Social Interactions of Artificial Ventilated Patients in Intensive Care – an Example of a Monitoring System

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***Abstract*—Only qualitative data on social interactions between ventilated patients and their caregivers and families are available from interviews. To improve sociological research in this highly sensitive setting, a concept of an observation system is described and presented. The system will be autonomous and is designed to collect information for a better understanding of the impact of using autonomous life-supporting systems like mechanical ventilation on the social system family with as minimal interfering as possible to the considered framework. From the analysis of the pilot study a multi sensor system, which combines Kinect, infrared-array and sound pressure data of a happening social interaction, is derived.**

***Keywords*—social interaction; multi sensor system; intensive home care; artificial / mechanical ventilation.**

I. Introduction

The demographic change with an increasing number of older people and people with the need of care leads to a rising importance of home care services and understanding of the environment of the patients, their families and nursing staff. In addition, as people get older, the probability of being in need of care rises [1]. In Germany, 76% (2.59 million) of people in need of long-term care were treated outpatient in 2017 [1]. Figure 1 shows the increasing number of ventilated patients in Germany, which emphasizes the implication of a growing need for services in intensive care. Lloyd-Owen et al. (2005) identified a prevalence of 6.6 out of $100,000$ people in Europe are mechanically ventilated at home [2].

An impact of the affinity to human likeness of assistive devices like prothetic hands has already been described elsewhere [4]. The uncanny valley theory describes that the human likeness and affinity of industrial robots is low [4]. Moreover, a toy robot can represent a medium human likeness and affinity. Whereas, the human likeness of prosthetic hands is high, the affinity is very low. In addition, a healthy person is highly human like with a high affinity [4]. This theory of description might also be applied for other life supporting systems like mechanical ventilation devices, which changes the perception of the patient in need of intensive care to their environment. It might additionally be implied that the social family system and in particular the social interactions within the family and/or caregivers might be influenced by the mechanical ventilation. So far, no studies have been published in this regard.

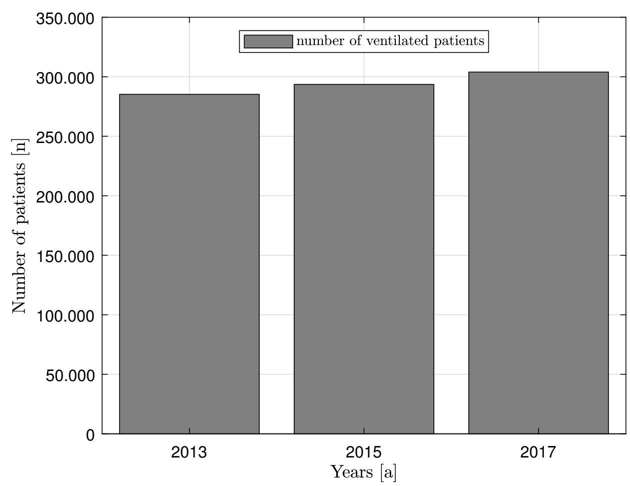

Fig. 1. The increasing number of ventilated patients in Germany [5].

Regarding quality of life of invasive ventilated patients, only few studies are available [6]–[9]. To our knowledge, no studies dealt with the social life of the ventilated patients, but with the safety of these patients [10]–[14].

At this point it remains unclear, to what extent intensively-cared patients or which dimensions of technical realization of autonomously life-supporting systems change the embeddedness of patients in the family context [15].

Artificial invasive ventilated patients are an example for people in need of long-term care. [3] describes the connection of social interaction and nursing procedures as a strong link. Therefore, they cannot be considered as separated actions.

In Section II, the method is described with the individual components (pilot study, measurement setup and video analysis). The results are discussed in Section III, additionally a concept to collect more detailed information about social

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interactions in the context of mechanical ventilated patients with intensive care staff, therapists for artificial ventilation and in the best case a social family system is proposed in Section IV. It has to be kept in mind that most invasive ventilated patients spend most of their time in bed, which is caused by their disability and/or the severity of the disease [13]. Therefore, adapted configurations for the novel system are described, which provide the patients intimacy. This is followed by the conclusion, in Section V.

II. METHODS

A detailed description of the conducted pilot study, measurement setup follows. In addition, the analysis of the generated data is discussed.

A. Pilot Study

The pilot study was conducted with two professional therapists for artificial ventilation. These therapists performed the process of suction via tracheostomy tube and the change of the tracheostomy tube on a training mannequin (Resusci Anne). The tracheostomy tube provides a bypass of the larynx and pharynx area of the throat and is used for the invasive mechanical ventilation of a patient [16]. In addition, the process of suction via tracheostomy tube was also performed on a participant. These nursing processes were in the focus of this pilot study as they represent typical nursing procedures for invasive ventilated patients [17] [18].

TABLE I
MEASURED NURSING PROCEDURES AND CONSTELLATIONS

Procedure	RGB-D pos.	Subject	Caregivers	Repetitions
Suction	1	Mannequin	1	7
Suction	1	participant	1	5
Change	2	Mannequin	1 and 2	5

In total, 29 minutes and 45 seconds of data within 17 videos (see Table I) were recorded during this pilot study.

B. Measurement Setup

In the pilot study, a depth camera (RGB-D), Microsoft Kinect v2.0, was used for data collection. During the measurements only the points cloud and joint positions were stored. The RGB-D sensor was placed in two different positions around the patient's bed, as shown in Figure 2.

The first position was used during the process of suction via tracheostomy tube, which was performed by one professional caregiver. In addition, the second sensor position was used during the process of tracheostomy tube change. This position was selected based on the fact that two professional caregivers were executing the tracheostomy tube change together, so that the RGB-D sensor in position one would have been covered by a caregiver.

C. Video Analysis

The recorded RGB-D data was analyzed independently by two researchers to determine the patterns of social interactions between the patient and caregiver. Therefore, the data was analyzed by searching for typical patterns and the orientation of the caregivers to the participant or training mannequin. The videos were analyzed regarding the following questions:

- Which patterns represent social interactions?
- Which patterns represent typical nursing procedures?

During the acquisition, only the point clouds of the RGB-D sensor were saved. The Microsoft Kinect Studio v2.0 delivers the joint positions out of the point clouds.

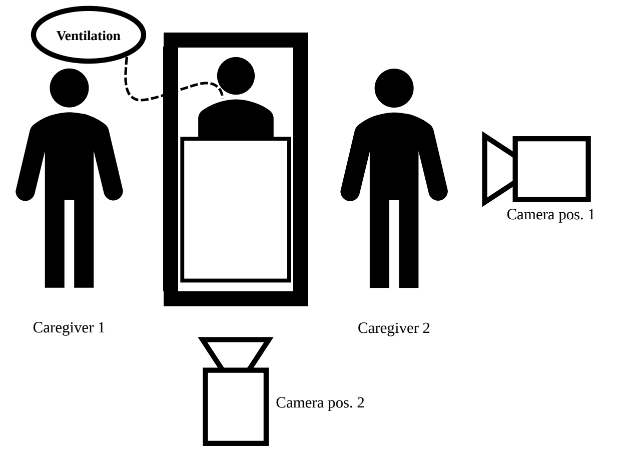


Fig. 2. Positions of the RGB-D sensor and the caregivers during the pilot study.

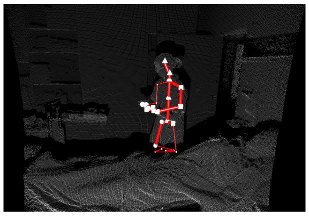
III. RESULTS

The processes were divided in two different nursing procedures. In Figure 3 and Figure 4, the red lines illustrate the skeleton of the caregiver and the white circle, square and triangle present the joint positions, delivered by the Microsoft software Kinect Studio v2.0. The collected data of the pilot study shows repetitive patterns during the nursing processes of suction via tracheostomy tube and the change of the tracheostomy tube. The differences of these procedures are discussed below.

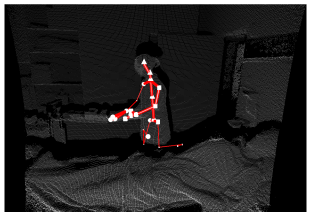
A. Suction via Tracheostomy tube

Figure 3 presents and describes the process of suction via tracheostomy tube. This process was performed at a participant by a therapist. As shown in Figure 2, camera position 1 is used to document this procedure. The skeleton and joint positions, delivered by the software, are stable for the upper parts, but not the (for this process irrelevant) lower body parts, due to the shadow of the bed, which was placed between the caregiver and the RGB-D sensor (Figure 3).

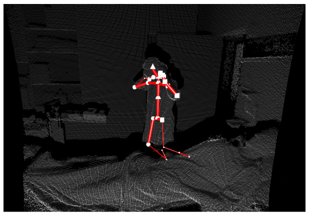
The process starts with disinfecting the hands, where the caregiver was averted from the participant. Afterwards, the caretaker puts on rubber gloves and a mask, also averted from the participant. The suction hose gets connected and the caregiver puts on an additional sterile glove, while facing the participant. The mechanical ventilation gets disconnected and the actual process of suction via tracheostomy tube is performed, the caregiver is as well facing the participant. Then the mechanical ventilation gets reconnected and the caregiver is cleaning up, still facing the participant. The last step is the



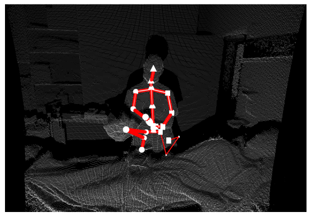
1. Disinfecting the hands. Averted from the participant.



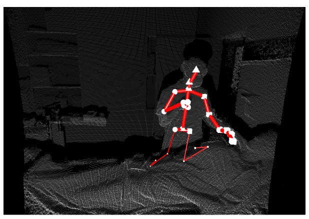
2. Putting on the rubber gloves. Averted from the participant.



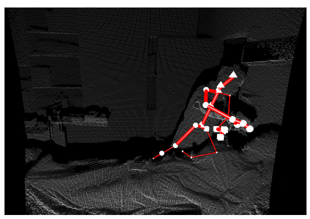
3. Putting on the mask. Averted from the participant.



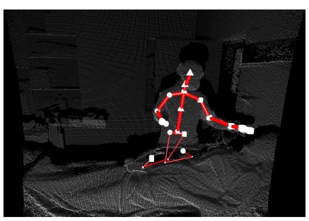
4. Connecting the suction hose and putting on sterile glove. Facing the participant.



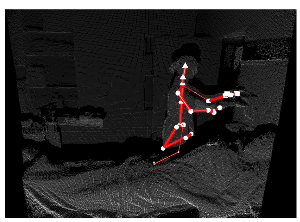
5. Disconnection of mechanical ventilation. Facing the participant.



6. Process of suctioning via tracheostomy tube. Facing the participant.



7. Reconnecting of mechanical ventilation and cleaning up. Facing the participant.



8. Disinfecting the hands. Averted to the participant.

Fig. 3. Process of suction via tracheostomy tube.

disinfection of the caregivers hands, while averted from the participant.

As shown in Table II, an interesting behavior by the nursing staff executing the process of suction via tracheostomy tube at a participant or training mannequin was found. In this study, the caregivers were averted from the participant during the process of hand disinfection before executing the process of suction via tracheostomy tube four out of five times, whereas the training mannequin was faced by the nursing staff five out of seven times and the nursing staff was averted only one time.

Being averted from the patient suggests that there is no evidence of social interaction based on data from a RGB-D sensor.

TABLE II
ORIENTATION OF THE CAREGIVER IN RELATION TO THE PARTICIPANT DURING THE PROCESS OF HAND DISINFECTION.

Type of patient	**Orientation**		
	Averted	Halfway facing	Facing
Training mannequin	1	1	5
participant	4	0	1

B. Tracheostomy tube change

Figure 4 shows the process of the tracheostomy tube change. For this nursing procedure, the camera position 2 was used and the caregiver 1 and caregiver 2 are performing the nursing procedure (as seen in Figure 4). In comparison, the nursing procedure of tracheostomy tube change is more complex than the procedure of suction via tracheostomy tube. In addition, the procedure of suction via tracheostomy tube is a sub-procedure of the tracheostomy tube change. The nursing procedure of suction via tracheostomy tube is performed by the caregiver 2, during the preparation of tracheostomy tube change by caregivers 1. Therefore, in Figure 4 only the steps of the tracheostomy tube change are presented. The change of the position of the RGB-D sensor did not lead to a better detection of the lower body skeleton of the both caregivers.

For the tracheostomy tube change the tracheal cuff gets unblocked and the tracheal collar is changed by caregiver 2, while caregiver 1 is preparing the actual process. Afterwards the process of suction via tracheostomy tube is performed by caregiver 2. Then the new tracheostomy tube is carried to the participant by caregiver 1 and the actual tracheostomy tube change is performed by both caregivers. After that caregiver 1 blocks the cuff and caregiver 2 puts the old tracheostomy tube away and reconnects the mechanical ventilation. Followed by auscultation with a stethoscope performed by caregiver 2 and caregiver 1 disconnects a syringe of the cuff. Finally, both caregivers clean up and get rid of the waste.

No evidence for other anomalies during this nursing procedure were found. Since there is no data of this procedure conducted on a participant, no difference in the behavior of the caregivers could be analyzed.

As no sound pressure was recorded, no evidence of spoken words or other vocal interaction between caregiver and participant as an element of social interaction is present, when being averted. Due to the fact that there is no information about any vocal interaction the mentioned assumption might not be true. With the aim to better understand the social interactions between participants and their families and caregivers in this sensitive operating field a new autonomous system to collect data is needed. In this concept, camera position 2 should be used, as this position covers the two nursing procedures observed in the pilot study. The following section presents and describes a promising concept for the collection of data set in a highly sensitive environment like the participant room of bedridden participants with the need of intensive care.

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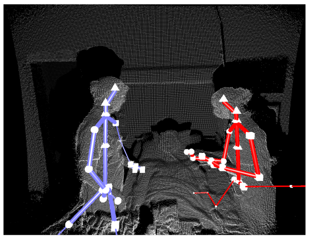
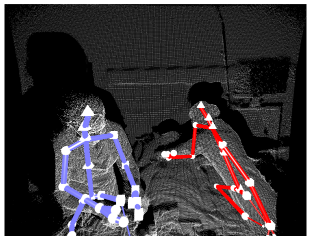
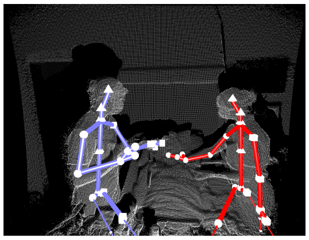


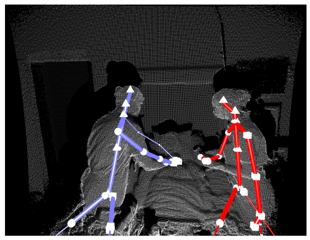
1. C2: Unblocking tracheal cuff and changing tracheal collar.



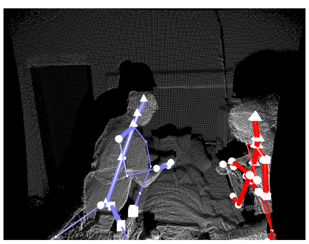
2. C1: Preparing new tracheostomy tube. C2: Procedure of suction via tracheostomy tube.



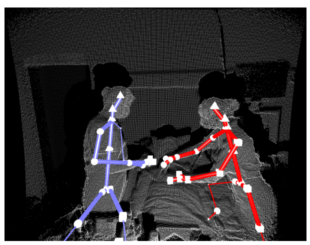
3. C1: Carring prepared tracheostomy tube to participant.



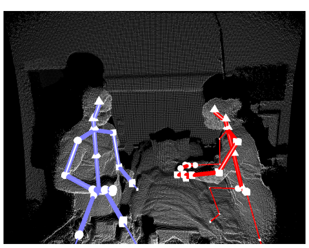
4. C1 and C2 performing actual change of tracheostomy tube.



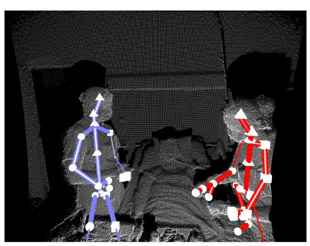
5. C1 blocking cuff. C2 putting old tracheostomy tube away and connecting mechanical ventilation to participant.



6. C2 auscultating participant with stethoscope.



7. C1 disconnecting syringe of cuff.



8. C1 and C2 cleaning up and getting rid of waste.

Fig. 4. Process of tracheostomy tube change.

IV. CONCEPT

This section describes a concept to collect combined data of infrared, RGB-D and sound pressure sensors from social interactions of bedridden patients. This system detects the quantity of interactions in the patient room. Further, the system will identify when and where the social interactions happen in the patient room.

Due to the high sensitivity of the environment in which the system will operate and collect information, a high standard to protect privacy and anonymity of the patients, their families and caregivers must be ensured. In addition, there is the possibility to choose between three different modes. Firstly, there is a full recording mode, integrating all in the following described sensors. Secondly, during the limited recording only the infrared array sensor, sound pressure and the motion detection by the passageway and motion sensor is enabled to collect information. This mode will be implemented to collect information about sensitive interactions without recording of video data. The third mode is the passive mode, which disables the total system for a defined period of time.

The system is set up at the patient's request, i.e., the patient can choose between the first and second mode as the activated standard mode. If the first mode is chosen as standard, the system can be switched into the second mode or disabled by the patient's choice. In addition, if the second mode is chosen as standard mode, there will also be the possibility to disable the entire system for a defined period of time.

Therefore, it will be possible to deactivate the entire system via a wireless switch. This type of switch is used, because the system will initially not be installed as permanently. The system state (active/inactive) will be mirrored via a highly visible and clear to interpret display with appropriate symbols and colors.

The multi sensor system will consist out of sensors (hardware), special designed software for the sensor evaluation and a control system (software).

A. Sensors

In Table III, the sensors used in this setting with their assigned task are shown. The passageway sensor consists out of two light barriers, which allow to detect the direction of movement through the sensors field of view. The motion sensor reacts to the change of the infrared field in sight of the sensor. This sensor can detect motion in a certain area. In addition, the Grid-EYE infrared array sensor from Panasonic consists out of an 8*x*8 matrix infrared array, which delivers the temperature of each of the 64 measurement fields [19]. To protect the mentioned privacy a wireless switch will be installed near the door of the patient room, which can be used to deactivate the total system for a defined period of time. Further on, the sound pressure instrument is a microphone, which records the loudness of an event and not the actual noise. The Azure Kinect is a RGB-D sensor from Microsoft. This sensor consists out of a depth camera, RGB camera and infra red (IR) emitters [20].

TABLE III
LIST OF SENSORS

Sensor	Function
Passageway sensor	Detect person entering/leaving the room
Motion sensor	Detect person in bed area
Grid-EYE	Detect number of people in the bed area
Wireless switch	Deactivation of the system
Sound pressure instrument	Detect vocal interactions
Kinect 4 Azure	Deliver basis for data labeling

B. Sensor tasks

The tasks mentioned in Table III can be differentiated in two groups: Firstly, in a group of different start trigger sensors (see Table IV) to detect an event and start up the multi sensor system. Possible events, which trigger the start of the system are mentioned in Table IV. These kinds of events should accompany a social interaction at a high possibility, like entering the patient room. When the passageway sensor is located in the door frame, assumptions of people entering or leaving the patient room are possible. In interaction with the motion sensor, which is independent of the passageway sensor, general motions of infrared emitting objects in a certain area of the patient room can be detected. In addition, the permanent evaluation of the Grid-EYE data motion of heat sources can be detected and provide the possibility to identify a moving source of heat, which may lead to a possible social interaction.

TABLE IV
LIST OF EVENTS USED FOR THE START TRIGGER.

Deployed sensors	**Event trigger**		
	Event	Start	Stop
Passageway sensor	Entering/leaving the room	x	x
Motion sensor	Movement in nursing area	x	
Grid-EYE	Min. 2 sources of heat in sight	x	
Wireless switch	Manual deactivation		x

Secondly, the recording of sensors can be grouped. Whenever one of the mentioned start triggers is detecting a possible social interaction, the recording sensors will start collecting data. In this case the recording sensors are the sound pressure instrument, the Grid-EYE and the RGB-D sensor. During the recording the Grid-EYE sensor is used to determine, whether a person is laying, sitting or standing in the sensor sight. The additional usage of a sound pressure instrument enables to distinguish whether a person is speaking or listening to music, for example. The RGB-D sensor in this setting is used to determine if the usage of a RGB-D sensor is needed or the Grid-EYE sensor is able to provide all needed information of movements and gestures to analyze social interactions. Using the RGB-D sensor in this setting might lead to a system that makes itself independent of a camera to analyze social interactions.

C. Process of Multi Sensor System

In this section the process chain of the multi sensor system is proposed. Due to the process chain in Figure 5, the privacy of the patient, caregiver and family will remain guaranteed.

Whenever one of the above described start triggers (see Table IV) detects an event, the collection of data will be started, if the system is not deactivated by the wireless switch. When the system is active and a start trigger is caused by an event the recording of the sound pressure, Grid-EYE sensor and RGB-D sensor will started, if there is more than one person in the room. In consideration to the high sensitivity of the operating environment the multi sensor system will additionally check the deactivation message/bit after each collected data frame. This way the deactivation message will be checked two times in different steps of the algorithm. If the algorithm is collecting data and the deactivation is true, the system will stop immediately the collection of data and will wait for a defined period of time to check for a new event detection of one of the start triggers. The defined period of time should be long enough to execute sensitive nursing procedures or interactions in the patient environment.

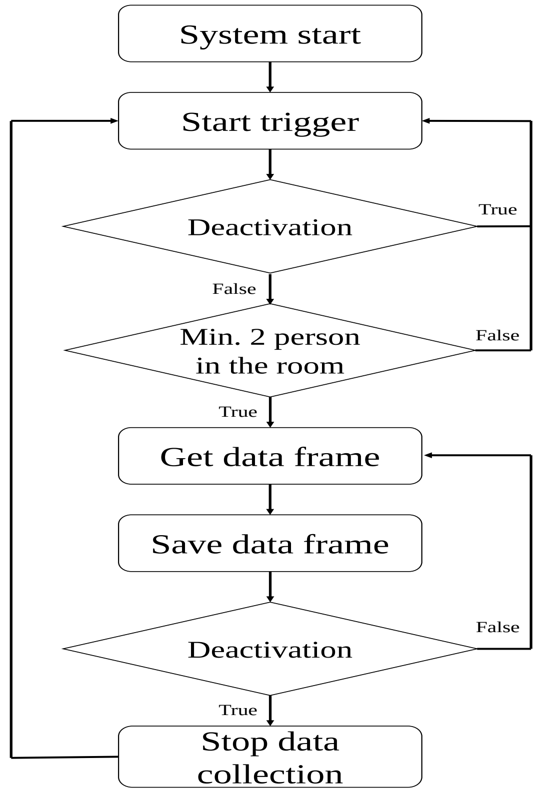


Fig. 5. Design of the proposed system process order to ensure the high sensitivity.

V. CONCLUSION

These findings are of great importance as they support the future development of home care systems and appreciation towards the patient in order to realize family-sensitive technical systems in the field of intensive care.

The importance of ambulant intensive care services, due to the demographic change with the increasing number of older people and the higher probability of older people to be in need of care and intensive ambulant care, is rising. We found a differentiation between handling a training mannequin and a participant. This findings lead to the assumption of using real patients in future work for further understanding of social interactions of mechanically ventilated patients. For a better understanding of the social interactions of patients, who are mostly bedridden, with their family system and caregivers a novel concept to collect information about social interactions is presented. The autonomous system will be used to understand the impact of using autonomous life-supporting systems like mechanically ventilation on the social system family with a minimal disturbance of the considered framework. The presented multi sensor system combines RGB-D, infrared-array and sound pressure data with the quantity of social interactions in a highly sensitive environment. In pursuing studies the sensors and their positions should be selected in consultation with the patient. In addition, a wireless deactivation switch should be used to maintain the patient's intimacy and privacy. It should also be considered to only use skeleton data, like joint positions, in future studies. Due to the findings of this project we hope to contribute our part in creating a higher quality of life for these patients and their families.

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