Development of a low-cost occupation monitoring device for care home and hospital bed

Tim Dudziak, B. Eng.

***Abstract*—The demographic shifts towards an older society. As falls are one of the biggest risk for elderlies besides cardiovascular diseases, it is a field in which medical technologies can be implemented to improve the situation. With about a third of every patient in a care unit, the number of persons effected is enormous and results in a huge risk for the health of every elderly, a burden for the healthcare sector as well as high cost for the health insurance companies. Because of that, there is a need for technical solutions to lower the risk for falls. As most falls are bed related, these devices should focus on that area. As it should be feasible to equip as may beds as possible with these devices, an inexpensive solution is favoured.**

In this work, a prototype is designed to tackle this problem. With the development method of the VDI 2221, this is organized. The output is a membrane force resistance sensor which is placed under the mattress of a hospital or care home bed. To cover over three quarters of the surface, a sensor as small as 12 x 600 mm is sufficient. The algorithm based on a threshold to detect the occupation status of the bed was tested in a trial with 87 participants and gave satisfying results. The downside that the detection can be outsmarted by placing a weight on the bed was tackled in a further version of the algorithm, which focuses on the change of resistance, as the sensor is able to detect even the breathing pattern of the person lying in bed. With this the concept proved its effectiveness and even leaves room for further research to improve the field of application to the contactless monitoring of body function as well as tracking the activity of the patient. In the current setup, the prototype is able to detect the occupation status of the bed with an accuracy of 99,1% when the bed is empty and with 97,1% if the bed is occupied

***Index Terms*—hospital falls, care home falls, bed exiting alarms, fall prophylaxis**

I. Introduction

THE worldwide population has constantly been growing over the past decades [1], with the trend showing that the demographic shifts to an older society [1]. This is also visible in Austria, where the number of people aged 65 and older is growing since the last decade [2], as shown in Fig. 1. For the age group 65 years and older, the second largest threat for their health are the results of fall accidents, only topped by cardiovascular diseases. The results of a fall are the leading cause of injury deaths and visits of emergency departments because of trauma [3].

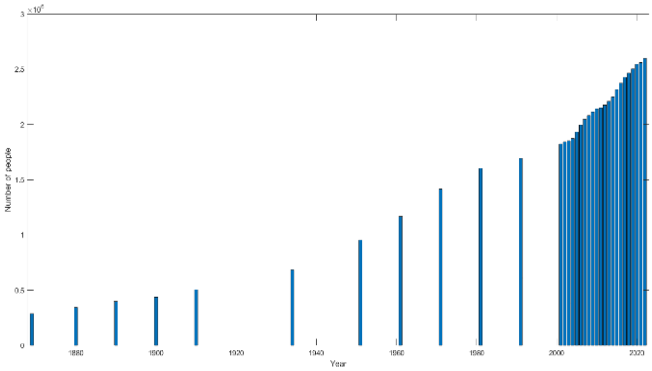

Fig. 1. Visualization of the number of people aged 65 and older in Austria from the year 1869 till the estimated numbers for 2022

II. Fundamentals

A. Falls in hospitals and care home facilities

A fall is defined as "unintentionally coming to rest on the ground, floor, or other lower level, but not as a result of syncope or overwhelming external force." [4]. Elderlies are especially affected by this, which is caused by multiple factors. One is the loss of skeletal muscles mass with older age, which is known as sarcopenia. Others are the loss of muscle strength and declining motor coordination, as well as exciting-contraction coupling and skeletal integrity to name some [5]. All of these lead to a reduced security when standing, reduced ability to balance and with this an inclined risk of falling.

In hospital care units, the mean age of patients having a severe bed fall is 63,4 as Hitcho et al. [6] reported after observing a 1300-bed urban hospital in St. Louis, USA, for 13 weeks. A study through various nursing and community homes from 2009 shows, that each year, about a third of all patients and residents will have a fall accident and out of these, half of them will fall multiple times [7]. Another survey showed, that in hospitals, 22,4% of all patients had a fall in the previous three months [6]. Luckily, 9 out of 10 falls will not result in a serious injury, but still, 10% will experience injuries such as a fracture, joint dislocation, traumatic brain injury or damage of the soft tissue [7]. The prospective analysis by Eileen B. Hitcho [6] analysed 200 falls of patients and concluded, that these mostly happen in the patient's room with 84,7%. The main activities carried out when the fall occurred are shown in Table 1.

TABLE I

Analysis by Eileen Hitcho [6] of activities performed when a fall occurred in patients of a 1300 bed hospital in a time span of 13 weeks.

Activity	**Percentage of falls occurred**
Ambulating	19.1
Getting out of bed	10.9
Sitting down or standing up	9.3
Using bedside commode	2.2
Using toilet	2.2
Standing or sitting (not trying other action)	3.8
Reaching for object	3.3
Sleeping or repositioning in bed	2.2
Getting into bed	1.1
Using bathtub	0.5
Dressing or undressing	0.5
Unknown	33.3

When all bed related activities are combined ("Getting out of bed", "Using bedside commode", "Sleeping or repositioning in bed", "Getting into bed") it shows that these are responsible for 16,4 percent of all accidents. Furthermore, 19,1% of all falls happen when the person is ambulating. The paper states that out of that, another 54% are also related to the bed, like getting from the bed to the bathroom. In total, falls referring to the bed in any way make up 26,7% of all fall events.

Moreover, most of all fallen persons were discovered lying on the floor (76,5%), meaning that no other person was in the room with the patient. With this, there is no way health care workers can assist the patient when the fall occurred, which could prevent the accident. Furthermore, undiscovered falls without being able to call for help lead to a higher risk of severe trauma and even death. Besides injuries of the head, fractures of large bones are common as results of falls. Untreated, these lead to a rapid blood and death.

B. Fall prevention measures

To reduce the numbers of falls and with that enhance the patients' safety, there are multiple approaches to deal with them.

The most common and easily applicable is the application of anti-fall-protocols, that evaluate the risk of falling for every patient and provide information about how to reduce them. Examples for this are the Barthel index [8], the STEADI tool kit created by the US Centre for Disease Control and Prevention [9] and in Germany, the guideline "Expertenstandart Sturzprophylaxe" [10]. Measurements are for example the reduction of falling hazards and balance training for the patient.

But there are also technical solutions, the so-called fall detection and alarm devices. These are surveillance systems, which signal dangerous or risky situations via an acoustic or visual message and require an immediate intervention [11]. For bed related calls, the available devices can be grouped into Wearables and ambient sensors.

Wearables are devices that the patient has to wear on his body or on his cloths. These have multiple sensor like accelerometers and gyroscopes or even barometric pressure sensors [12], [13]. They have shown some promising detection precision [12], but have the problem that the patient does not want to wear them for a longer period of time [14].

Ambient sensors are devices to monitor the patients' surroundings and can be implemented in numerous ways. Visual fall detection with one or multiple cameras can registrate falls or falling risk factors, but the issue with them are the privacy of the patient and therefore their acceptance is not always given [12]. To provide the patient with more privacy, proximity sensors can be used. The walking aid Lea by Spark Design as well as the walking aid developed by Hirata et al. [15] use a proximity approach to detect falls of the user by measuring the distance and the speed of distance change between the user and the device. The effectiveness of these varies and is not totally proven yet.

As a large number of falls are related to the bed, there are several devices that monitor, if a patient is about to leave the bed. These are called bed exiting alarms and they follow multiple technical approaches. On the one hand there are visual systems, on the other hand there are multiple nonvisual approaches. Out of the latter, the majority is placed under the mattress and measure the pressure. Other solutions are built into the bedframe or are part of the mattress itself. Other approaches are devices that are placed on the edge of the bed or floormats that are placed in front of it.

The effectiveness of these alarms is questionable. In the analysis of twelve papers Kosse et al. concludes that "The evidence is inconsistent whether the current sensor systems can prevent falls and fall-related injuries in institutionalized elderly" [17]. They state that three randomized clinical trials showed no change in the number of falls, while some before-after studies reported a wide range of prevented falls, varying from 2,4 up to 37 less falls per 1000 patient days. Even with a reduced injury risk, a false alarm rate of 16% is too high, which drew the nursing stuff away from using the alarm. [24].

Hrickiewicz stated that the Bames-Jewish Hospital in St. Louis, USA, managed to reduce their fall rates in the first 6 months of usage from 4.48 to 1.98 per care unit. Also, the injury rate dropped from 1.56 to 0 [16], but the report neither gives further information on how this numbers are created, nor which device was applied.

That the use of bed alarms does not prevent falls in hospitalized patients is also reported by Shorr et. al in a pair-matched, cluster randomized trial [25]. The same conclusion is stated by Sahota et al.: "bed and bedside chair pressure sensors as a single intervention strategy do not reduce in-patient bedside falls, time to first bedside fall and are not cost-effective in elderly patients in acute, general medical wards in the UK" [26]. Besides the controversy of the effectiveness, their usage is also an ethical debate, as they can be interpretated as an restrain measurement, and with that contravene the human right of freedom.

As seen, falls in care homes and hospitals are a major problem for the patient as well es for their surroundings. Electronical devices can help to create a safer environment. The aim of this work will be to create a prototype for a system that helps reducing the risk for everyone involved.

III. Method

This chapter focuses on the following key points. At first, the method used for the development is introduced. After this, the material chosen and finally the prototype is tested in a trail to evaluate its workability is described.

A. Development method

The development method applied for this work is a waterfall approach based on the VDI 2221, which segments the process of development into four parts, each containing an individual workload. These parts must be fulfilled in their right order. These phases are shown in Figure 2.

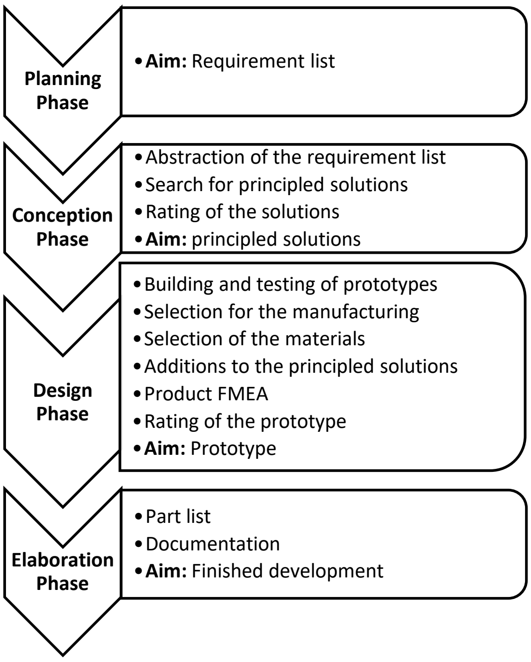

Fig. 2. The VDI2221 is a method for developing new products. It is a waterfall model with four phases, each with an aim with should be reached before jumping into the next phase.

In the first part, the planning phase, the requirements for the final product are stated. In the Conception phase the principal solution is defined, which is done by extracting the main problem out of the requirements and state it free of possible solutions. Out of this solutions are found with a creativity method. In this work, this was done by an open innovation contest, where multiple people could state entries for the problem solution. The found solutions are then rated on how well they fulfil the theoretical ideal solution. This is done by applying the VDI 2225, a method to rate solutions. The best one is further approached in the design phase. There a prototype is built and tested. The last step is the elaboration phase, in which the product is finalized. This work focuses on the development of the prototype, so only the first three steps are worked on.

B. Technical implementation

The technical implementation of this work is done by using a membrane force resistance sensor. This consist of two Polyethylene terephthalate, short PET membranes. On one a conductive film printed on, the other is coated with a textured resistive ink. Both membranes are separated by a thin air gap, created by a spacer or by the layer of glue which sticks both membranes together. This commercially available sensor has a size of 12 x 600 mm. The signal of the sensor is filtered by a low-pass filter before it is measured with a microcontroller, in this case an Arduino uno, to remove unwanted noise. For the measurement a voltage divider is build, with which it is possible to measure resistances with the analog input port of a microcontroller.

The development of the algorithm was first based on comparing the value to a selected threshold, but this showed that by that the system can give false interpretation of the bed occupation status. The other approach was to not be focused on the value, but on its variation, as test showed that the sensor was able to detect smallest changes, even the breathing pattern of the person in bed.

C. Test setup

To evaluate the effectiveness of the developed sensor and algorithm, a trial was performed. The aim of it was to test if the chosen components and the way to detect if the bed is occupied or not is effective. For this a test setup was developed. It was performed with multiple participants randomly chosen. The targeted sample size was n = 75 over a time of five hours.
The points of interest being reviewed were:

1. Detect if a person is in bed
2. Detect if a person is leaving the bed
3. Can a person leave the bed without the sensor detecting it

To make the test participation more attractive, it was designed as a game. This gamification is known to increase the motivation to perform in trials [20]. The test setup consists of a Wissner-Bosserhoff image 3 bed frame with a TheraRest Classic mattress by arjo which is equipped with the sensor. For the game, a table with sweets is placed next to the bed with a distance of two meters, out of reach for a person lying down in the bed. Additionally, a buzzer is connected to the Arduino which makes a sound when the threshold is undercut, i.e., creates an audible bed-exiting alarm. The participants lying on the bed are then challenged to reach the sweets without triggering this alarm.

To protect the participants privacy and prevent interfering with data privacy standards it is decided not to record any personal data from the participants, but rather only classify them into one of two groups: “Male” and “Female”. Further they are sorted into one of three subgroups: “small”, “medium” and “big” With this, it is not possible to link any data recorded from the senor to a certain participant.

IV. Results

A. Development methodology

The development methodology of the VDI 2221 is applied to create this work. All requirements were stated in a requirement list, which is the outcome of the planning phase.

In the conception phase, these got extracted to get the main problem, which is:

"Development of a sensor, which can be retrofitted on hospital and care home beds to detected if the bed is occupied, without limiting the functions of the bed or be limited by these. The sensor should work without maintenance"

To find solutions that are decoupled for any bias, an open innovation contest was held, which generated 13 solutions to the problem. To find out, which of these entries is the closest to the theoretical ideal solution, the rating of the VDI 2225 was applied. This showed that the solution "Sensor belt under the mattress" fulfils the requirements with 73,8% which was the highest ranking. Following this evaluation, the sensor belt was developed further in the design phase, which is described in the following chapter.

B. Technical implementation

The solution of a sensor belt, which can be strapped to all common bed frames used in hospital and care home facilities is implemented into a prototype. The sensor should be able to detect the occupation status of the bed from under the mattress. As hospital and care home beds do not have much flexibility in the slatted frame like home use beds have, a solution that measures any angle or length difference is not feasible. In the end, the decision falls on a membrane force sensor, specifically the FSRTEC FA408, shown in Figure 3.

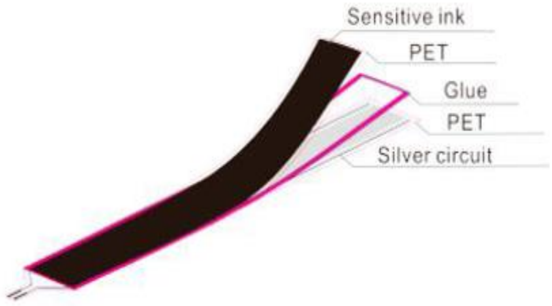

Fig. 3. Membrane force sensors like the shown FA408 by FSRTEC consist of two layers of membrane separated by a thin air gap. One membrane has a conducted film printed on, the other one has a textured resistive ink [16]

The sensor was sewed on a polyester belt and strapped across the bedstead. For the fixation, two ladder locks were threaded onto the belt so that they created an adjustable loop on each end, making it variable which gave a high level of freedom when it came to the location of the sensor. The fixation is shown in Figure 4.

Fig. 4. The Force membrane sensor was sewed on a nylon belt which can be fixed on the bed stead. This allows the sensor to be placed in multiple ways and on various beds.

The measurement of the resistance of the sensor was done with an Arduino uno. The complete measuring setup, shown as a schematic in Figure 5, consisted of a low-pass filter with a cut of frequency of 15,92 Hz to get rid of unwanted noise and a voltage divider circuit with one known resistor of 1 kΩ. The system was powered by the 5 V output of the Arduino and the sensor resistance was measured by an analog input port.

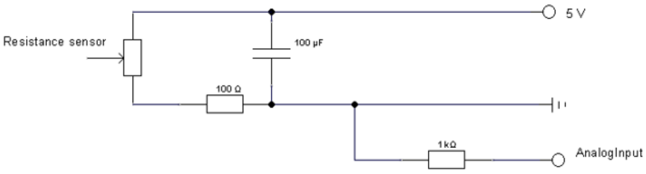

Fig. 5. The schematic of the setup consists of the resistance sensor, a low-pass filter, and a resistance bridge to measure the resistance with a microcontroller.

The general prove of concept was done by testing the sensor on a care bed with partial slatted frame and a memory foam mattress. Test persons with a body height ranging from 165 – 190 cm and a weight ranging from 65 – 100 kg laid in the bed at various positions and the measurements of the sensor were recorded. The location and orientation of the sensor belt was varied, to find the best position of it, find the largest covered area. Figure 6 visualizes the measurable area which is covered with each different sensor placements.

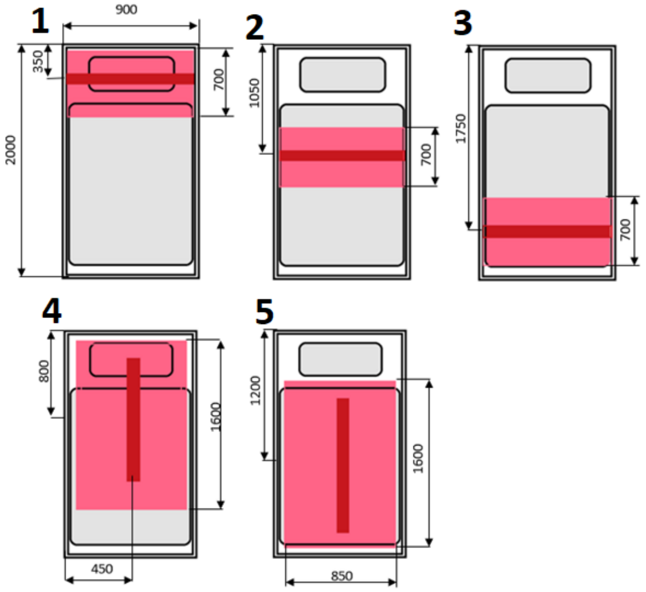

Fig. 6. The orientation and the placement of the sensor had an impact on the area, in which pressure on the mattress could be detected. The dark red area represents the location of the sensor, the pink area visualizes the area in which pressure could be detected. The measurements were in relation to the centre of the sensor. All measurements are displayed in millimetre.

This test showed that the horizontal placement, pictured in 1, 2 and 3 of Figure 6, only covered an area of 0,63 m², while the vertical placement, pictured in 4 and 5, covered 1,36 m² of measurable area. Therefore, the vertical placement was in favor. Furthermore, the sensor ideally was placed in a way that covered the top part of the bed, where the patients' head was placed (bed 4 in Figure 6), rather than the footboard (bed 5 in Figure 6), as it is more likely that a person lays there.

The algorithm to detect if the bed is occupied or not was implemented by comparing the measured resistance to a threshold resistance. This threshold is found by comparing the values of the senor for multiple persons and in multiple positions. After comparing these, the lowest measured value is selected and a safety factor of 2 is applied. The rounded result is 1500 Ω.

C. Testing

To prove the effectiveness of the threshold and the workability of the sensor itself, a trial is conducted. In total 87 persons took part in the survey, 47 women and 40 men. In this, the probands were challenged to leave the bed and reach out to a table. For the purpose of gamification, some sweets were placed on the table, and it was the task to get some of these without the sensor being able to detect if the bed is vacant. The setup is shown in Figure 7.

Fig. 7. The setup to evaluate the effectiveness of the sensor and the detection by a threshold consist of a hospital bed with build in sensor and a table on which sweets will be placed. The participants are challenged to get some of the sweets without the sensor detect that they are leaving the bed. For this the table is placed out of reach from the bed.

Out of the 87 participants, only five medium sized men were able to reach the sweets on the table. All of them used props to outsmart the sensor as they kept on applying weight on it. No other person was able to leave the bed without the measured resistance undergoing the threshold. With this, the concept of the sensor and the effectiveness of the tested threshold was proven.

Even with this being a very promising result, a disadvantage manifested itself: the sensor could be outsmarted by placing objects on the bed. In further tests it was showing that a weight of 1,5kg placed exactly over the sensor was enough to reach the threshold and with that, signal that the bed is occupied. As an adjustment of the threshold leads to a bad sensitivity, it is not a solution which improves the device.

To tackle this problem, the collected data was analysed. The goal was to find other indicators that signal if a person was lying in the bed or not. When comparing the data of these two cases, it shows that the sensor could detect smallest rhythmic changes of resistance, when a person is lying in bed (Figure 8). These changes in the value are not present when a static weight is place in the bed, although some noise is registered, but not in the same level as the rhythmic changes (Figure 9). The standard deviation of the measurement was 441.06 Ω and a range of 1,6 kΩ when a person was lying in bed. With a static weight the standard deviation was 7,5 Ω with a range of 36 Ω.

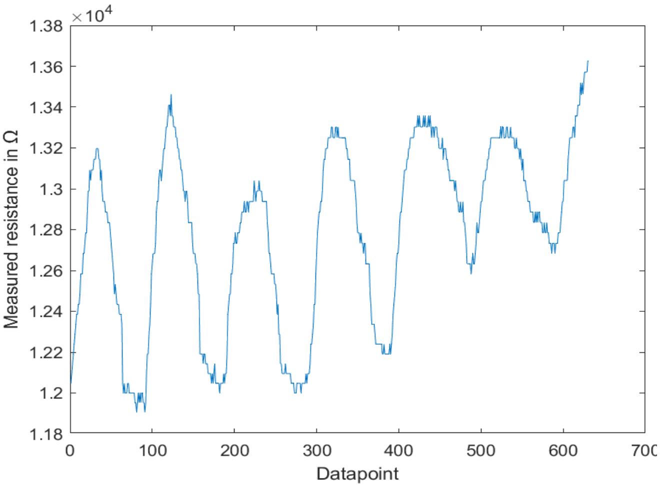

Fig. 8. Rhythmic changes of the resistance measured by the sensor are recorded when a person is lying in bed as motionless as possible. These changes correlate the breathing of the person

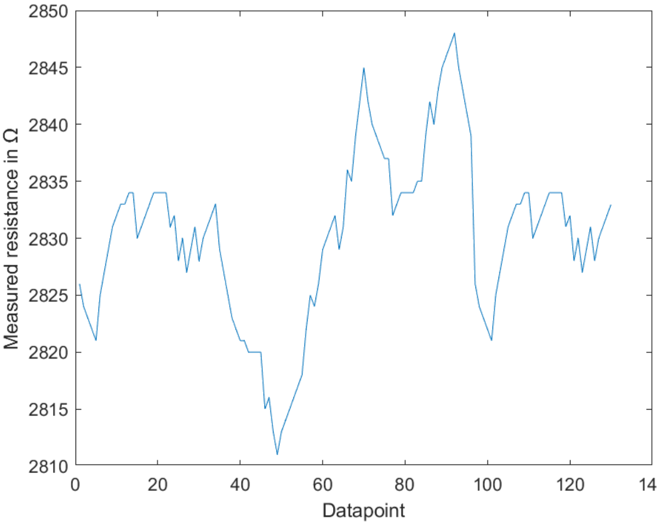

Fig. 9. Changes of the measured resistance when a static weight of 8 kg was placed on the bed.

To investigate this change in value, the breathing and heartrate of a test subject was monitored and showed that this variance correlates with the breathing of the patient.

This gave the possibility to detect a patient in bed by checking the sensor output by its alteration. If a change of the resistance was above a certain level, it indicates that a living person is in bed.

To find a way to detect this, the signal must be separated into smaller segments. After this, the highest value was tested, if it is a statistical outlier, as these can have a negative impact on the further calculation. When proven that no outlier was interfering with the further process, the standard deviation was calculated. The standard deviation for a static weight in bed was 7,5 **Ω**. To ensure a clear differentiation, a safety factor of 4 is applied, which results in a value of 30 **Ω** of standard deviation as a threshold. When the standard deviation of the segment was greater than this threshold, it can be said that the bed was occupied by a living person. For this a new algorithm is developed. For better understanding, this new one is further called the new algorithm, the on that compares the measured resistance with a threshold is called threshold algorithm.

To find the right size of the array and to test the difference of the significance value, the algorithm was tested with different lengths of segments and the accuracies. The array size is set from 5 to 30 in steps of one with the significance value of α=90%, α=95%, α=99%. To test the algorithm, the already collected and labelled data was used. For this, a MATLAB code was written, which imports the data and analyses it with the algorithm, the estimated label is put in an array which then can be compared to the known labels, enabling the evaluation of the algorithm accuracy.

As Figure 10 shows, the highest accuracy with 0,975 is reached at an array size of 24 with the significance value of α=99%.

This indicates that the algorithm could label the data with an accuracy of 97,5%. Compared with the algorithm which compares the resistance to a threshold, which has on the test data set only an accuracy of 84,4%. But this is value is questionable to compare, as the more datapoint with only a static value were applied, the worse the accuracy got. To analyse this, three scenarios are selected to compare both algorithms.

Case 1: The bed is empty

Case 2: A static weight is place in bed

Case 3: A person is lying in bed

For all these cases, data samples were selected, which then were used to test the algorithms. The accuracy of both was then compared. The result of that is shown in Table 2. For case 1 and case 3, both algorithms were comparable, but in case 2, the difference was enormous, which was expected from the previous tests. Hence the new algorithm had an advantage was in favour to use it further.

TABLE II

The two algorithms to detect the status of the bed are compared in three scenarios to identify what are the limitations of both. This is done by three separated datasets that represent the scenario. Each of them contains 1000 datapoints.

	Case 1	**Case 2**	**Case 3**
New Algorithm	1	0.9910	0.9714
Threshold Algorithm	1	0	1

The new algorithm was further tested with the rest of the collected data and showed the same efficiency in labelling the data correctly, even in the cases where objects are place on the bed. With that the development of the algorithm was finished.

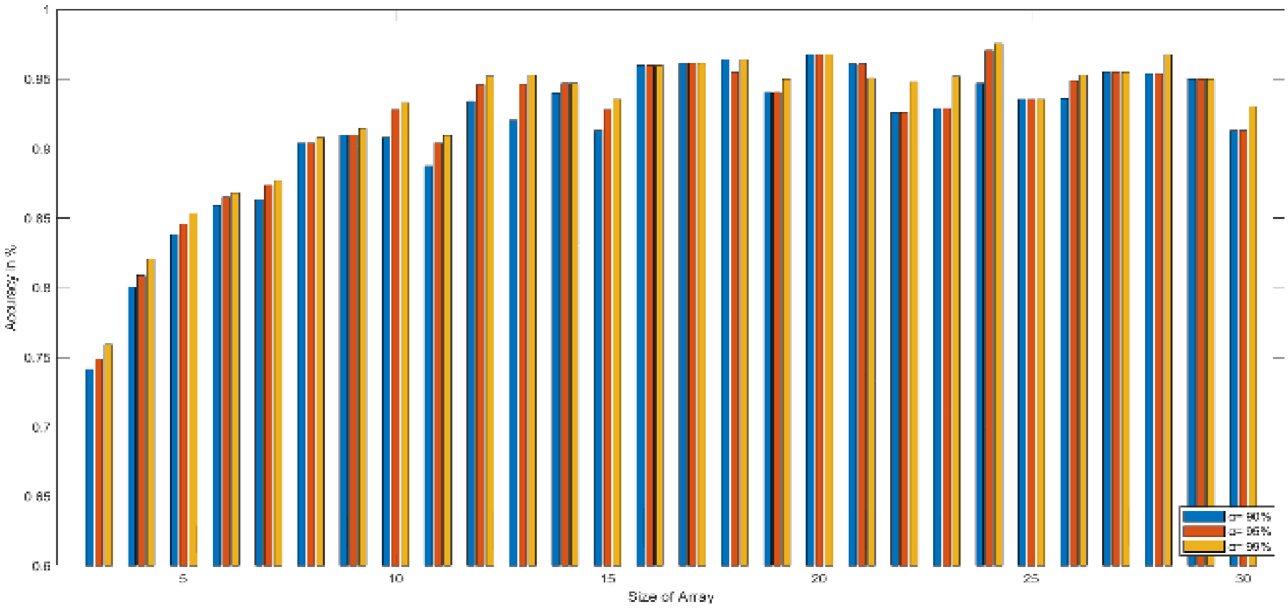

Fig. 10. Accuracy of the algorithm 2 in dependence of the array size and significance value was tested with a labelled dataset.

V. Discussion

This paper aims to develop an inexpensive device to monitor the occupation status of hospital and care home beds. After the development of a prototype and testing it with probands in a controlled step up, the results are promising. In the end, the prototype showed an overall accuracy of 97,5% with the data recorded from the test.

A. Development method

The utilization of the development method created by the VDI 2221 ensured a structured process. As the start- and endpoints of this work were clear from the beginning and the task was not too complex, there was no need for a more agile development methods like the Scrum or Kanban method [23], which have the downside, that most of the time a moderator is needed.

The utilization of the open innovation contest to acquire new and creative solutions guaranteed an innovative way for the search of solutions. With the rating of the VDI 2225 it can be ensured, that the solution which fulfils the requirements as good as possible is further developed. With that, a good way to detect the occupation of care home and hospital beds is found.

B. Technical implementation

The technical implementation of this work was done by using a membrane force resistance sensor. This sensor with a size of only 12 x 600 mm was able to detect more than three quarters of the hospital bed. The uncovered area can also be neglected as it is common, that a person does not only lay in these areas. The signal of the sensor is filtered by a low-pass filter before it is measured with a microcontroller. This led to a reduction of noise in the recorded data. The development of the algorithm was first based on comparing the value to a selected threshold, but this showed that by that the system can give false interpretation of the bed occupation status. The other approach was to not be focused on the value, but on its variation, as test showed that the sensor was able to detect smallest changes, even the breathing pattern of the person in bed. With this new algorithm, an overall accuracy of 97,5% was reached.

C. Trial

The trial was performed to test the performance of the sensor itself as well as the method of analysing if the bed is occupied or not. The setup was created in a way in which the task of getting out of bed was free to the participant to decide how he wants to do it. This ensures that this is done in multiple and unbiased way. The targeted sample size of 75 was reached and surpassed it by twelve people. The trial was successful in a way as it proved the workability of the sensor and showed the limits of the algorithm. As the data was recorded, but not with a link to the participants to ensure data rights, it was possible to also use it for testing the newly created algorithm.

D. Limitation

As it was not possible, to test the sensor on multiple beds and mattress combinations at the performed trial, it can not be ensured that it will show the same performance with every possible combination. Of special interest are active anti-decubitus-mattresses, which are common in long-time care units. These are special in the way, that they have multiple air pillows build into it, which can be in- and deflated individually, to vary the zones of pressure of the patients and with that reduce the risk of skin damage and ulcers. How this effects the sensor should be the investigated in further studies. The same can be said about the fixation solution.

Also, it was not possible to perform an other trial for testing the algorithm 2, so it was only possible to test it with the recorded data from the first trial. Although this is data from realistic scenarios, it should be investigated how it performs in real set-ups.

VI. Conclusion

The aging society leads to a shift in the organization of the health care system and changes the way we deal with elderlies. As technological solutions could help tackling the problem of lacking care workers and reduce the overload of the existing ones, a bed occupation sensor returning the status of the bed could have a great benefit.

The final prototype of the bed occupation sensor, developed in this work, can predict the beds occupancy status with an accuracy of 99,1% when the bed is empty and with 97,1% if the bed is occupied. This was tested with data collected at the performed trial. To avoid the calibration of the device for every bed and patient, it does not measure the total weight, but analyses the smallest variations of the signal, which are caused by normal body functions.

But it must be tested how the sensor is affected by different bed frame and mattress combinations. And, in case of long-term care patients, it needs to be evaluated how the sensor reacts to active anti cubitus mattresses. Furthermore, it should be investigated, if the field of application can be extended, e.g., towards monitoring of the vital functions of the person in bed or the use as a sleep monitor. All these application forms could benefit from the utilization of a machine learning algorithm, which would allow to label more than two states of the bed, i.e., the bed being occupied or not, but could also detect patterns that are common for a certain application field. Additional relevant information could be e.g., the act of getting up, or even the patient having trouble falling asleep, as in both cases it could be useful to have a caregiver look at the patient and assists them with their situation.

Although the task of this work was to develop a monitoring device for the occupation of the bed rather than a surveillance device, it cannot be guaranteed that the results of this work are not used for the latter. There is the possibility to utilize parts of it or the prototype in total to create exactly this, but the author of this work pleads that the creation of a restraining device is not useful, neither for the patient nor for the healthcare workers. However, with the trend showing that these restrictive procedures find more and more resistance in the society, it is likely that the developed device will not be used for such purposes.

To put it all in a nutshell, it can be said, that this work proves the possibility to create a low-cost device which monitors the occupation bed status in hospitals and care homes, and with that lays the foundation to equip every bed in these facilities with such a system. As fall accidents are a major threat to every elderly, this device can provide more safety for the patients, reduce the stress on the caregivers and, with the possible reduction of these incidents, even save money in the health insurance sector. If further research can prove the effectiveness of this technology, it could have an enormous impact on the growing group of elderlies in our society, which is often overlooked and to this day, might even be cut on their human right of freedom. The further development should be pursued, as every one of us is getting older and could someday benefit from such a device.

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Bibliography

[1] "United Nations," 13 May 2022. [Online]. Available: https://population.un.org/wpp/ Graphs/ DemographicProfiles/ Pyramid/ 900.

[2] S. Austria, "Bevölkerung nach Alter und Geschlecht seit 1869," statistik.at , 2022.

[3] Z. O. Y. C. K. S. Shan W. Liu, "Frquency of ED revisits and death among older adults after a fall," *Am J Emerg Med.,* vol. 33, no. 8, pp. 1012-1018, August 2015.

[4] A. Lane, "Evaluation of the fall preventing program in an acute care setting," *Orthop Nurs.,* pp. 37-43, 1999.

[5] I. T. B. C. Michael Tieland, "Skeletal muscle performance and ageing," *Journal of Cachexia, Sarcopenia and Muscle,* vol. 9, no. 1, pp. 3-19, 2 2018.

[6] M. J. K. S. B. Eileen B Hitcho, "Characteristics and circumstances of falls in a hospital setting: a prospective analysis," *J Gen Intern Med,* pp. 732-739, 2004.

[7] T. E. M. E. G. H. G. A. Thomas Gill, "Association of Injurious Falls With Disability Outcomes and Nursing Home Admissions in Community-Living Older Persons," *American Journal of Epidemiology,* pp. 418-425, 2013.

[8] F. M. D.W. Barthel, "Functional evaluation: The Barthel index, A simple index of independence useful in scoring improvement in the rehabilitation of the chronically ill," *Maryland State Medical Journal,* vol. 14, pp. 61-65, 1965.

[9] J. A. Stevens, "The STEADI Tool Kit: A Fall Prevention Resource for Health Care Providers," *IHS Prim Care Provid.,* vol. 39, no. 9, pp. 162-166, 2013.

[10] Expertenstandard Sturzprophylaxe in der Pflege, Osnabrück: Deutsches Netzwerk für Qualitätsentwicklung in der Pflege, 2013.

[11] A. Gärtner, "Patientenüberwachung: Normative Anforderungen an Alarmsysteme - Teil 1," *EHealthCom,* 2012.

[12] I. L. T.-P. J. Ramesh Rajagopalan, "Fall Prediction and Prevention Systems: Recent Trends, Challenges, and Future Research Directions," *Sensors,* vol. 17, no. 11, p. 2509, 2017.

[13] S. R. M. N. S. C. N. L. F. Bianchi, "Barometric pressure and triaxial accelerometry-based falls event detection," *IEEE TransNeural Syst Rehabil Eng.,* vol. 18, no. 6, pp. 619-627, 2010.

[14] A. C. F. C. N. H. L. B. G. C. S. R. L. A. T. Marryn j Mathie, "A pilot study of long-term monitoring of human movements in the home using accelerometry," *J Telemed Telecare,* vol. 10, no. 3, pp. 144-151, 2004.

[15] S. K. K. K. Y. Hirata, "Fall prevention control of passive inteligent walker based on human model," *IEEE/RSJ International Conference on Intelligent Robots and Systems,* pp. 1222-1228, 2008.

[16] M. Hrickiewicz, "Infrastructures to improve safety," *Trends in Healthcare,* no. December , pp. 32-35, 2015.

[17] K. B. J. B. T. H. N.M. Kosse, "Sensor technologies aiming at fall prevention in institutionalized old adults: A synthesis of current knowledge," *International Journal of Medical Informatics,* vol. 82, no. 9, pp. 743-752, 2013.

[18] M. C. L. M. T. W. M. L. M. D. L. K. S. M. Ronald Shorr, "Effects of an Intervention to Increase Bed Alarm Use to Prevent Falls in Hospitalized Patients," *Ann Intern Med,* vol. 157, no. 10, pp. 692-699, 2012.

[19] A. D. D. K. M. G. C. V. T. S. J. G. M. A. Opinder Sahota, "REFINE (REducing Falls in In-patieNt Elderly) unsing bed and bedside chair pressure sensors linked to radio-pagers in acute hospital care: a randomised controlled trail," *Age and Aging,* vol. 43, pp. 247-253, 2014.

[20] J. Hamari, "Does Gamification Work? - A Literature Review of Empirical Studies on Gamification," *47th Hawaii International conference on System Science,* pp. 3025-3034, 2014.

[21] FSRTEK, *Membrane Force Sensor Model: FA408 Type: Strip force sensor,* Nanjing : Nanjing Momao Electronic Technology Co.,Ltd.

[22] J. T. M. J. W. Y. Charles E. Clauser, “Weight, volume, and center of mass of segments of the human body,” Aerospace Medical Research Laboratory, Ohio, 1969.

[23] H. C. Kelbel, “Agile Entwicklungsmethoden für die Materialentwicklung: Vorteile und Anwenderempfehlungen,” *Vorrausschau und Technologieplanung,* vol. 3, no. 12, pp. 125-146, 2021.

[24] J. K. H. S. J. Hamari, “Does Gamification Work? - Aliterature Review of Empirical Studies on Gamification,” *47th Hawaii International conference on System Sience,* pp. 3025-3034, 2014.

Tim Dudziak B. Eng. is a Master Student of the Department of Medical Technologies at the MCI in Innsbruck/Austria.