Integrated System for Pressure Ulcers Monitoring and Prevention

Luis Fonseca[1], Fernando Reinaldo[1,2], José Metrôlho[1,2], Filipe Fidalgo[1,2], Rogério Dionísio[1,2], Arlindo Silva[1,2], Osvaldo Santos[1,2], Mohammad Amini[3]

[1] Polytechnic Institute of Castelo Branco, Portugal
[2] DiSAC – Digital Services, Applications and Content, Portugal
[3] SENSOMATT, Lda, Portugal

Abstract. Pressure ulcers are a critical issue for patients and healthcare professionals, requiring their frequent monitoring, with a consequent impact on healthcare costs. This problem has been gaining attention and approaches have been proposed, using sensor-based systems, to facilitate this monitoring and help health caregivers to achieve greater effectiveness in the treatment of this type of ulcer. In this paper, the architecture, and the prototype of a new system for pressure ulcer monitoring and prevention are presented. It considers information related to both intrinsic and extrinsic predisposing factors and it addresses the components of data acquisition, data analysis, and production of complementary support to well-informed clinical decision-making. The system includes a pressure ulcer management portal and a mobile application, that allows caregivers to manage clinical information about pressure ulcers of the patients and uses data acquired from a pressure sensor sheet under the mattress to provide useful information for monitoring the patients. Considering the situation of each patient, the system will produce indicators/alerts to healthcare professionals, simultaneously improving pressure-ulcer patient care quality and safety and minimizing the burnout in healthcare professionals.

Keywords: E-Health, Pressure Ulcers Prevention, Sensor-Based Systems, Smart Healthcare.

1 Introduction

Quality of healthcare is an important goal for patients, healthcare professionals, and the healthcare system. However, close monitoring is often still essential to implement specific prevention measures and ensure patients' quality of life. It is a healthcare intensive task and many technological approaches have been proposed to help both improve the outcome for patients and alleviate the burnout risk of healthcare professionals.

Particularly, in patients at risk of developing Pressure Ulcers (PU), or patients with PU, intrinsic data about the patient (e.g., limited mobility, poor nutrition, comorbidities, aging skin) [1][2][3][4] and/or extrinsic data (e.g., pressure from hard surfaces, shearing from involuntary muscle movements, excessive moisture) are very important to provide the healthcare provider with additional information which can facilitate the definition of appropriate monitoring schedule and treatment. Thus, close monitoring is essential to ensure their quality of life and that their condition does not become more

serious. The improvement of these services can be supported by systems that can monitor the status of patients in real-time and provide information for acting according to individual diagnoses. These solutions help in monitoring and treatment, generating alerts and recommendations that are relevant to support healthcare professionals' decisions/actions, reducing their burden, contributing to an improvement in the patient's quality of life, and a decrease in health service costs [5]. In this sense, the use of IoT technologies associated with ML technologies creates new opportunities to develop a large range of solutions.

In this paper, we present a system, denominated SensoMatt, for pressure ulcer prevention cantered around body pressure data acquired from a sensor sheet placed under the bedridden patient. The system produces indicators/alerts to healthcare professionals, simultaneously minimizing the burnout in healthcare professionals and improving pressure-ulcer patient care quality and safety.

The remainder of this paper will be as follows. Section 2 presents the goal and main requirements of this proposal. Section 3 provides an overview of related works. Section 4 provides an overview of the proposed solution, including the proposed architecture technologies and main functionalities. Finally, Section 5 presents the conclusion and directions for future work.

2 Goal and Requirements

The main goal of this project is to conceptualize, model, and develop a system that could be suitable for supporting healthcare professionals' decisions when taking care of pressure ulcer patients. The research and development are focused on the establishment of indicators based on two ways of acquiring data: a sensor sheet (placed in the bed of the patients) and data observed and inserted by healthcare professionals. Data will be stored resulting in intelligence reports and alarms for healthcare professionals for preventing and lowering the risk of pressure wounds developing further, so that actions can be adjusted according to the generated alarms.

Based on the demands and needs for this specific target of application, for this system the functional requirements that were identified are:

- The system should allow registering of users and editing of their personal data;
- The system should allow the creation and validation of indicators KPI (Key Performance Indicators);
- The system should allow the building of dashboards with direct and/or parameterized consultation, with the option to produce reports and the respective consultation;
- The system should generate alerts and allow users to consult them.

The non-functional requirements are:

- Portability - Limitations regarding hardware and software on which the system will be implemented and on the ease of migration;
- Security – blocking unauthorized access;
- Usability – Ease and accessibility in using the system.

The developed functionalities are displayed in the use case diagram of Fig.1:

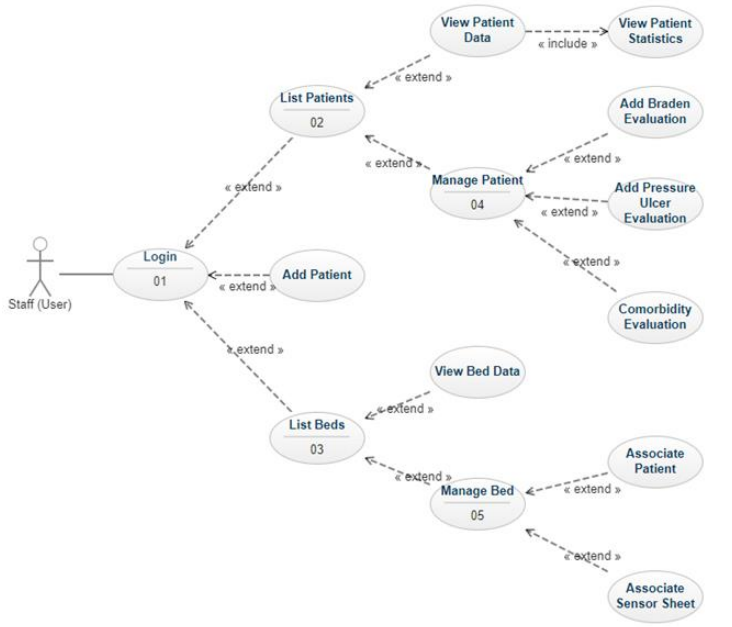

Fig. 1. Use Case Diagram.

The staff role represents every user with access to the platform, this access must be given by the system administrator. The Staff User is required to login information to have access to the platform, once entered, the staff user will be redirected to whichever page they were trying to access. The system should allow the Staff User to see a list of patients. The patient list view can be searched for patient information (name, age, birthdate). It should also allow the Staff User to create new patients in the system or select a specific patient from the list and manage his medical record. The patient's clinical information should include information on risk factors for pressure ulcers (intrinsic and extrinsic) as well as other relevant Inputs for pressure injury predictive algorithms. This includes providing information about the actions that are taken on that patient's condition but also information about the patient's condition and pressure ulcers. Staff Users should be able to monitor and visualize the patient's condition at each moment, as well as analyse statistics about the patient's pressure map in the most critical parts of the patient, over time. Whenever necessary, the user must be allowed to enter information about any actions he has taken that change the patient's conditions. Finally, the system should allow the staff user to see a list of beds. The beds list view can be searched by location or bed identification. It should also allow the staff user to insert new beds in the system or select a specific bed from the list and manage its features and status. It must also be allowed to assign a patient with a bed. The implementation of these requirements will be described in section IV.

3 Related Work

In the last decades, there have been several research works to propose technical approaches to gather sensorial information deemed useful for pressure ulcer prevention. The fundamental goal of these approaches is to acquire the information needed to classify the lying position of the patient using some sort of pressure sensor usually placed below the patient's sheets (e.g., [6] [7]). Furthermore, other different approaches based or complemented by several types of inertial sensors [8][9][10], video images [11][12], and others [13], also get satisfactory results. The fact that pressure sensors do not need to be attached to the patient is relatively flexible in the information they provide, are easily installed, and can be used successfully with different algorithms for lying position classification, seems to have increased, over the years, of the number of approaches based on this type of sensor. The information acquired from the sensors is processed in varying ways according to the sensor type. Mostly it included simple processing steps of the numerical raw data obtained from the sensors, but, mainly in the case of the pressure sensors, some effort is made by various authors to obtain higher-level features from the original data matrix (e.g., [6] [7]).

The algorithms can be used in pressure ulcer prevention approaches in the following three stages:

- preprocessing of data: In this stage, the processing is usually relatively simple, but in some works, more sophisticated algorithms were used (e.g. [14]).
- lying position classification: this is a very important factor for pressure ulcer prevention, and it can be implemented using many combinations of different sensors and algorithms. Some form of pressure sensor matrix is possible, and it is the most common sensor used. Regarding the classification algorithms, neural networks (including deep networks) (e.g. [8][15][6][7]), support vector machines [9][13], principal component analysis [13], and tree or rule-based systems [8] [16] are some of the usual approaches. Neural network-based approaches are the most popular, followed by support vector machines.
- decision towards ulcer prevention: considering, as input, data about the lying position and other sources (patient history, etc.) generate outputs to help caregivers to decide what actions to apply to the patient.

However, most research works stop at lying position classification. The ones that go forward tend to contribute to pressure ulcer prevention in the following ways:

i. Monitoring [15][16][17][14]– data gathered from the sensors can be analysed by caregivers. This can include pressure maps or other values (e.g., time since the last change in position, physiological data, etc.). These values can be displayed, usually in graphical form or using mobile apps.

ii. Notifications [15][9][16][17][10][11][14][18][19] – Raising of alarms when the patient is resting in the same position for longer than a specified amount of time. This reduces the risk of the patient resting for extended periods in the same position (the most common cause of pressure ulcers) and can save the caregiver's time if the patient changes position spontaneously. Other alarms can be raised if the patient moves too much - when restlessness is a risk - or gets up from bed (maybe falling).

iii. Personalization e.g. [9][14] – allow that data to be visualized as is relevant for that particular patient. Information regarding the patient's medical history can be

inputted into the application, to be displayed or used in some decision-making processes.

iv. Actuation [16][17] – these are not common and tend to be very expensive. As an example, a few beds have pressure actuators that can control pressure in specific areas. Some of these actuators can be controlled remotely by caregivers.

v. Prediction [20] – offer some kind of prediction of pressure ulcer occurrence based on diverse sources of information, both sensor-based and obtained in other ways, such as patient history or physiological data.

Good results can be achieved in lying position detection using a variety of techniques. However, these results are yet rarely tested in real conditions and are measured in some form of a simulated environment. Several approaches raise alarms that are helpful to the caregivers and health professionals, namely as a warning system for the position changing cycle and as an alarm for dangerous situations such as restlessness or getting up of bed (or falling). So, there are several successful approaches to the lying position detection problem with clear practical implications, yet there are less successful cases of approaches able to use this information in conjunction with other data sources to effectively predict pressure ulcer development risk.

4 A System for Pressure Ulcers Monitoring and Prevention

In the context of what was mentioned in the previous section, the architecture and prototype of a new approach that is being developed to fill some of the identified gaps, and contribute to a more complete decision support system, are presented below. This system is also based on data from a pressure map, constructed from the acquisition of values using a pressure sensor sheet, and personalized data from the respective patient being monitored.

4.1 Architecture and Technologies

This section contains information regarding the overall implemented architecture of the system, split into two sections, one for the sensor sheet data and one for the clinical data.

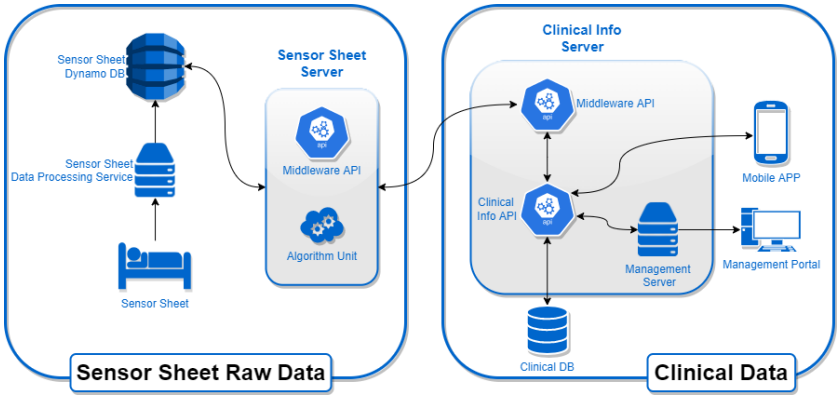

Fig. 2. Architecture Diagram.

The sensor sheet data section portrays the system capable of extracting data from the sensor sheet and, using artificial intelligence algorithms, the creation of alarms to be used by the applications used by the staff. The clinical data section is the section responsible for clinical data that will also be used in the algorithms, according to each patient's physical and medical characteristics the algorithm will have different outcomes.

The architecture on the left side of the Fig. 2 contains the sensor sheet, which gathers the data of the bedded patient, a data processing service that receives the data from the sensor sheet and cleans it so only the required data is stored in a database. The two other elements on the sensor sheet raw data section are responsible for passing the raw data through the algorithm unit so that body positions and body parts that are under pressure can be identified. This information can be translated into alarms to be used in the management portal and application. Alarms will be transmitted through an API that ensures communication between the different sections.

The right side of the diagram contains the architecture for the clinical data section of the architecture which accounts for the data acquired through the usage of both the management portal and the mobile application, the database (Clinical DB) is where the information regarding the patients, beds, and users is stored, this can be accessed through the backend, encapsulated inside a server where the clinical info API is responsible for managing data on the database, this API is the communication bridge between the management server/mobile application and the clinical database, the server also contains the Middleware API responsible for communicating with the left section of the architecture for the algorithmic processes regarding the patient's health condition. The front end of the architecture is hosted on a React server for the management portal which can be accessed from any browser with internet access.

4.2 Prototype

Most healthcare systems already have an application to facilitate patient data management, mostly generalized so they can have as much information as possible. For the SensoMatt system, there was a simplistic approach in which only the data considered relevant to pressure wounds (intrinsic/extrinsic factors) is managed. This way the responsible medical staff can view and edit information related to this subject more quickly and easily.

Fig. 3. Left: Sensor sheet in the bed. Right: Sensor sheet.

A pressure sensor sheet under the mattress provides useful information about the patient's body parts under pressure. Placing the pressure sensors underneath the mattress is a less intrusive solution for the patient. This way there are no changes in temperature or friction, it does however pose a challenge when trying to accurately measure the pressure and identify the patient's body position when lying down. The sensor sheet layout shown in Fig. 3 (left), presents the 3 corresponding intervening factors for its functioning. First the bed mattress, for an all-around solution the sensor sheet should be put below the mattress and be able to correctly measure the pressure distribution despite the differences in mattresses. Secondly, the sensor sheet measures patient movement and pressure and sends the measured data to the Sensor Sheet Data Processing service. Thirdly, the data obtained by the sensor sheet is registered, which allows producing a pressure distribution map of the body and identifying the posture of the bedridden patient, using Artificial Intelligence algorithms. Based on this information, it is possible to identify the parts of the body which are under pressure, and this information is used to predict the risk of pressure ulcers. The sensor sheet is presented in Fig. 3 (right). In its current version, it contains an array of 4 × 10 sensors, and a sheet sensor with a higher number of sensors is being developed.

The information is later processed using technologies such as cloud computing, mobile computing, and artificial intelligence to provide patients and clinical staff with personalized technology for the early detection and prevention of pressure ulcers.

Considering each patient's situation, together with the clinical information, the system will produce indicators/alerts to healthcare professionals, simultaneously improving the quality and safety of pressure ulcer patient care and minimizing the burnout on healthcare professionals. In the prototype's current stage, alerts are based on rules that consider the patient's existing ulcers, the patient's body position and for how long the same position is kept. The platform includes a web portal and a mobile application for managing information on pressure ulcers using information obtained by the sensor sheet. The management portal was designed to convene a faster way of evaluating the patient's state concerning pressure ulcers, the patient is added into the system with the filling of a simple form that includes some medical parameters like height and weight as well as some other possibly related health issues. The patient can then be associated with a bed in the system and be monitored by a sensor sheet when available. After admission, the medical staff can perform multiple evaluations, be it relevant medical information like comorbidities or Braden[1] scale evaluations that measure the risk of pressure ulcers or evaluate the patient's afflicting pressure ulcers so they can be recorded and monitored throughout the bedding period.

In Fig. 4 there is a portion of the pressure ulcer evaluation screen in which the clinical staff can evaluate the state of the patient's ulcers, in here the staff can select a body part from a body image mapped with the multiple body parts, after selecting a body part they are prompted to input the wound's width, depth, and pressure ulcer stage, this can be done for multiple body parts and once the user is finished they can complete the evaluation by clicking the "Evaluation Complete" button.

[1] https://www.bradenscale.com/

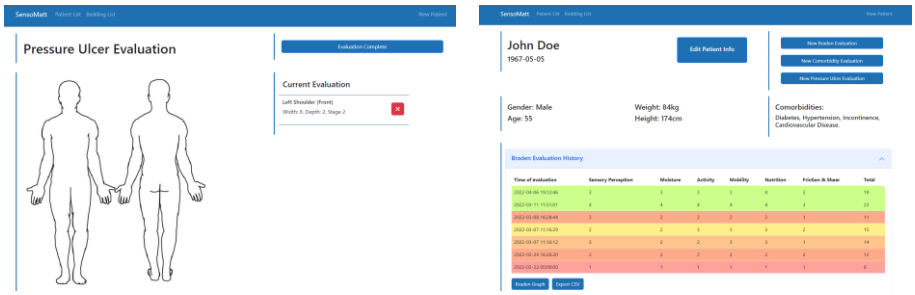

Fig. 4. Left: Pressure Ulcer Evaluation Screen. Right: Braden evaluation table.

The evaluations are then stored and can be viewed in a table, displaying all the previous evaluations along with the parameters for each body part's ulcer, for easier assessment of the evolution of the patient's wounds each body part can be selected from the table so the staff can view a graphical representation of it.

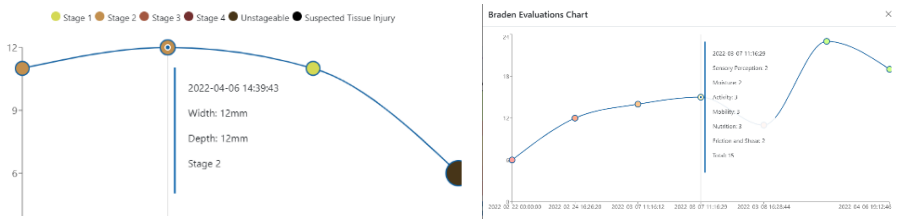

Fig. 5. Left: Pressure Ulcer graphical representation. Right: Braden evaluation chart.

Fig. 5 shows the graphical representation of a simulated pressure ulcer and its evolution over 4 different evaluations, each dot represents an ulcer, the Y-axis represents the depth of the wound, the size of the dot represents the width, and the colour represents the corresponding stage. The dots can also be hovered for a more detailed report on the evaluation of a certain ulcer at a certain time. Apart from this graphical representation the system also has a graphical representation for the Braden scale evaluations and all other data collected from the medical staff interactions with the platform.

The mobile app has a more simplistic approach to the functions included in the platform considering screen size and other conditioning factors. As such the main goal of the app is for healthcare professionals to have remote access to the patient's information and most importantly getting the same alerts the platform gets but in the shape of notifications for quicker access.

5 Conclusion and Future Work

In this paper, a system has been presented to support caregivers of patients with pressure ulcers. The architecture and the prototype of the new system for pressure ulcer monitoring and prevention were presented in their present state. This system is based on pressure data collection, using a pressure sensor sheet, and lying position determination. An information system to explore the acquired data, including back-office storage of relevant information and a mobile application for healthcare professionals are

still under development, with specific care being taken to ensure that privacy, security, and other specific regulations in the healthcare field are fully met. Considering the situation of each patient, the system will produce indicators/alerts to healthcare professionals, simultaneously improving pressure-ulcer patient care quality and safety and minimizing the burnout in healthcare professionals. Work is also being done with healthcare professional partners to adjust different aspects of the prototype system, that will influence the requirements for the mobile application being developed, the definition of the data that is both useful to store in the information system, and the several aspects of the visualization, alarm, and predictive components that these professionals consider more helpful in managing patients with pressure ulcers.

Thus, future work will evolve in two directions. On the one hand, a sensor sheet is being developed with a greater number of sensors to obtain more accurate pressure map images. It will also be necessary to obtain pressure map images from a larger sample of patients. These will be important to train the body position detection algorithms and thus improve their accuracy. On the other hand, predictive algorithms will be studied and implemented to make recommendations to health professionals. The results will be compared with other similar works and evaluated by potential users.

Acknowledgements

This research has received funding from the P2020 and EU FEDER Programme [PO CENTRO 17/SI/2019] under grant agreement No. 70107 [SENSOMATT].

References

1. Bluestein, D., Javaheri, A.: Pressure ulcers: prevention, evaluation, and management. Am. Fam. Physician. 78, 1186–1194 (2008).
2. Garcia, A.D., Thomas, D.R.: Assessment and management of chronic pressure ulcers in the elderly. Med. Clin. North Am. 90, 925–944 (2006). https://doi.org/10.1016/j.mcna.2006.05.018.
3. National Pressure Ulcer Advisory Panel, E.P.U.A.P. and P.P.: Pressure Injury Alliance. Prevention and Treatment of Pressure Ulcers: Quick Reference Guide. Emily Haesler (Ed.). Cambridge Media: Osborne Park,. , Australia (2014).
4. National Institute for Health and Care Excellence: Pressure ulcers. Quality standard [QS89], https://www.nice.org.uk/guidance/qs89, last accessed 2021/07/12.
5. Ribeiro, F., Fidalgo, F., Silva, A., Metrôlho, J., Santos, O., Dionisio, R.: Literature Review of Machine-Learning Algorithms for Pressure Ulcer Prevention: Challenges and Opportunities. Informatics. 8, (2021). https://doi.org/10.3390/informatics8040076.
6. Polo Rodríguez, A., Gil, D., Nugent, C., Medina, J.: In-Bed Posture Classification from Pressure Mat Sensors for the Prevention of Pressure Ulcers Using Convolutional Neural Networks. Presented at the (2020). https://doi.org/10.1007/978-3-030-45385-5_30.
7. Matar, G., jean-marc Lina, Kaddoum, G.: Artificial Neural Network for in-Bed Posture Classification Using Bed-Sheet Pressure Sensors. IEEE J. Biomed. Heal. Informatics. PP, 1 (2019). https://doi.org/10.1109/JBHI.2019.2899070.

8. Alinia, P., Samadani, A., Milosevic, M., Ghasemzadeh, H., Parvaneh, S.: Pervasive Lying Posture Tracking, (2020). https://doi.org/10.3390/s20205953.
9. Bernal Monroy, E., Polo Rodríguez, A., Estevez, M., Medina, J.: Fuzzy Monitoring of In-bed Postural Changes for the Prevention of Pressure Ulcers using Inertial Sensors Attached to Clothing. J. Biomed. Inform. 107, 103476 (2020). https://doi.org/10.1016/j.jbi.2020.103476.
10. Minteer, D., Simon, P., Taylor, D., Jia, W., Li, Y., Sun, M., Rubin, J.: Pressure Ulcer Monitoring Platform—A Prospective, Human Subject Clinical Study to Validate Patient Repositioning Monitoring Device to Prevent Pressure Ulcers. Adv. Wound Care. 9, (2019). https://doi.org/10.1089/wound.2018.0934.
11. Qidwai, U., Al-Sulaiti, S., Ahmed, G., Hegazy, A., Ilyas, S.K.: Intelligent integrated instrumentation platform for monitoring long-term bedridden patients. In: 2016 IEEE EMBS Conference on Biomedical Engineering and Sciences (IECBES). pp. 561–564 (2016). https://doi.org/10.1109/IECBES.2016.7843512.
12. Bennett, S.L., Goubran, R., Rockwood, K., Knoefel, F.: Monitoring the relief of pressure points for pressure ulcer prevention: A subject dependent approach. In: 2013 IEEE International Symposium on Medical Measurements and Applications (MeMeA). pp. 135–138 (2013). https://doi.org/10.1109/MeMeA.2013.6549722.
13. Lee, H.J., Hwang, S.H., Lee, S.M., Lim, Y.G., Park, K.S.: Estimation of Body Postures on Bed Using Unconstrained ECG Measurements. IEEE J. Biomed. Heal. Informatics. 17, 985–993 (2013). https://doi.org/10.1109/JBHI.2013.2252911.
14. Hsiao, R.-S., Mi, Z., Yang, B.-R., Kau, L.-J., Bitew, M.A., Li, T.-Y.: Body posture recognition and turning recording system for the care of bed bound patients. Technol. Heal. Care. 24, S307--S312 (2016). https://doi.org/10.3233/THC-151088.
15. Pongthanisorn, G., Viriyavit, W., Prakayapan, T., Deepaisam, S., Somlertlamvanich, V.: ECS: Elderly Care System for Fall and Bedsore Prevention using Non-Constraint Sensor. In: 2020 International Electronics Symposium (IES). pp. 340–344 (2020). https://doi.org/10.1109/IES50839.2020.9231781.
16. Abdelmoghith, A., Shaaban, R., Alsheghri, Z., Ismail, L.: IoT-Based Healthcare Monitoring System: Bedsores Prevention. In: 2020 Fourth World Conference on Smart Trends in Systems, Security and Sustainability (WorldS4). pp. 64–69 (2020). https://doi.org/10.1109/WorldS450073.2020.9210319.
17. Barroso, I., Soares, S., Rodrigues, V., Silva, S., Monteiro, M., Rainho, C., Duarte, D., Valente, A.: Assisted Caretaking System for Geriatric Home Care. Presented at the (2020). https://doi.org/10.1007/978-3-030-60149-2_34.
18. Lee, C.-N., Yang, S.-C., Li, C.-K., Liu, M.-Z., Kuo, P.-C.: Alarm System For Bed Exit And Prolonged Bed Rest. In: 2018 International Conference on Machine Learning and Cybernetics (ICMLC). pp. 439–443 (2018). https://doi.org/10.1109/ICMLC.2018.8527027.
19. Liu, J., Chen, X., Chen, S., Liu, X., Wang, Y., Chen, L.: TagSheet: Sleeping Posture Recognition with an Unobtrusive Passive Tag Matrix. In: IEEE INFOCOM 2019 - IEEE Conference on Computer Communications. pp. 874–882 (2019). https://doi.org/10.1109/INFOCOM.2019.8737599.
20. Hong, Y.-S.: Smart Care Beds for Elderly Patients with Impaired Mobility. Wirel. Commun. Mob. Comput. 2018, 1780904 (2018). https://doi.org/10.1155/2018/1780904.