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Conceptual Design of HMI and eHMI for an Autonomous Patient Transport System

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Abstract: This paper presents the development of a human-machine interface (HMI) and an external human-machine interface (eHMI) for an autonomous patient transport system (APTS). The idea of the APTS is to increase the efficiency of intrahospital patient transport and to reduce the physical stress on healthcare workers by autonomizing the transport of patients in hospital beds. The eHMI enables interaction with external persons, while the HMI supports direct patient communication. The development incorporated ergonomic and hospital-specific requirements. The eHMI and HMI were evaluated in an online study, assessing their usability and acceptance. The evaluation yielded a positive outcome in terms of perception and acceptance on the APTS.

Keywords: eHMI, HMI, AMR, hospital, patient transport, APTS

1 Motivation

The increasing proportion of elderly individuals in Germany is leading to an increasing number of hospital treatments and a great need for healthcare professionals [1]. However, there is already a shortage of healthcare professionals in Germany, which is leading to an increasing workload and physical stress for health care workers [2]. According to the German social accident insurance provider for non-state institutions within the health and welfare service sectors (BGW), one in two nurses suffer from musculoskeletal disorders [3]. Transporting bedridden patients is a physically demanding task with an increased risk of diseases of the musculoskeletal system [4]. An autonomous mobile robot (AMR), as already known from intralogistics, can be used to relieve health care workers of this task and reduce the physical and psychological stress. The overarching goal of the research described here is to develop an autonomous patient transport system (APTS) to ensure a safe and efficient transfer of patients in hospital beds. The system features a secure and user-friendly design, patient-adapted interaction, and comprehensive environmental sensing to enable accident-free navigation.

2 State of the Art

The need for robots in the healthcare sector, particularly in care, has been recognised for years. The possible applications of robots in healthcare are therefore being studied in numerous research projects, and the development of corresponding robotic systems is being successfully advanced [2, 5, 6].
The APTS incorporates the same functions as an AMR. AMRs are known from intralogistics and are already widely used there [7]. Consequently, the insights and applications from intralogistics can be transferred towards developing the APTS. In hospital logistics, including material, food and laundry transport, AMRs are already being used alongside established systems such as automated guided vehicles (AGVs) and pneumatic tube systems [8, 9].

The use of AMRs for intra-hospital patient transport is the focus of initial research approaches. Zachariae et al. [10] describe a system for autonomous wheelchair transport and guided walking through a hospital. Schneider et al. [5] developed a service robot for nursing tasks that navigates autonomously in hospitals and, in addition to other tasks, can also transport wheelchairs and guide patients through the hospital. Human-robot interaction in the hospital environment was examined by Horn et al. [11], whereby both non-verbal and informative verbal forms of communication were analysed. However, a fully autonomous system for intra-hospital patient transport in hospital beds has not yet been researched and designed.

In the context of developing the external human-machine interface (eHMI) for the APTS, existing research results from the automotive industry and automated vehicles (AVs) can be

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used. Bazilinskyy et al. [12] present various eHMI elements and technologies (e.g. display, LED light strip, projections) that are currently being used in eHMI research and development. They also evaluate user perception and understanding of these technologies [12]. The scheme developed by Gadermann et al. [13] can be used for a holistic view of eHMI including all relevant stakeholders, influencing factors and interrelationships.

3 Autonomous patient transport system

In order to successfully establish an autonomous patient transport system (APTS) in practice, acceptance by the stakeholders (healthcare professionals, patients and visitors) is of crucial importance. An important aspect here is the human-machine interaction, which takes place via the human-machine interface. This is where the present research focuses. The aim is to design the APTS and its interfaces in such a way that they promote trust in the system and enable intuitive and efficient human-machine interaction. In total, two interfaces have been developed, namely the eHMI (Figure 1, a), which is used for communication with external persons, and the HMI (Figure 1, b) for direct interaction with the patient.

In order to adapt the APTS in the best possible way to the conditions within the hospitals and to take into account the challenges and obstacles of intra-hospital patient transport, a hospitation was made to an academic teaching hospital at the beginning of the development process. This offered the opportunity to have an exchange with a doctor, a surgical planner and porters. The impressions from the observation were supplemented by findings and requirements from the literature and led to the requirements for the APTS.

The APTS shown in Figure 1 docks at the foot end of the hospital bed in the direction of travel. The direction of travel is defined in the patient's line of vision to reduce potential dizziness and disorientation, and to offer the patient more safety and comfort. The docking mechanism itself is not elaborated in detail in this paper but it will be based on existing mechanisms that have already been used in bed movers (e.g. PTS P4 Multi Bed Mover [14]).

The dimensions of the APTS were defined taking into account an ergonomic height grid according to Schmid & Maier [15]. Standing persons (female P5 and male P95 [16]) and wheelchair users (average eye height according to DIN 18040-3:2014 [17]) were taken into account. The height grid was used to ensure that the eHMI is positioned in such a way that the content can be seen by all persons and to ensure that the APTS does not tower over a wheelchair user. In addition to the ergonomic design, the dimensions of two commercially available hospital beds (e.g. Evario [18], Model S 962-2 [19]) were taken into account when dimensioning the APTS. This ensures that the APTS can be used on commercially available hospital beds. The height of the lying surface was set at 500 mm above the ground. Based on the ergonomic height grid and the dimensions to be considered, the following external dimensions of the APTS were defined: height: 1100 mm, width: 500 mm and underride height: 150 mm.

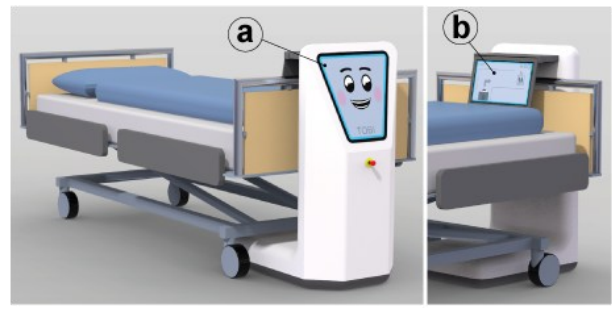

Figure 1: Autonomous patient transport system (APTS) connected to a hospital bed (a: eHMI; b: HMI).

As can be seen in Figure 1, the structural shape of the APTS is angular. The angular shape was chosen to allow the eHMI and the HMI to be fitted at the required height and to provide space for the coupling mechanism at the same time. The eHMI, which consists of a display (Figure 1, a), is mounted at the front of the APTS in the direction of travel. The types of indicator elements available for the eHMI and their suitability were developed and evaluated during a creative workshop (participants: 6 engineers from medical technology and interface design, age: 26 – 32 years, work experience: 0.5 – 7.5 years).

In order to ensure that the APTS appears trustworthy and non-intimidating an abstract representation of a face was chosen as the default view (Figure 1, a). To create an emotional connection, the APTS has been given a name, in addition to its friendly and childlike face, which is displayed on the eHMI. The name is based on the idea of using an acronym and achieving a humanisation through the use of a nickname. The result is the name TOBI, which originates form the term ‘transport robot’.

In addition to a friendly and amiable appearance the main task of the eHMI is to transmit information to the surrounding environment and the stakeholder within it. The information to be provided by the eHMI was developed based on insights gained from the hospital visit, discussions with a doctor, a surgical planner, and porters, as well as a literature review. These information are for eHMI and HMI: current direction of travel, change of direction, standstill, start of a movement, obstacle detection, evasive action, external assistance required; eHMI only: crossing the travel path is safe, warning of contact: HMI only: information on the route progress.

In the eHMI information is conveyed using pictograms since they can convey information regardless of nationality and language comprehension. In addition to the visual transmission of information, an acoustic signal is also emitted in safety-relevant situations, e.g. before the start of a movement (beep sound). In addition to the choice and design of the pictograms, attention has also been paid to the choice of colours to support the recognition of the information. Based on Carmona et al. [20], the colour cyan blue is used to indicate the driving status, orange for the change of direction and red for safety-related information. Green is used to symbolise consent (e.g. 'It is safe to cross'). The approaches for the pictograms were also developed as part of the creative workshop, followed by elaboration, evaluation, and finalization.

Alongside the external human-robot interaction via the eHMI, the patient-robot interaction takes place through the HMI. It is particularly important to build trust and acceptance, as patients in hospital are often in an exceptional situation and vulnerable. Due to the heterogeneity of patients, it is not possible to cover all use cases from the beginning, which is why specific use cases and subgroups of patients were defined and considered for the development of the HMI. Only patients who are awake and responsive, who have not received any premedication that could impair their cognition and who have a medically stable state of health that does not require continuous monitoring by healthcare professionals were considered. However, it was taken into account that the patients may have sensory impairments, such as visual or hearing impairments.

The HMI also consists of a display (Figure 1, b), which is attached to the APTS. After docking to the hospital bed, it is aligned for the patient and is then located at the foot of the bed in the patient's field of vision. The position of the HMI along the hospital bed and the technology of the HMI were also developed in the creative workshop. When dimensioning the HMI, care was taken to ensure that the display was within the patient's field of vision and that the pictograms and text were sufficiently large, considering the reading distance (1300 - 1800 mm) as recommended by Schmid & Maier [15]. In the HMI information is conveyed using pictograms and the familiar layout of navigation apps to enable language-independent interaction. In order to provide visually impaired people with the information, it is also possible to transmit the information using loudspeakers. The current HMI draft stipulates that the language and acoustic output of the information will be set by the hospital staff when the transport is requested. This information (e.g. deafness or preferred language) is usually stored in the patient's file.

4 Evaluation

The evaluation of the APTS design, the HMI and the eHMI, was conducted through an online survey. As part of the survey, 293 participants [162 female, 125 male, 2 divers, 4 N/A; average age of 44.11 years (range = 19 – 96 years; SD = 16.81 years)] were asked to provide feedback based on images of the APTS (similar to Figure 1) and other detailed images featuring the pictograms. In addition to collecting demographic data, parts of the Godspeed Questionnaire (GQS) (likeability, perceived intelligence, perceived safety) and the UEQ+ (novelty, value, aesthetics) were used [21, 22]. The UEQ+ was adapted to the GQS for a standardised question layout and used in the form of a 5-point scale (1 = negative item; 5 = positiv item) instead of a 7-point scale. The GQS and UEQ+ items were complemented by self-generated questions. The participants had no time limit finishing the questionnaire.

The survey on the perception of the APTS (GQS & UEQ+) yielded that the APTS and its design were well accepted. The best result was achieved by the GQS for likability (4.00, interpreted as likeable appearance), followed by perceived safety (3.56, interpreted as a trend towards a positive sense of safety) and perceived intelligence (3.48, interpreted as a neutral to slightly intelligent presence). In the UEQ+, the highest score was achieved for value (3.58, interpreted as a valuable design), followed by novelty (3.34, interpreted as an appealing perception, with the potential for innovation) and aesthetics (3.13, interpreted as a neutral perception towards the aesthetics). Figure 2 shows the results of the questions about perceived safety during the transport or an encounter with the APTS in the hospital and the willingness to be transported by the APTS.

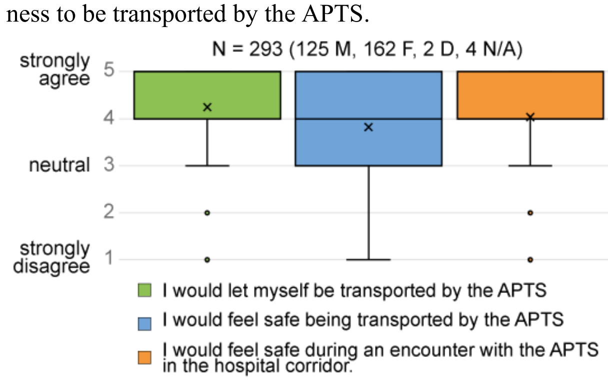

Figure 2: Participants' responses regarding their willingness to be transported by the system, their perceived safety during transport, and their perceived safety when encountering the APTS.

The boxplots illustrate a generally positive perception of the APTS. The highest agreement is observed for the willingness to be transported by the system (green, mean 4.25), followed by the perceived safety when encountering the system as a visitor (orange, mean 4.03). While the perception of safety as a patient during transport (blue, mean 3.82) is also predominantly positive, greater variability in the responses is observed, indicating the presence of some reservations. In summary, it can be concluded that the design engenders a fundamental level of trust; however, there is still scope for enhancement, particularly from the perspective of the patient.

5 Discussion and prospects

A concept for the APTS for communication with patients (HMI) and external persons (eHMI) was presented. The results of the evaluation highlight the need for improvements to the HMI. Furthermore, there is additional potential for improvement in the general perception in order to increase trust in the APTS. In conclusion, the concept and the associated evaluation results can serve as a basis for further developments in the field of autonomous patient transport systems.

Author Statement
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