An User-centred AI-based Assistance System to Encounter Pandemics in Clinical Environments: A Concept Overview

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Abstract: The current coronavirus pandemic has highlighted the need for enhanced digital technologies to provide high quality care to patients in hospitals while protecting the health and safety of the medical staff. It can also be expected that there will be a second and third wave in the corona pandemic and that preparation for future pandemics must be made. In order to close this emerging gap, we propose a concept aiming at boosting the adoption of AI and robotic related technologies to ensure sustainable, patient-centred care in hospitals. The planned assistance system will provide a continuous and safe monitoring of patients in the whole hospital environment from entrance to the ward, including data security and protection. The benefits consist in a fast detection of possible infected persons, a continuous monitoring of patients, a support by robots to reduce physical contacts during epidemics, and an automatic disinfection by robots. In addition to the technical challenges, medical, social and economic challenges for such an assistance system are discussed.

1 INTRODUCTION

The COVID-19 pandemic is affecting all continents including Europe. The globalisation and increasingly interconnected economies mean that most countries are, and will be affected by COVID-19 and its consequences. Global effort is therefore required to effectively break the chains of the virus transmission in the population, while protecting the health of frontline workers, particularly health professionals, from infection.

Robotics, sensor technology and AI assistant systems can significantly reduce the risk of infectious disease transmission to frontline healthcare workers by making it possible to triage, evaluate, monitor, and treat patients from a safe distance without having the risks of contagion. In addition, robots, sensor technologies and AI assistant systems have the potential to be deployed for disinfection, delivering medications and food, measuring vital signs, and supporting health professionals in various tasks. As the epidemic escalated and a great number of health professionals have been infected by the virus during their work, the benefits of robotics are becoming increasingly clear.

We intend to develop an assistance system in order to improve healthcare uptake and treatment of patients during pandemics (e.g. COVID-19). The system enables an increased speed and effectiveness of diagnoses, treatment and monitoring of patients, and thus protects patients, caregivers and healthcare professionals in hospital settings. The objectives comprise a continuous, contactless monitoring of patients and medical staff through optical sensors, a secure hospital infrastructure and assistance robots to support caregivers. To achieve our ambitious objectives, we present each step required to integrate such an assistance system within a hospital ecosystem, whereby an interdisciplinary team with partners from industry, science and healthcare is necessary.

In order to outline our findings, this paper is structured as follows: Sect. 2 provides a system overview of all aspects of the proposed solution. In Sect 3. the secure infrastructure in the hospital is described. This

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is followed by the description of the tracking of patients and medical staff by means of smart sensors in Sect 4., Sect. 5 focuses on the contactless extraction of patients' vital parameters. Sect. 6 follows this with the use of telepresence robots. All technical details and other factors are discussed in Sect. 7. Conclusions for further actions are presented in Sect. 8.

2 SYSTEM OVERVIEW

The global objective of the assistance system is to improve healthcare uptake and treatment of patients during pandemics (e.g., COVID-19) and beyond in hospital settings for patients, caregivers and healthcare professionals by increasing the speed and effectiveness of diagnoses, treatment and monitoring of patients. This concept is visualised in Figure 1 and represents an assistance system in the clinical environment to improve treatment and care for patients, enhance the work balance of medical staff and improve logistics while reducing costs.

2.1 Objectives of System Concept

Our system concept is divided into two technical objectives, which are:

1. Fast Triage and Continuous Monitoring: of potential infected patients in hospitals during pandemics by the use of optical sensors to measure vital signs automatically in the entrance and emergency rooms for fast detection of infected people and the contactless continuous monitoring of patients in patient rooms and corridors for automatic health status determination and for pathway tracking.

2. Protection of Patients, Caregivers and Infrastructure in Hospitals: during pandemics by deploying a contact map for detecting patients and clinical staff in order to track and trace contacts of persons in the hospital using optical sensors to isolate infected persons and contain superspreading events.

Furthermore, the system concept envisages the deployment of assistance robots for automatic disinfection and for working tasks of clinical staff, thereby reducing contact between patients and caregivers, and the assurance of the system inviolability against cyberattacks by redundancy in the systems and stable firewalls.

This is accompanied by objectives for rapid and effective conversion of hospital processes and structures in the case of epidemics and the establishment of a reliable, quantifiable and large-scale AI assistance platform for the deployment in European hospitals.

2.2 Related Technologies

Autonomous monitoring of the health status is a crucial task during pandemics. We aim to have a fast detection in the hospital entrance of possible infected persons for isolation, and the continuous monitoring of already infected. The measurement will be automatic, contactless to prevent contamination and fast for high throughput. Both tasks can be realised by the monitoring of vital parameters by means of optical sensors. Literature shows that there is research in determining heart rate (Poh et al., 2010; Verkruysse et al., 2008) and respiration rate (Wiede et al., 2017; Lukac et al., 2014) remotely in various application fields. However, non of them targeting the fields of patient recovery monitoring and triage of patients, which both have different demands on the algorithms (see Sect. 5.2 and 5.1). Monitoring respiration rate has turned out to be particularly advantageous due the fact that COVID-19 patients suffer from shortness of breath. To date, the remote, contactless determination of patients' vital parameters has not yet been part of a large-scale clinical survey for pandemics comparable to the one planned in this project concept. Therefore, we have chosen this as a significant focus area in this project where vital parameter monitoring will be done in 2D images captured from 3D smart sensors.

Furthermore, emergency situations such as falls and circulatory collapses have to be detected immediately. If such emergency cases are not immediately recognised, it is conceivable that the patients' health would suffer and that the care costs would increase. In contrast to the approach using wearable sensors for fall detection by (Ferrari et al., 2012), the authors of (Rantz et al., 2013) investigated an image-based method that detects human falls through analysis of a depth map. This depth map can be partially rendered as a 3D image without the full rendition (colour / brightness) of the scene. The proposed method was tested successfully in multiple hospitals (TRL 7) (Rantz et al., 2013). A fall detection which is adapted to fisheye images (Seidel et al., 2020) is integrated in our system concept and will perform fall detection without physical contact. Furthermore, an accurate tracking of persons is guaranteed while respecting privacy issues.

Another aspect of our system is the consideration to use robots. Robotic solutions for hospitals and in the healthcare ecosystem can be organised into categories depending on their application and use cases (Bodenhagen et al., 2019). Telepresence robots are

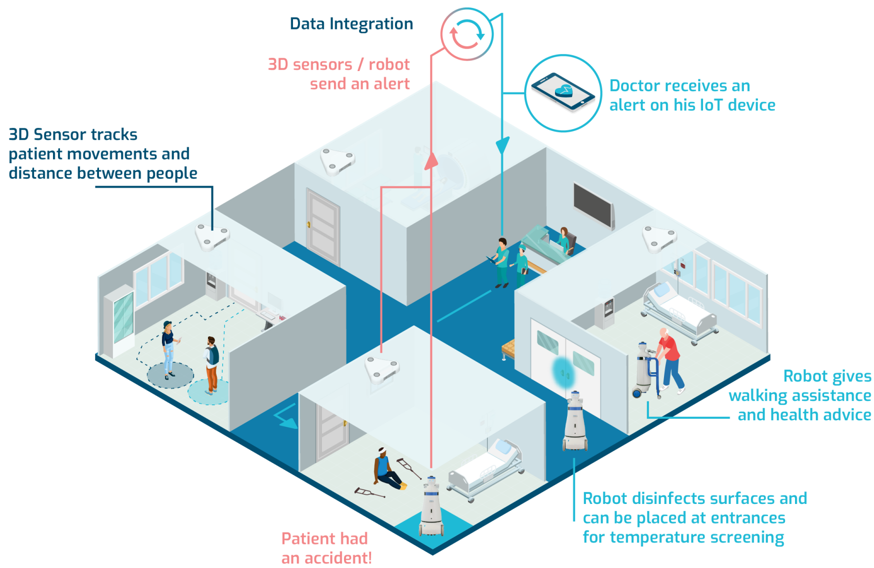

Figure 1: Overview of the technical assistance system with 3D sensors, a robotic platform and a data integration unit. The system can be integrated in a hospital ward. As an example different use cases are shown in the patient rooms and in the corridor.

remote-controlled robotic devices that enable a person - such as a health professional - to be virtually present, to interact and socially engage with patients remotely and to physically manipulate the robot and its immediate surroundings. This way, the user is able to maintain a large degree of control over their virtual presence and interactions with people and objects in that physical space. Potential use cases envisaged within the project include reducing physical interactions between patients and carergivers.

There are existing studies of telepresence robots supporting elderly people and patients that demonstrate strong, positive influences over the interactions with a manageable overall level of care delivered to patients (Cesta et al., 2016; Gonzalez-Jimenez et al., 2013; Lee et al., 2017; **?**).

Especially in the COVID-19 pandemic, patients suffered from isolation effects. Therefore, existing robots will be integrated for telepresence purposes, to guide and assist patients in hospitals. Telepresence robots effectively and accurately monitor the health status of the patients, can alert carers where specific problems are arising and are able to intervene where possible and necessary.

They are also able to actively remind or "nudge" patients to keep an appointment or to take their required medicine. Moreover, the robots will be capable of physical transportation tasks such as movement of physical objects (meals, medical devices) or physically guiding patients and their families themselves from one location to another within the hospital environment. Furthermore, the robots can perform tasks for automatic disinfection of areas in the hospitals by using ultra violet (UV) light. Data from robots, 3D sensors and other Hospital Information System (HIS) related sources will be fused within a data integration unit, analysed and interpreted by the hospital staff. The data is stored in dedicated servers hosted in the hospital and analysed by an AI module designed to identify further emergency situations requiring decisions and intervention.

3 SECURE INFRASTRUCTURE

Since the collected data contains a huge amount of sensitive information from different sensors, the data integration into the HIS needs to meet certain requirements regarding the data management infrastructure, privacy and security. A secure communication, computation, data management and standardisation is essential for a reliable AI assistance platform in hospitals. A distributed system design is required to support all hospital AI components. For this, multiple means of visualisation, computing, communication architectures as well as database management systems for real-time operation and security will be considered. Data specifications are defined beforehand, especially the outputs of the AI methods employed by the robots and smart sensors. Additionally, regulatory requirements like necessary certifications, compliance, and data anonymisation needs to be considered.

3.1 Data Management and Interfaces

The data management comprises services for systematically collecting data from the registered sensors, robots and other HIS-related sources, as well as the management for further processing and distributing data in a secure way. It provides the basis for ensuring interoperability between data sources, providing a common operational picture in real-time during hospital emergency situations. Events, such as incoming messages from HIS and Health Portals (HL7, CDA, FHIR-standard) may trigger further actions such as email-indications, or tracing and tracking of medical personnel, patients, mobile equipment and devices across hospital premises.

Due to the heterogeneous data sources (e.g. hospital robot) and streams (e.g. smart sensors), a harmonisation of the data is required. Algorithms transferred herein, thus, could include tools for descriptive analytics (i.e. statistical summaries of integrated robot and sensory data), time-series analysis of critical parameters (e.g. symptoms like changes in temperature, respiration rate, and pulse), and anomaly detection (e.g. using auto-regression). This shall provide medical staff with holistic descriptions of the patients' states, while also feeding key features for diagnostic detection of critical events into the event bus. In order to allow medical staff to interpret and use information from these heterogeneous data sources, data harmonisation and visualised analyses will be provided. Finally, a set of visual components should be integrated into the hospital system by providing front-end visual analytics integrated into the end-use environments. Hence, medical staff can monitor vital parameters and alarms on a generic hospital control display component. Customised visual components will be prepared for displaying status of selected components e.g. current vital parameters and the patient's medical record from the HIS.

3.2 Data Privacy and Security

To provide transparency, data privacy and security (legal and ethical) restrictions and policies with an elaborated roles and rights concept will be enforced and monitored. Especially during public health crisis, hospitals have been targets of cyberattacks in the past. Thus, the inviolability of the system against such attacks needs to be assured by redundancy in the system and stable firewalls. IT security and user management policies ensure that only eligible personnel can access the systems' sensitive data. The work of (Dašić et al., 2017) explores solutions for clinical monitoring via state-of-the-art of video surveillance clouds. Another approach is to process images and videos either locally by a 3D sensor and a robot itself or remotely via a secure and powerful processing node that routes generated meta-data to a data integration unit. No video data itself is processed by the integration unit and only necessary data is transmitted through the hospital network, thus improving data security. In addition, for data protection reasons all data is processed directly in the hospital and no data is transferred to a cloud. Moreover, network monitoring across all layers of ISO/OSI model, forensic analysis for investigation of security or operational incidents should be provided.

4 RE-IDENTIFICATION AND TRACKING

In order to determine user-group-specific information it is necessary to distinguish between the user groups: clinical staff, visitors and patients. The re-identification of users in the clinical environment ensures that information retrieved from sensors like for tracking or vital parameter monitoring are assigned to the right person. Persons will be re-identified by analysing the 2D images from the smart sensors. In contrast to body mounted sensor technology such as radio-frequency identification (RFID) technology image sensors have advantages in terms of number of required sensors and are not object-related. To reduce the number of necessary 2D image sensors per room, fisheye lenses with a complete 180° top view (covering the entire scene below the ceiling) are used. Deep learning approaches can be adapted to re-identify persons in fisheye images. Focusing on facial information as performed by algorithms based on front-view images is error-prone for top-view image analyses since the face itself covers only a small portion in the image. Therefore, features incorporating the entire appearance of the patient (like AMOC (Liu et al., 2017)) and the training of a detector with synthetic data (Scheck et al., 2020) will be used. The goal of this system concept is to achieve a high (rank-1) identification rate while providing a confidence value indicating the certainty of the identification. For this, existing re-identification methods have to be retrained and fine-tuned on top-view fisheye images.

A continuous movement tracking in the hospital will retrieve and analyse the position of all persons within the hospital based on the person re-identification. In case someone is reported to be infected, the previous pathways of this person in the hospital can be traced back, relevant persons are informed and automated disinfection processes can start. For this, smart 3D sensors are mounted at the ceiling of each hospital room to track only the identified patients in the room. The 3D sensors consist of multiple 2D fisheye image sensors and capture images for anonymously analysing persons' locations in the hospital. Fully integrated distance maps between people to identify contact chains and potential infection areas will be measured by the smart sensors directly in 3D, after the tracking of identified persons is completed. Furthermore, emergency cases such as falls can be detected by means of Support Vector Machine (SVM) classifiers. They are based on the 3D pose referring to the 3D skeleton extraction. If a patient falls down onto the floor, the SVM would detect it and the smart sensor sends an alarm signal to the data fusion unit which immediately informs medical professionals or the robots.

5 VITAL PARAMETERS

The contactless measurement of vital parameter is sensible to do at the hospital entrance to isolate potential infected persons and for the continuous monitoring of already infected in the wards. To date, the remote, contactless determination of patients' vital parameters has not been part of a large-scale clinical survey for pandemics as planned in our assistance system.

5.1 Triage in Hospital Entrances

In order to establish a fast detection of potential COVID-19 infected people, an access lock is to be installed in the entrance area of the emergency room. Symptomatic COVID-19 cases are characterised in particular by shortness of breath and fever. In case of a combination of sympathetic symptoms, these patients have to be isolated from others immediately in order to prevent contagion. The measurement will be carried out using thermal imaging cameras to measure temperature and RGB cameras to determine the respiration rate. The measurements will be fully automatic and without contact to the patient. This saves time and reduces the possible sources of infection.

For the respiratory rate measurement, the patient needs to sit in front of a camera for 30 seconds without moving. With an RGB camera it is possible to detect and track the torso motions (Wiede et al., 2017). This can be realised by determining a region of interest (ROI) on the upper body with an detector (Liao et al., 2016), then detecting minimum Eigenvalue features in this region (Shi and Tomasi, 1993) and track them by means of optical flow (Tomasi and Kanade, 1991). A time channel can be extracted from the trajectories of the tracked points. The signal information is improved by applying a bandpass filtering and a principal component analysis (PCA). Finally, the respiration rate is obtained from the signal spectrum's highest peak. This value is one indicator for the diagnoses made by the clinical personnel.

First tests in a hospital during the first wave of COVID-19 crisis have proven successful (Wiede et al., 2020).

5.2 Recovery Monitoring

Furthermore, the embedded omnidirectional sensors in the patient rooms enable the remote monitoring of the vital parameters such as heart and respiratory rate. To account for data privacy, the person identification assures on the one hand that the data is retrieved only for the user groups patients and medical staff (not visitors), and on the other hand that the retrieved data is assigned to the right person. In case the health status changes drastically or emergencies occur, an alarm is triggered and either a robot or a caregiver will come and assist.

Unlike in the case of triage, an omnidirectional image will be processed. This has the advantage that the whole room can be monitored, but at the expense of strong distortions. One solution lies in the use a virtual perspective camera such as proposed by Meinel et al. (Meinel et al., 2014). Thereby, the detected person in the omnidirectional image will be projected to an artificial perspective image.

First, the heart rate can be estimated by detecting the face of a person by the method of Zhu and Ramanan (Zhu and Ramanan, 2012), determining a person-dependent skin colour model and tracking the features with optical flow (Tomasi and Kanade, 1991). Subsequently, all pixels in the face matching the skin colour model criteria are extracted and averaged in every time step to obtain three colour channels. These channels are normalised, bandpass filtered and processed by an ICA. Finally, the heart rate is determined by dominant frequency within the Fast Fourier Transform (FFT) spectrum. This determination of the respiration rate is analogous to the procedure described in Sect. 5.1.

The use of omnidirectional sensors for the determination of heart and respiration rate has already been investigated for ambient assisted living (AAL) applications (Wiede et al., 2019), whereby a transfer into the clinical area is generally possible. Moreover, the mobile robot platforms are able to detect vital parameters in the same fashion as their additional tasks in the hospital.

6 ROBOTS

In the context of pandemics, the field of robotics in combination with intelligent sensors offers enormous potential to meet some of the challenges ahead, i.e. automation of processes in hospitals, reduction of physical contact between people and better monitoring of patients' health state. We will focus on telepresence robots and personal assistants, since these are robot types that seem to be particularly well suited to meet rapidly expanding healthcare demands in epidemics. In order to be really useful these robots need to be aware at all moments of their current position. We will use algorithms such as semantic SLAM (Bowman et al., 2017), long term SLAM in dynamic environments (Biber and Duckett, 2009; Pomerleau et al., 2014), and strategies for switching between SLAM (when exploring and updating the map of the world) and localisation (when exploiting the current map information). It will be necessary that the robot walks at the same pace as patients/visitors, while the robot is guiding the person to reach a specific destination or when a telepresence visit is taking place. Distance between robot and the person should be fixed according to the circumstances. During telepresence meetings, the robot should maintain a close distance to allow a private conversation, but a longer distance for a chat with a group of people.

6.1 Telepresence Functionality and User Interfaces

Especially in the COVID-19 pandemic, patients suffer from isolation effects. Telepresence robots enable health professionals and relatives to be virtually present, to interact and socially engage with patients remotely, and to physically manipulate the robot and its immediate surroundings. However, associated benefits as well include the reduction of physical contact between patients and care givers. The human-robot interaction will be based on gesture recognition, as gestures are natural communication codes, and complementary to a graphical user interface (GUI). The information being displayed on the GUI monitor will depend on the user group and on the task being carried out. Another option can be voice interaction, especially for patients who have difficulties moving. However, in noisy environments, achieving acceptable performances can be very challenging

6.2 Robot for Assistance, Transport and Disinfection

Furthermore, assistant robots as shown in Figure 2 can take responsibility for simple tasks and routines, allowing nurses to focus on more complex and pressing patient needs and reducing physical contact to prevent infections. These simple tasks will include performing regular check-ups on patients in a critical state, reminding patients to take their medication, to effectively and accurately monitor the health status of the patients, to alert carers where specific problems arise and to intervene where possible and necessary. In this context, enabling robots with the skill of verifying and re-identifying people is necessary to provide services to the right person. Perceiving people is needed in order to navigate efficiently and safely, to approach people in an appropriate manner, to initiate and maintain social interaction, and to recover the contact with people. Together with the ceiling-mounted smart sensors, robots will jointly reduce the amount of physical contact between healthcare professionals and patients and ensure that patients do not get lost and do not leave their ward or room unattended, informing care staff when necessary. This type of support allows for an immediate and automated retrieval of medical findings and issuing alerts in pre-defined emergency situations such as falls, respiratory distress and circulatory collapse. Moreover, robots are capable of physical transportation tasks such as movement of physical objects (meals, medical devices) or physically guiding patients and their families themselves from one location to another within the hospital environment avoiding crowded places.
Furthermore, the robots will perform tasks for automatic disinfection of areas in the hospitals by using UV light, which kills the pathogens. For this purpose, a path planning is implemented in the hospital to disinfect all areas and not to forget any corner.

7 DISCUSSION AND CHALLENGES

To separate infected from non-infected persons as early as possible, it is unavoidable to identify the user group of each person in the hospital and track its pathway through the hospital. With the help of multi-object (person) tracking (MOT) each person gets an automatically assigned ID. Challenges in MOT are ID switches which occur mostly while person crossings or during occlusions.

Figure 2: Overview of the different functionalities of the robots. Besides the transportation of different containers and goods, the robot can be a mobility assistance for patients or disinfect hospital wards.

The challenges for the remote vital parameter determination consists in high accuracy requirements, low resolution in omnidirectional sensors, robustness against illumination and motion artefacts. Furthermore, a night working mode by operating in near infrared has to implemented. It is crucial that all remote vital parameter algorithms are validated in the hospital by gold standard measurement methods.

In addition to the optical sensors, robots can be employed to automate processes in the hospital. Assistance robots can perform time-consuming transportation tasks, as well as being a mobility support for patients or UV-disinfecting hospital wards. This allows nurses to focus on more complex patient needs and reduces physical contact preventing infections. For this purpose, path planning and perceiving people in the dynamic environment is crucial for a save navigation and appropriate human-robot interaction.

During the COVID-19 pandemics many healthcare related institutions have been targeted by cyberattacks which shows the need for the identification of data leaks in the digital infrastructure. This fact leads to two recommendations for action; first, the improvement of existing infrastructure especially in hospitals and second, the consideration of these aspects during the development of new technical systems.

Beside data security one of the major challenges is the protection of the user data and its identity. For this, the data captured by a fisheye camera in a 3D smart sensor device needs to be anonymised. To overcome the trade-off between privacy and video analytics each usergroups' data (patient, visitor, staff) is anonymised through face anonymisation and the addition of depth maps.

In the near future the assistance system is planned for large-scale piloting in several hospitals in the EU. A secure infrastructure for sensor-communication and data storage needs to be integrated into the telematics infrastructure of the hospital. The major challenges here are the design of the interface due to different HIS-providers on the market and the lack of technical and administrative staff at the hospitals. To increase the user acceptance in hospitals it is necessary to create an AI-guidbook with a fast-response reaction plan for switching the hospital to crisis mode.

8 CONCLUSION

In our work, we proposed a concept for an assistance system in hospitals to encounter the effects of pandemics such as COVID-19. The components of such a system consist of the contactless measurement of health state for patients and medical staff, of robots with several assistance and guiding function and the implementation in a secure hospital infrastructure. Whereas single components are in the market nowadays, a combination of these tools is not implemented in clinical environments. Therefore, the next step is the implementation in a hospital embedded during a clinical study in order to measure technical, medical, social and economical effects. We expect a significantly smaller amount of infections in the hospital, a reduction of workload for caregivers and a cost reduction due to digitalisation.

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