

DIY-PressMat: A Smart Sensor Mat for Posture Detection Applicable for Bed-exit Intention Detection, Pressure Ulcer Prevention, and Sleep Apnea Mitigation

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ABSTRACT

In this research, we present a proof-of-concept Do-It-Yourself (DIY) bed sensor mat that is capable to detect five user postures, including: Supine position, Prone position, Lateral position (left), Lateral position (right), and Sitting. Our prototype incorporates two types of sensors: Pressure Tiles and Capacitive Sensing. To gain an impression on the accuracy, we conducted a study with 11 participants and developed a machine learning model showing accuracy of 85% for an unknown user. In fact, nocturnal postures extend to a third of ones lifetime and therefore, a posture detection can be particularly interesting. Enabled application scenarios include pressure ulcer prevention, bed-exit intention detection, diabetes detection, and sleep apnea mitigation.

CCS CONCEPTS

• **Hardware** → *Emerging tools and methodologies*; • **Applied computing** → **Health care information systems**.

KEYWORDS

Bed Sensor, Pressure Sensor, Capacitive Sensor, Activity Recognition, Decubitus Prevention, Bed-exit Intention Detection, Sleep Apnea Mitigation, Care-giving Facility, Hospital

ACM Reference Format:

Denys J.C. Matthies, Marian Haescher, Wencke Chodan, Gerald Bieber. 2021. DIY-PressMat: A Smart Sensor Mat for Posture Detection Applicable for Bed-exit Intention Detection, Pressure Ulcer Prevention, and Sleep Apnea Mitigation. In *The 14th Pervasive Technologies Related to Assistive Environments Conference (PETRA 2021), June 29-July 2, 2021, Corfu, Greece*. ACM, New York, NY, USA, 4 pages. <https://doi.org/10.1145/3453892.3454001>

1 INTRODUCTION

The bed is an important place we utilize to regain energy. Emerging technology could be used to even improve our stay in bed, such as with the capability to understand our posture in bed. This can be

beneficial for a variety of use cases, in particular in care giving facilities and hospitals. We identified the following three applications to be of interest.

Bed-exit intention detection: A shift in the sleep-wake rhythm in elderly people is caricaturedly referred to as "senile escape from bed". This is because people's individual need for sleep decreases in high age. In combination with dementia, which is also often pronounced in elderly people. As care-giving personal is limited, a surveillance system can help deploying staff in an efficient way to ensure the safety of patients.

Pressure Ulcer Prevention: A common condition in bedridden elderly people is pressure ulcer or decubitus or bedsores, which is a condition of tissue damage caused by sustained pressure on an area of skin. These pressure sores can grow to a considerable extent causing pain and even be life-threatening due to tissue change. Once symptoms occur, therapy is difficult and therefore an intervention would be of importance. The most important measure is a pressure relief through frequent changes of position in bed.

Sleep apnea mitigation: A third application is sleep apnea mitigation. It is known that certain postures during night can trigger snoring and apnea. Detecting these postures provides the base information for an intervention, such as by vibration.

In this paper, we provide a proof-of-concept to address these applications with a sensing device, we call DIY-PressMat. We present an inexpensive technical solution that can detect postures efficiently. In the following, we provide insights to replicate our device and reproduce our results.

2 RELATED WORK

2.1 Human Activity / Intention Recognition

Intention recognition or prediction is a typical goal in Human Activity Recognition (HAR) [22]. A typical use case is in detecting whether the patient leaves the bed such as to go to the toilet. Current solutions usually rely on a floor mat placed next to the bed [1] or a proximity sensing deployed with ZigBees [6]. In other related research, pressure sensitive non-contacting electrodes have been applied under the bed to extraction vital signs, such as heart rate and respiration from the recorded ballistocardiographic (BCG) [16]. This can be used for sleep monitoring. In particular Emfit sensor foils placed into bed mattress have been shown to be effective for sleep monitoring by looking at the picked up heart-beat interval (HBI) [15]. In terms of bed posture recognition, rather recently Enayati et al. [10] placed hydraulic bed transducers underneath the mattress to classify four postures with an accuracy of 93%. In

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PETRA 2021, June 29-July 2, 2021, Corfu, Greece

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ACM ISBN 978-1-4503-8792-7/21/06...\$15.00

<https://doi.org/10.1145/3453892.3454001>

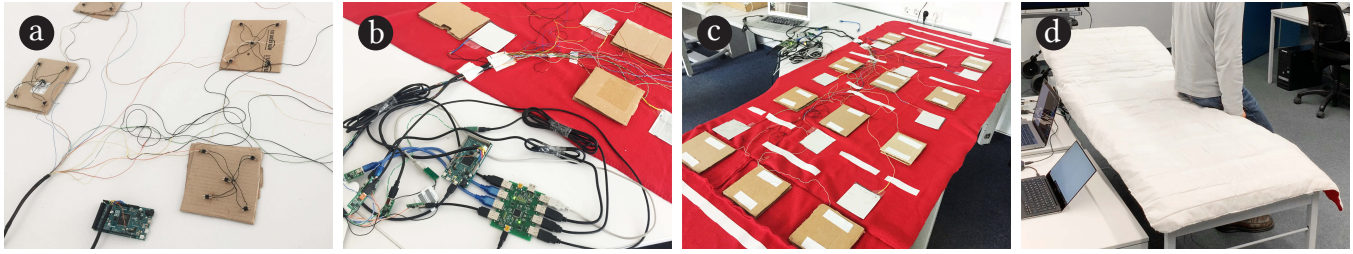


Figure 1: Prototype Assembly: (a) Pressure Tiles consisting of 5 binary switches each, (b) Pressure Tiles and Capacitive Sensing Electrodes attached to a red wool matt, (c) Base of the mat, (d) sewn mat on a doctor's bed.

the same year, a flexible piezo-electric polymer film sensor was embedded in a mattress. With 11 study participants the authors prototype was able to classify four body postures (supine, left lateral, prone and right lateral) with an accuracy of 97% [18]. In contrast to the state-of-the-art, we additionally added the sitting posture. This helps to predict the intention of an upcoming bed-exit, which is an essential research focus as mentioned in the beginning.

2.2 Pressure Ulcer / Bedsores

Pressure ulcers, also known as decubitus, pressure or bed sores, are the effects of a long-term pressure to the skin and/or underlying tissue [25]. Usually, a long time lying in bed without changing the posture leads to Pressure ulcers. Therefore, it is common to change the posture of bed sore patients every two hours [9]. Pressure ulcers are highly relevant for immobile patients, in hospitals approx. 10 percent of the patients suffer on this disease [17]. A reliable method for prevention is the securing of optimized pressure to the body. This is realized by automatized mattress that changes the structure in a predefined time interval. Often, adjustable arrays of pressure points (e.g. 256 sensor points) with integrated sensors are used to provide changing pressure conditions to the skin and tissue [20]. The monitoring of the pressure condition and automatically adjustments of the mattress requires a technical equipment that is not available in standard nursing homes or home care. Hence, the caregiver has to assure that the patient changes posture in bed to relief the stressed skin region, which is of great effort [24]. The monitoring of posture changes and the usage of pressure-monitoring devices are very efficient in the treatment of bed sores [23].

2.3 Snore-/Apnea Mitigation

Sleep Apnea is a well known issue leading to cardiac pathologies [3, 19]. Besides cardiac issues, sleep apnea is known as a leading cause for early dementia [5]. In addition to the aforementioned secondary diseases that can result from sleep apnea, patients often suffer from poor sleep quality and symptoms such as headaches and a lack of concentration [14]. Besides these factors, sleep apnea patients often have social issues, since side effects such as snoring and the resulting lack of sleep do also effect the domestic partners. Several products tackle these issues by interacting with the user in order to foster a change of posture [4]. These posture changes influence the behaviour of the palatopharyngeal muscle which can have a positive effect on the airflow [8]. The interaction with the user is usually provided by haptic / tactile feedback or acoustic feedback [21].

3 DIY-PRESSMAT

We showcase an easily replicable DIY pressure-sensitive bed mat that is capable of detecting user postures. A bed that is capable of detecting postures would be of tremendous benefit as it would enable for a variety of medical applications. We believe the most three compelling applications to be a 1) Bed-exit Intention Detection, 2) Decubitus Prevention, and 3) Snore and Sleep Apnea Mitigation.

3.1 Implementation

In the following, we demonstrate how to prototype a pressure-sensitive bed mat that can be easily put on top of the mattress. In our case, the prototype consists of a red wool base (bottom layer), which is sewn to an IKEA LUDDROS mattress protector (top layer) in the size of 90x200 cm [12]. In between both layers we stored the sensors, which are 12 Pressure Tiles and 8 Electrodes for a Capacitive Sensing. To further increase hygiene, once could add another non-permeable sweat protection layer. For the sake of simplicity and cost-efficiency, we forfeited on applying such layer.

3.1.1 Pressure Tiles (Binary Switches). The simplest way to prototype a Pressure Tile is to use some binary on/off switch. We used a 6x6x4.3 mm micro push button [7] and glued 5 of them in a parallel connection to a 15x15 cm carton tile (see Figure 1a). Once a single switch is activated, an Arduino MEGA sends out a binary information for the associated tile via the serial port. Any other prototyping platform that for instance can be found on Adafruit, are feasible too [13].

3.1.2 Capacitive Sensor (Continuous Data Stream). Another sensor stream is provided by a Capacitive Sensor, which uses a flexible aluminium electrode of the size of 8x8cm (see Figure 1b). We utilized the OpenCapSense Toolkit developed at the Fraunhofer IGD [11]. Each electrode is driven in loading mode. Each electrode streams a continuous signal close to 100 Hz. It is to note that the signal provided with a Capacitive Sensor is heavily dependent on the connected mass/grounds. When connected to a mains the signal strength increases and the signal/noise ratio improves. This enables the richness of the signal in a way that we can also sense the proximity of a nearing body. Alternatively, we highly suggest to use the Ardino CapSense Library by Paul Badger [2].

4 EVALUATION

To evaluate the effectiveness (in terms of accuracy) of our DIY bed mat, we ran an evaluation with several users.



Figure 2: Showing the lab study: The DIY-PressMat lies on top of a doctor's bed. A participant demonstrates all five postures, including: a) Supine position, b) Prone position, c) Lateral position (left), d) Lateral position (right), and e) Sitting.

4.1 Study Design

4.1.1 Participants. We invited 11 participants (including 3 females) with an age range between 21 and 60 ($M = 31.45$; $SD = 10.24$). The study was voluntary and participants were not financially compensated as the study did not involve any great effort in terms of time and mental or physical demand.

4.1.2 Apparatus. In a lab environment, we utilized a doctor's bed, which can be commonly found in doctor's offices. Our mattress prototype was put directly on top of the doctor's bed. Moreover, we put Load Cells under each bed leg, which we believe could also help to infer on the user's bed posture (see Figure 3).

4.1.3 Task & Procedure. The task was straightforward; the participant had to sit and lie down on the bed in different positions. Before the task started, the participants were welcomed and informed about their rights as a volunteer. An oral consent to record their data has been given by the participant. Due to COVID-19 pandemic, a greater physical distant and other hygienic measures were undertaken to minimize risk. The participant was introduced to the upcoming task and goal of the study. To not bias the participant, the study leader did not demonstrate any postures on the bed and asked the participant straight away to sit or lay down on the bed. The participant had to perform five different postures on the bed for at least 120 seconds. The postures were called out loud by the study leader, which included: Supine position, Prone position, Lateral position (left), Lateral position (right), and Sitting on the bed. The order of the position was randomized to avoid any cross-talk between different postures. Each position was only recorded once. After finishing the task, the participant was dismissed with heartily thanks.

4.1.4 Data Gathering. The sensor mattress provided data from the pressure tiles as well as from the capacitive sensor. The capacitive



Figure 3: We additionally put Load Cells under the bed poles that additionally measure the pressure exerted on the bed.

sensor provided a data stream from all 8 sensors with slightly varying readings close to 100 Hz. This was required to straighten so the data could be constantly dumped with 100 Hz. The pressure tiles matrix consists of 12 tiles and only sends out data once a change in state of a tile is recognized. For easier data processing we up-sampled the data to a 100 Hz data stream. Our 4 Load Cells provided a slightly irregular sampling rate around Hz, which needed to be stabilized. The data is then windowed to fill a 128 array (for real-time classification: $\sim 1.3s$) and a 1024 array for post-processing. For our post-processing, we receive at least 12 instances for each position per user that will be classified. We did not pre-process the data and calculated 46 state-of-the-art statistical and frequency-based features commonly used in literature over the entire window. This approach is part of a conventional machine learning pipeline.

4.2 Results

We decided to perform a leave-one_{user}-out cross-validation. Thus, we trained a model based on user 2–11 and tested it against user 1. We continued this process for all users. We selected the Random Forest as a suitable classifier for our investigation. The performance of the our pressure mattress showed an average accuracy of 85.02% when combining the pressure tiles and the capacitive sensor. The accumulated confusion matrix across all users is shown in Figure 4.

	a	b	c	d	e	<
a	99.4	0.15	0.45	0	0	a
b	2.91	81.9	11.4	3.79	0	b
c	1.3	11.9	70.1	10.6	6.06	c
d	4.2	1.52	12.3	82	0	d
e	0	0	8.33	0	91.7	e

Figure 4: Confusion Matrix [in %] using a Random Forest. Average accuracy: 85.02%. a) Supine position, b) Prone position, c) Lateral position (left), d) Lateral position (right), and e) Sitting.

In Table 1 we compare different sensor setups. Next to the leave-one_{user}-out cross-validation, we also applied a random 50% split on the data to have a look at the robustness.

Table 1: Accumulated accuracy across all 11 users for different sensor-combinations: Capacitive Sensing (CS), Pressure Tiles (PT), Load Cells (LC). Classifier: Random Forest.

CS+PT	CS	PT	LC	Sensors / Method
85.02%	69.05%	77.25%	48.12%	leave-one _{user} -out
99.50%	61.76%	65.69%	55.67%	50% split

5 APPLICATION SCENARIOS

5.1 Human Activity / Intention Recognition

The mattress can be used especially in the activity recognition area. One application relates in particular to intention recognition. For example, it can be recognized when a patient sits up at night and escapes from bed. Frequent position changes can be detected and sleep quality can be measures. Also, it could be predicted when a patient is going to wake up. Moreover, current activity recognition technologies could be complemented with such bed sensor when included with current HAR systems.

5.2 Pressure Ulcer / Bedsores

There are various measures to prevent pressure ulcers (decubitus prophylaxis) or also called bedsores. In hospitals, rehabilitation facilities and nursing homes, patients at risk are supposed to be motivated to move regularly. However, usually there is insufficient resources to regularly re-position every patient. Therefore, an intelligent system should recognize which patients are actually in need of a re-positioning. DIY-PressMat can help here and provide this valuable information. Once an inactivity is recognized by DIY-PressMat, a nurse can be instantly alarmed, increasing patients safety and efficiency.

5.3 Snore-/Apnea Mitigation

A third application would be snore or even apnea mitigation or even prevention. It is well known that certain postures during night can trigger snoring and even apnea. These posture can be also individually pronounced. Once known, DIY-PressMat can trigger an action once an unfavourable posture is recognized. An intervention could be audio or haptic feedback moving the user to change his position.

6 CONCLUSION & FUTURE WORK

In this paper we presented DIY-PressMat, an approach to easily instrument any bed with smart activity recognition capabilities. Prototyping DIY-PressMat took 4 days in sum and could be done with DIY hardware and opensource software toolkits. We demonstrated our device of being capable of detecting 5 postures with an accuracy of 85.02% for users that are unknown to the system. Considering the short time in prototyping and the high accuracy, we can talk of a highly effective prototype, which we would like to share with other researchers and practitioners.

We developed a real-time classifier, demonstrated it in several hospitals, and received positive feedback. This project already inspired investors and a start-up, which aim to elevate this research to a product in future. We sketched three applications that would be enabled with DIY-PressMat and could be implemented in a future product. Further, by investigating the sensor data, we realized that pressure sensing, such as by using a Capacitive Sensor, or Load Cells under the bed poles, to be capable of picking up vital signs too. This is another direction we suggest to look into in more detail. A sensor network, that includes a bed sensor can provide more detailed information on the user's activity. Additionally utilizing a state-machine approach can improve overall accuracy of such smart home systems.

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