of two studies, several workshops, and a comprehensive user and context analysis. We identified three categories relevant for the interaction, namely look and feel, sensors and actuators.

1 Introduction

Intensive care is specialized in the treatment of the most critically ill patients. In contrast to other hospital wards, intensive care units (ICU) are staffed with experienced personnel and characterized by a high nurse-patient ratio. The treatment puts a high strain on everyone involved, particularly patients themselves, their relatives, and therapeutic staff. Mechanically ventilated patients represent a significant patient group in intensive care units. In 2016 2.1 million cases of intensive care treatment were reported in Germany. About 425,000 of them were mechanically ventilated (Destatis, 2017, p. 76). The first step and a necessary condition to have the patient breathe autonomically again are to reduce the sedation. Since the human body gets used to mechanically supported ventilation, it has to readapt to breathing effectively on its own again. This can be achieved by gradually decreasing mechanical ventilation. This process is called weaning and causes high physical and psychological stress for patients. Based on their serious

ailment, the influence of sedating medication and the endotracheal intubation, patients often have problems to interact socially with therapeutical staff or relatives. Often reported strains are insufficiently treated pain (Bohrer et al., 2002), physical effort, fear, as well as feelings of unfamiliarity and identity loss (Abuatiq, 2015; Rose et al., 2014). These influences can slow down the healing process.

The importance of a continually (non-)verbal communication with patients is well-known among therapeutic staff, but there is a lack of effective supporting methods and in many cases, interaction is perceived as onerous (Abuatiq, 2015). A communicative interaction between patients and the therapeutic staff is inevitable to support recovering physical and psychic capabilities and must be established as early as possible. Literature shows coherences between positive communicative activities with ventilated patients and successful nursing results (Nilsen et al., 2014). Besides, lacking communication ability increases the risk of a poorer treatment, which reinforces the need for augmentative and alternative communication (AAC) in intensive care (Handberg and Voss, 2018).

In the last decades, information and communication technology (ICT) underwent a rapid evolvement, especially in health technology. Based on this trend, we provide a specialized solution to support ICU communication. Since patients bound to the bed are not able to use traditional interaction devices like keyboard/mouse and common alternatives like gesture and speech control efficiently, we develop an innovative *Ball-shaped Interaction Rehabilitation Device (BIRDY)* tailored to the intensive care context. It is designed to be used with the hand while lying in bed and consequently, not posing strong or special restrictions to the context of use. We decided to have a playful design to stimulate users exploring possible interactions with the device and the connected system. As balls have the affordance to play or interact with them, we consequently decided to specify a spherical shape. Patients may use BIRDY to interact with the ACTIVATE system, a technical solution to support communication, (re-)orientation and control in intensive care. A possible setup for the system can be seen in Figure 1.
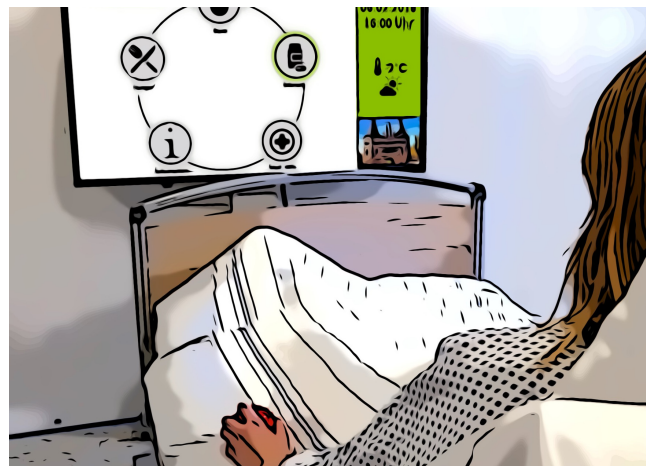

Figure 1: A possible setup of our system where a patient interacts with it using BIRDY.

In this article, we present key requirements for the novel interaction device BIRDY, which are relevant to the interaction itself. These requirements were gathered in a human-centered design (HCD) approach including two studies, several workshops and a comprehensive user and context analysis. Three categories relevant for the interaction were identified and addressed, namely look and feel, sensors and actuators. In the following, our applied methods and resulting insights are described.

2   Related Work

Various work on novel interaction devices has been done in the past. Yet, there is only limited work targeting the support of communication in intensive care, particularly during the weaning phase. Recently, several requirements for such systems were presented (Goldberg et al., 2017a). Based on the results, a controller was developed (Goldberg et al., 2017b). Its design is focused on domain-specific communication needs such as suitable content, infection control, simple design and capitalization of motor movements easily performable by ICU patients. Furthermore, the device is adaptable to the patients' physical deficits and impairments and provides feedback based on a vibration motor. As far as we can tell, the controller is not ball-shaped and hence, the interaction with it is only roughly comparable to those with BIRDY. Nevertheless, the work provides valuable insights relevant for the ICU setting.

Furthermore, several other ball-shaped interaction devices were already described. They are typically designed to control a traditional desktop computer. For instance, the *Roly-Poly Mouse (RPM)* was inspired by a roly-poly toy, which is keeping its position despite having a round bottom (Perelman et al., 2015). RPM combines the advantages of a standard mouse and 3D devices by allowing translation, roll, and rotation. However, RPM does not provide any actuators making the RPM lacking feedback needed for ICU patients. Another comparable device is *PALLA*, a spherical input device that also provides simple feedback (Varesano and Vernero, 2012). It is designed for games and leisure activities and is equipped with a set of sensors and actuators allowing a user and environmental input (e.g. device motion, mechanical stimuli or changes in external conditions) as well as feedback based on its RGB-LED and vibration motor. Due to its robustness, users may interact with it carefreely. Neither RPM nor PALLA is squeezable. *Qoom* is an interactive omnidirectional ball display using a foam rubber ball consisting of a sensor module, electrodes for touch sensing and a display (Miyafuji et al., 2017). By having roughly the size of a handball, it is too large for one-handed interaction in a bed. Besides, it does not provide further actuators. Some other similar, partially spherical, interaction devices are *TDome* (Saidi et al., 2017), combining a semi-spherical shape with a touch display, *Mouse 2.0* (Villar et al., 2009), a mouse enriched with multi-touch sensing on a hemispherical surface, and *Globefish* (Froehlich et al., 2006), an embedded 3-DOF trackball in an elastic frame. Unlike BIRDY they do not have a vulnerable target group and primarily aim at simplifying interactions with complex applications.

3   Method - Human-Centered Design

Since our system is planned to be deployed in practice, it will be evaluated under realistic conditions in a systematic field study to prove usability and to show the impact on the user groups. Hence, one major aspect is the acceptance of potential users, patients, relatives, and nursing staff. Towards this end, considering their needs already in the development process and focusing on the system's usability are crucial factors. Consequently, the development is based on the HCD process for interactive systems as specified in ISO 9241-210 (see Figure 2).
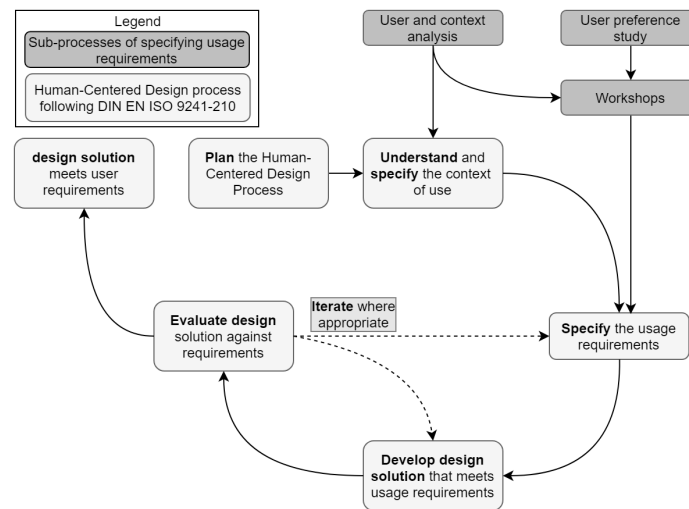

Figure 2: Human-Centered Design process following DIN EN ISO 9241-210 (ISO, 2009)

An important part of the HCD process is understanding and specifying the context of use and the users' needs and requirements. Based on these requirements, design solutions are developed and formatively evaluated. Once they meet the requirements in a summative evaluation, the process is finished. For our system, this will be the point where its impact can be tested in the field study. One part of this development process was specifying requirements for BIRDY. They were gathered in three partially parallel sub-processes. Besides requirements relevant to human-computer interaction, additional technical requirements were collected. However, these additional requirements are not discussed in this paper. Performed sub-processes are a user and context analysis (including qualitative interview studies as well as the construction of personas and problem scenarios), user preference studies and finally, workshops with stakeholders to discuss insights and derive concrete requirements. These sub-processes, their methods, and results are described in the following parts.

3.1   User and Context Analysis

For a better understanding of the user group, their needs, and the context of use, we conducted a user and context analysis. As a first step towards an analysis, a comprehensive literature search was done to identify similar work in the field and key findings from these. The search was focused on socio-technical systems to support communication in intensive care, especially the need for AAC in this context. Results show a demand for AAC in intensive care and only limited work on technical solutions (see Related Work). The patients' first reaction typically is attempting to communicate and receive information. Hence, one suggestion is to help patients "develop usable communication methods in connecting with their surroundings and enabling patients to express their feelings" (Tsay et al., 2013, p. 532). Furthermore, information on the context was gathered from the literature. Comprehensive information on context, persons involved and surroundings of ICU is given by Marx et al. (2014). Next, qualitative individual interviews with 16 patients and 16 relatives as well as 6 members of the medical staff were conducted. Additionally, three focus group interviews with 18 members of the therapeutic staff were carried out. Besides patients' needs from their own and from nursing staff's perspective, staff's and relatives' own needs were documented. On top, conductive and obstructive factors for the use of a system to support information, communication, and control in intensive care were identified. Based on these two steps, our interdisciplinary team iteratively developed personas to represent the target user groups. They were derived from the collected data and carefully modeled according to key characteristics, namely (un-)planned hospitalization, fitness, medical discipline, (non-)native speaker and (non-)delirious. Next, we modeled a typical weaning process to later construct persona-based problem scenarios. In further discussions, the scenarios were refined multiple times.

3.2   User Preference Study

An important factor of an interaction device is its look and feel as well as targeting a high usability. Considering our vulnerable target user group defining appropriate characteristic attributes is very important and choices must be well-founded. Thus, we conducted a user study to collect participants' preferences regarding device properties, especially referring to the optimal size, weight, shape, surface properties and deformability. A two-step process with a preliminary and a main study was conducted. We acquired 30 commercially available objects with various characteristic attributes potentially suitable for BIRDY that were tested in the preliminary study with 12 participants on an exhibition at the health fair *Gesundheit Morgen* in Kiel, Germany 2017. Participants randomly chose objects, tested and finally ranked them, resulting in a list of preferred objects. Based on these results and the criteria of the highest variety in the characteristic attributes a subset of eight objects was determined for our main study.

For this study, we recruited 40 participants, divided into two age groups: young and old adults (each 20). The young adults were aged from 18 to 40 years (M=23.45, SD=3.03) with a gender distribution of 11 females and the old adults were aged over 58 years (M=67.25, SD=6.6) with a distribution of 12 females. Participants were primarily asked about their object preferences. First, they conducted a pair-wise comparison, then ranked their favorites regarding predefined characteristics, namely size, weight, shape, surface properties and deformability. Finally, they

chose their overall favorite object regardless of a given characteristic. We documented choice and the underlying reason for all participants. Also, we recorded how they would interact with their favorite object. During the study, we created a setting that resembles realistic conditions in a clinic. Participants wore special gloves simulating swollen hands (and thereby a reduced hand mobility) and they lied in a hospital bed in a $30°$ upper-body position (Wang et al., 2016).

3.3   Workshops

The members of our research project work in several different disciplines, namely nursing research, hospital IT, hospital nursing, hardware engineering, software engineering, usability, psychology as well as augmentative and alternative communication (AAC). All previous results were discussed and refined in joint workshops to determine concrete requirements for BIRDY. In particular, personas and scenarios were enhanced and then used for further considerations finally leading to requirements. As a last step in our process we conducted several workshops with the stakeholders in our project to define actual requirements addressing the look and feel, sensors and actuators of BIRDY. During these workshops, we shared the results of previous work, clarified unresolved aspects of the preference studies, and discussed design options. The scenarios and personas, as well as the results of the user preference studies, were used to show potential use cases and for the discussion of possible solutions. In total, 20 experts were involved in the workshops. We had one workshop focusing on the application of the HCD process, four workshops to discuss technical details, scenarios, and personas, three workshops to consider preliminary requirements, two workshops to realize safety and security by design, and one workshop to analyze state of the art devices for AAC. Finally, we had six telephone conferences to finalize technical details and requirements with our hardware engineers *Cognimed GmbH*, who will realize the final product.

4   Results

In this section, we describe results of our subprocesses and how we used them to specify our requirements.

4.1   User and Context Analysis

The procedure resulted in an elaborated user analysis including descriptions of user groups along with their characteristics and personas of different types (primary, negative, served and customer). Furthermore, a detailed context analysis was done (Henkel et al., 2018). An organization and a task analysis gave additional information on the context. Several barriers and enablers could be identified. Here, we focus on those relevant to the interaction with BIRDY. Besides required time and expertise for installation and use, a slow system performance was named obstructive for a possible application. On the other hand, intuitive or natural operation, stability, and simple usage were found constructive. One key aspect is the intuitiveness since weaning patients cannot be expected to learn complex interactions. In fact, we plan to apply the system at an early stage in the weaning phase. Interaction and its effect must be immediately

clear because of the patient's short awareness phases. Most of the time, they must be instructed by the system itself. Furthermore, typical first interactions with our device must be taken into account within the context intensive care. A second key aspect is the usability despite various impairments caused by being bound to the bed, the medical condition, swollen hands, reduced manual force (due to age and condition), and reduced arm mobility due to invasive accesses. The interaction must not cause any injuries, requiring the device to be robust, having no rough edges and a good weight balance.

4.2   User Preference Study

After analyzing the gathered data, we got several rankings, based on the pair-wise comparison, preferences regarding fixed characteristics, and the overall favorite object. In combination with results from other analyses, a comprehensive overview of user preferences on ball-shaped objects is given. We already published the results of the study (Kopetz et al., 2018), an analysis of the choice of an overall favorite ball-shaped object and the underlying reason (Burgsmüller et al., 2018), as well as an analysis of the first impulse in spontaneous interaction with an overall favorite spherical object (Vandereike et al., 2018). These obtained rankings and known characteristic attributes of the objects were discussed in workshops with the project's stakeholder to finally determine the look and feel requirements for BIRDY. The results of these workshops are described in the next part.

4.3   Workshops

Our detailed discussions focused on results of the previous studies, on different designs and concepts, their feasibility and technical details. After all, we found a consensus among all experts and were able to define technical details, possible solutions, and designs. Furthermore, the stakeholders confirmed our design choices. Key insights are the confirmation of the spherical shape, a translucent and white design, a softness range as well as technical details, like midi speakers and the number of RGB LEDs for instance. Finally, all requirements were determined. They are described in the following.

4.4   Requirements

The results of our analysis and specification process are several requirements concerning the interaction. We identified three relevant categories, namely look and feel, sensors and actuators.

4.4.1   Look and Feel

Relevant look and feel related characteristics to be specified for our device were size, weight, surface properties and deformability. BIRDY was defined to have a diameter of $64\,\mathrm{mm}$ to $90\,\mathrm{mm}$ since the favored study objects regarding the size had these physical dimensions. Based on the study results, we specified a weight ranging from $40\,\mathrm{g}$ to $150\,\mathrm{g}$. Since the technical lower bound is $70\,\mathrm{g}$, the weight will be within the range of $70\,\mathrm{g}$ to $150\,\mathrm{g}$. The weight plays a minor role in the planned interactions on a bed surface. However, for potential mid-air gestures, the

weight becomes relevant. In this case, lower weight means less physical effort while interacting. Though, a low weight provides little tactile feedback. In summary, for mid-air gestures, the weight should be closer to the lower bound than the higher bound but not below. The surface was fixed to have a rough texture in order to be palpable by touch. Deep, detailed textures would make the device hard to disinfect and thus, would contradict hygiene guidelines. A small number of tiny nubs could be a pragmatic design on this matter. The majority of participants preferred objects with rough surfaces. Besides, ICU patients' medication causes swollen hands and decreased tactile perception. Therefore, a palpable tactile feedback is chosen, also to encourage interaction. Furthermore, the surface was set to have a high elasticity due to the decreased gripping force of weakened patients and the usage on a mattress. The device was determined to have a translucent and white design to keep the internal light undistorted but make the internal components invisible.

4.4.2 Sensors

In our study, we observed rolling or rotating the objects were most often used for a selection. As a consequence, we propose rolling and rotating interactions with BIRDY on the mostly planar bed surface. Additionally, we observed squeezing the object was predominantly used to perform a discrete action, e.g. confirming a choice. To enable these interactions, pressure, orientation, and acceleration sensors are required and therefore, specified within the requirements.

4.4.3 Actuators

Feedback has a major impact on the user experience, especially when interacting with a physical device. Feedback for interactions between humans and machines can be of passive nature or controlled by actuators. Besides passive feedback based on elasticity and the texture, BIRDY should provide tactile and visual feedback to encourage further interactions. Additionally, acoustic feedback should be implemented for possible errors. Hence, BIRDY needs a vibration motor, several LEDs, and a midi speaker.

5   Discussion

In this paper, we presented design choices and concrete requirements for a novel interaction device for ICU patients in the weaning phase. For an actual device and to evaluate its impact on the target user group, additional work has to be done. Results of the qualitative individual interviews and focus group interviews in terms of possible solutions for communication barriers show limited imagination of the participants. Hence, we organized the described workshops to propose and discuss solutions by a team of domain and engineering experts.

Our user preferences study was limited to acquirable objects and thus, in particular, the favorite objects were based on real objects and not based on a combination of favored attributes. Yet, results of the study, namely preferred size, weight and first interaction patterns, are comparable to the results of the study of Perelman et al. (2015). In the future, we plan to evaluate design choices and technical details of BIRDY in practice in a field study. However, the next step

to perform is the realization of the device in terms of hard- and software engineering based on present requirements. Moreover, we will implement the overall system based on defined requirements (Kordts et al., 2018) within the scope of our research project to finally be able to evaluate the effect of supported communication on weaning patients.

Besides, an analysis of the first impulse in spontaneous interaction with the actual device is planned to find suitable gestures and interaction options for weaning patients. We plan to evaluate different options for social interaction with therapeutic staff as well as relatives and for the expression of patients' needs.

Acknowledgements

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