An application of Engineering 4.0 to hospitalized patients

Roberto Mosca[1], Marco Mosca[2], Roberto Revetria[3], Fabio Currò[4], Federico Briatore[5]

[1]Emeritus Professor at Mechanical, Industrial and Transport Engineer department (D.I.M.E.), University of Genoa, Genoa, Ge 16126. Italy (e-mail: mosca@diptem.unige.it)
[2]Researcher at Mechanical, Industrial and Transport Engineer department (D.I.M.E.), University of Genoa, Genoa, Ge 16126. Italy (e-mail: marcotulliomosca@gmail.com).
[3]Professor at Mechanical, Industrial and Transport Engineer department (D.I.M.E.), University of Genoa, Genoa, Ge 16126. Italy (corresponding author to provide phone: +39 320 7982 156; fax: +39 010 317750; e-mail: roberto.revetria@unige.it).
[4]Fabio Currò is a Ph.D. at Mechanical, Industrial and Transport Engineer department (D.I.M.E.), University of Genoa, Genoa, Ge 16126. Italy (e-mail: 4452164@studenti.unige.it).
[5]Ph.D. Student at Mechanical, Industrial and Transport Engineer department (D.I.M.E.), University of Genoa, Genoa, Ge 16126. Italy (e-mail: federico.briatore@gmail.com)

Abstract. In this paper the authors address the problem of surveillance of bedridden patients in hospitals and residences for elderly. Unfortunately, patients cannot be supervised by operators 24 hours a day, given the associated costs. An attempt to solve this problem is already provided by wearable devices. This paper describes a 4.0 system implemented to overcome the limits (identified by interviewing a sample of nurses belonging to different facilities) of the wearable devices available on the market. The system proposed consists in monitoring the bed, instead of the patient, through applied sensors. By centralizing and analyzing the data collected it is possible to promptly inform the operative center of the occurrence of risky events to which bedridden patients are normally subjected. The scope of the system is preventing such risks, where possible, or mitigating their effects with a real time intervention. A case study on an active facility, conducted as a pilot project, confirms the humanitarian and economic benefits for patients and facility.

Keywords: Bed management, Bed 4.0, IOT, Bed, Healthcare 4.0.

1 Premise

The paper aims to highlight one of the many applications of Engineering 4.0, in which this discipline can make a positive contribution to the Healthcare sector, without interfering with the “care activity” which is exclusive task of the doctors. Such application is based on a peripheral device designed and created by the authors in both versions:

- Wired (ethernet) or wireless (wi-fi / Bluetooth 5.0) normally offered to hospitals, medical and surgical outpatient clinics, recovery rooms in operating blocks and residences for elderly.
- Telemetry (GSM, GPRS) offered to healthcare facilities for home assistance.

The system allows to monitor and notify the surveillance operators in case of non-conformities, so that they can intervene and anticipate unwanted event. A prompt intervention avoids critical situations as well as to the inevitable economic, criminal and image consequences for the hosting facility. Particular attention in design was paid to reliability and cost. This because, being the device considered by the authors as a tool to alleviate the suffering of bedridden patients, the goal was to ensure the maximum diffusion for the benefit to the largest number of patients achievable.

2 Introduction

The authors have conceptualized and designed a system to fix some serious problems common to hospitals, nursing homes and residences for elderly, with which the development team have been in contact for over 15 years. A major risk identified is the manifestation of painful bedsores bedridden patients for long periods, favored by the droppings and by reduced mobility. Healing from this requires painful and expensive long care. Another problem occurs, in the absence of surveillance, when they try to leave the bed, by climbing over the protective sides. The result can be disastrous, with multiple fractures and hemorrhages, due to falls. Another problem is represented by elderly patients subject to prolonged bed rest, who frequently wander around the structure without reason, with exposure to risk for themselves and for others. When asked about ward doctors and health directors, as highlighted in the literature, they explained that to avoid such events it would be necessary to have 24-hour surveillance, which is not compatible with the associated costs. Determined to help fixing a problem that causes further pain to hospitalized people, the authors have resorted to what Engineering 4.0 currently makes available, to create a system capable of perceiving, through appropriate sensors, both the wet bed both the stasis and preparatory movements to climb over the containment barriers. Sudden alerts indicating the bed number and the type of event in place are sent to a central control center. This triggers an operator to intervene. A systematic use of this system will allow to solve this problem, thus reducing pain and high social costs. The phases of conceptualization, engineering and development took over six months. This system, tested in a pilot project (as described in the case study), then extended to more facilities, received enthusiastic comments from the staff, releasing the operators from the responsibility of continuously monitoring the safety of patients. The system allows for more safety for the patients, less responsibility for the staff and less costs for the facilities for causes and compensation.

3 LITERATURE REVIEW

A careful literature review was conducted by researching predominantly on Scopus, WOS and Google Scholar. Over 82.700 papers were found by researching about bed management over these 3 data bases. It was then realized that the keyword “Bed Management” was used for a wide range of applications, even outside healthcare. Therefore, the selection was largely reduced to 28.608 (by filtering with keywords like medicine/nursing/health). Then, restricting again the field by focusing on hospitalization, the number was reduced to 8.856 articles. A last filtration was necessary to focus the actual topic of the study (since bed management in hospitals is mainly referred to the practice of nurses of managing bedridden patients), further reducing the selection to 326 papers, related to the use of technical devices. Such papers were screened, downloaded, and analyzed. The conclusion of the research was that only 46 articles were related to the topic treated, involving the use of sensors of which 19 are reported in bibliography. This result made the authors aware that literature does not currently treat much about the application of sensors to beds in healthcare. The literature review was then extended to wearable devices, in order to compare the method proposed with possible alternatives. That said, the literature of the sector takes the surveillance of bedridden patients in great consideration and reports that in charged personnel is often insufficient with respect to the demand. [14], [15], [16], [17]. All articles agree that there are problems with overcrowding of beds and shortages of staff. Adding the aging of the population, the WHO (World Health Organization) predicts that by 2060 the 30% of the European population will be over 65 years of age [16]. In 2019, the article [17] was published, which deals with how it is necessary to use technology to obtain automated solutions for the problems that arise. In 2020 in Healthcare 4.0 [16], is emphasized the "new promising vision for the Healthcare Industry" by the use of Industry 4.0 methodologies. On the same theme the articles [3], [5], [6], [7], [8], [10], [11], [12]. From literature emerges the tendency of monitoring the patient by using wearable devices located on wrist, chest, lower back, and ankle, for monitoring of parameters to ensure a better supervision and, therefore, a reduction in injuries, especially from falls. It is reported, nevertheless, about limits related to the discomfort of wearing [18], [19].

4 DESCRIPTION OF THE DEVICE

The system is based on peripheral devices (1 per bed) and sensors (normally 3-4 per device) such as a load cell, a vibration sensor and one for the presence of moisture in the sheets. The weight variation detector senses the patient's attempts to leave the bed when the patient begins to hold on to the safety rails or headboards, while the vibration sensor identifies any pathologies associated with unusual movements and, finally, the humidity detector perceives the presence of liquids. The devices convert these variations into signals which are centralized on a server, analyzed and transmitted to the Operations Center.

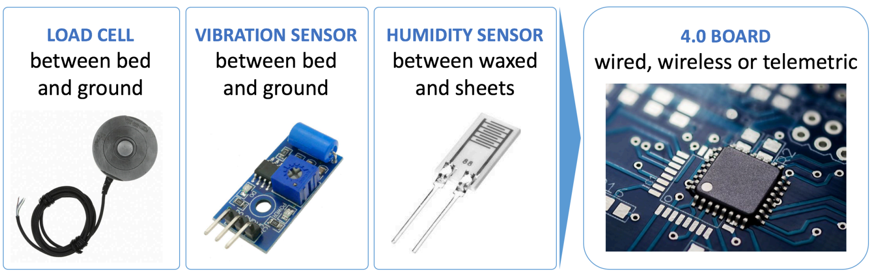

Fig. 1 System peripheral components (bed hardware)

As hardware details, the selected sensors are high compliance and highly efficient components: the load cell guarantees an accuracy of +/- 1% of span (interval of measure) with a tolerance of 10 µV/V. The vibration sensor has a capacitance of 750pF with an accuracy +/-70. The humidity sensor measure is Boolean (Y/N) with an accuracy of 99,9%. The motherboard developed was successfully tested EMC (Electromagnetic Compatibility) in an anechoic chamber to guarantee not to interfere with any medical equipment of the facility, the test was passed on second attempt after removing any quartz component from the PCB (Printed Circuit Board). The operator immediately requires the intervention of surveillance personnel, thus avoiding such problems. The signal is also recorded in a log file and kept available for statistical processing.

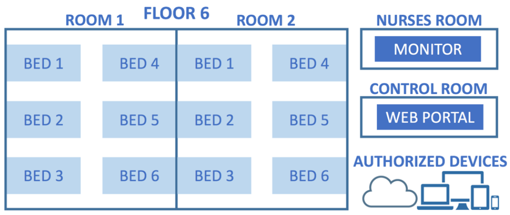

Fig. 2 Layout of the infrastructure to be monitored

In architectural terms (Fig. 3), the use of a concentrator gateway per couple of rooms is envisaged, to integrate the data collected from each bed. The same transmits the data (using different protocols depending on the location, thus avoiding interferences with the medical technologies in use) to a dedicated server, which structures the data in a relational DB, divided by channels, and analyzes them by building information understandable by the operators (as graphs, tables, …). The analysis conducted are consolidated into reports, distributed internally in a hard-wired closed circuit and externally on the Web portal via private cloud, allowing access to authorized devices only, in full compliance with cyber security.

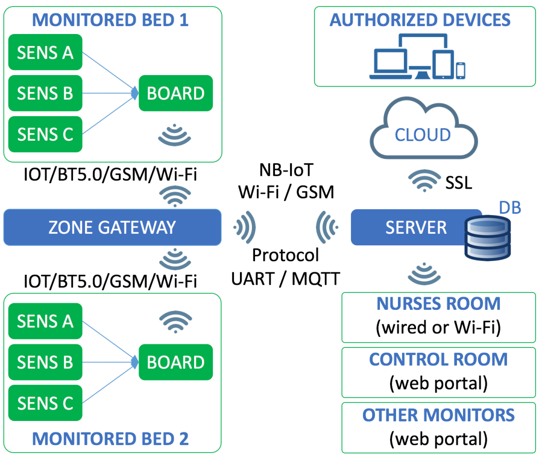

Fig. 3 System architecture

M2M (Machine to Machine) communication, was designed redundant in consideration of the specific needs of installation in different type of environments, therefore it can be selected on the PCB whether to connect via narrow band IOT, Bluetooth 5.0 or even GSM (for centralized surveillance of bedridden patients assisted from home). Therefore, this approach led to the necessity to make available both ethernet wired solution and different non wired alternatives. The flexibility achieved required the use of different protocols of communication, from UART (Universal Asynchronous Receiver-Transmitter) to MQTT (Message Queue Telemetry Transport) and, in order to be compliant to cyber security, the data flow was 24 bit crypted by using SSL (Secure Socket Layer) protocol for any external communications.

5 OTHER FEATURES

5.1 Stasis monitoring

The device, by monitoring the center of gravity of the bed, is able to detect if the patient remains immobile for prolonged periods of time (stasis) with the consequent risks for his health. The control center, through the information received from the platform, will real-time assess whether it is a normal situation or it is necessary to take urgent action in order to avoid worsening the patient's condition.

5.2 Tremor monitoring

In case the patient is prey to abnormal tremors such as those caused by the onset of high fevers or seizures (for patients subject to this type of pathology), the system equipped with a special sensor for monitoring the vibrations of the bed, launches an alert to the central for the necessary measures.

5.3 Weight tracking

The system is also capable of monitoring the patient's weight. This function allows the structure to measure losses of body mass and increases in patient’s weight due, for example, to water retention. Such information allows the medical staff to better assess the patient's condition and to take appropriate measures. It should be noted that the system, by sampling thousands of times per second, is able to distinguish whether the weight variation is real, or it is due to the sudden presence of foreign bodies like books, mobile phones, etc., or exogenous factors, such as drinking a glass of water.

5.4 Standardization

The system has been designed to be compatible with beds from different manufacturers. In this regard, the load cell is installed in a mini platform (3D printed), with safety edges, on which the braked wheel of the bed (or the foot of the bed) surmounts. Another 3 passive platforms, of equal thickness, are used to balance the remaining feet of the bed, to keep the heights aligned.

5.5 Software features

For a real-time monitoring of the possible states of the patient, a dedicated software was created to allow the central officers to keep the beds under constant control. Figure 4 shows the screen relating to 2 rooms of a given floor. The color code highlights the possible states of the bed-patient system. In case of critical situations, it is enhanced by specific sound signals or even sirens. In this way the surveillance is facilitated with benefit for the patients and for the staff, who is less stressed by the pressure and the responsibility of the work, due to a supporting technology that makes monitoring safe.

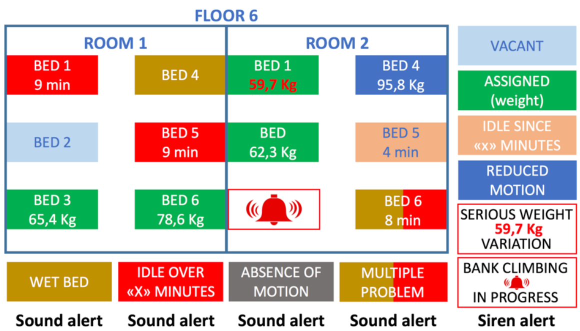

Fig. 4 Monitoring software (layout overview)

Important prerogatives of the system consist in the ability to cover most of the needs of a facility in terms of patient monitoring, allowing the control of each bed in every room. The system may be extended indefinitely, with a plug and play logic. Other types of sensors can be implemented in a second step, in relation to new needs. It is also possible to integrate, because of IOT, any departments and facilities even located at a great distance. The system is easy and intuitive for the operators and the alerts can be set according to the preferences of the same.

6 INNOVATION

As it emerges from the literature review the application of sensors to beds is still very poorly investigated by researchers, so leaving wide space to innovation. Compared to the use of wearable devices (currently used for a 24h surveillance of patients) the benefits of the system proposed consist both in releasing the patients, as much as possible, from body applications both in introducing new monitoring functions like droppings identification, fall prevention and weight trend. Contrary to the wearable devices bed management acts in full respect of privacy, since it does not collect any biometric data. Moreover, the data transmission is made via IOT, allowing the centralization of data also in case of multi-site facilities, making information and data accessible via Cloud or Web-portal from any Internet point on the globe, by authorized devices.

7 BENEFITS

According to the case study presented forward (section 7), the adoption of the proposed system brings a multitude of positive relapses. In fact, it allows the operators to reduce their presence in the departments, thus permitting them to perform other activities. There are also clear benefits for patients in terms of safety and of comfort and for their relatives, who enjoy a higher level of visibility. The facilities who adopt the system, in addition to freeing themselves from responsibilities and costs for the above-described occurrences, will be able to boast and advertise the higher level of service (also in case of domestic assistance) and, therefore, enhance their competitive positioning on the market. In a perspective of continuous improvement, it was included the statistical process control, made easy to understand to any operator through control tables (Figure 5 shows weight trend). With numerical support, the Management may improve the efficiency from a medical and an economic point of view. In fact, the system allows the facility to decrease costs for causes and compensation due to injuries. As a consequence, it is no wonder the great interest encountered in hospitals, nursing homes, residences for the elderly. The saving achieved translate into an economic advantage, that can be used to improve the service level or to increase the profit for the shareholders.

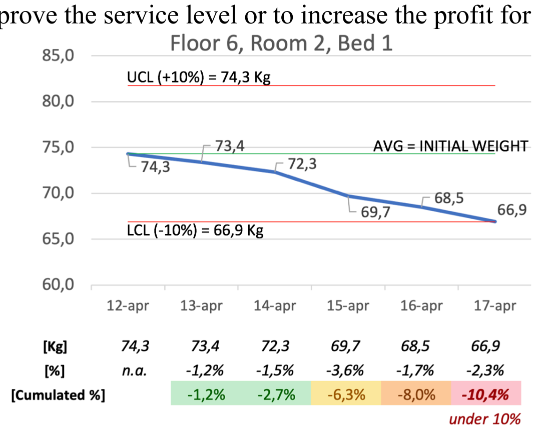

Fig. 5 Monitoring software (patient's weight trend)

8 FUTURE DEVELOPMENT

As a new feature the authors believe that the possibility of monitoring the quality of sleep could be of interest, in order to allow doctors to evaluate the opportunity to administer appropriate drugs to give patients an adequate night's rest. In addition, the teams want to investigate the advisability of correlating the effects of certain drugs with any states of impatience / psychomotor agitation of the patient, in order to allow doctors to better calibrate the dosage, or to use substitute drugs, which are better tolerated.

9 CASE STUDY AND ECONOMIC SUSTAINABILITY

This paragraph reports the case study relevant to the application of the system described to a nursing home, that hosts full service up to 100 patients aged over 80, with an average presence of 90 patients / day for 365 days / year.
The analysis conducted on historical data highlighted the following:

- Average number of wet beds 120 / month
- Average number of bed abandoned 10 / month
- Average number of consequent fractures 5 / month
- Costs incurred by the institution for repairs € 6,000 / year
- Costs incurred by the National Health Service n.a.
- Costs incurred by the institution for legal claims € 10,000 / year

The data necessary for the economic evaluation are:

- Avoided costs (due to the adoption of the system) € 15,000 / year
- Costs for the purchase of a system with 100 devices € 50,000
- Various costs (server, gateway, cables, SW, installation) included
- Maintenance costs over the life cycle (annual fee) € 1,000 / year
- Disposal costs negligible
- System life cycle 9 years
- Actual savings (€15,000-€1,000) € 14,000 / year

The PBP (Pay Back Period), calculated as the initial investment divided by the cash flow, is equal to 3.57 years (€ 50,000 / € 14,000). The NPV (Net Present Value), calculated as the sum of the discounted cash flows at the discount rate of 8%, is equal to € 63,989 as shown in table 1.

	YEAR 0 2021	YEAR	YEAR 10 2031
Discounting exponent	0,0	...	5,0
Expenses			
Investment	50.000 €		
Maintenance cost		...	1.000 €
Income (annual benefit)			
Labor saving		...	15.000 €
Total income	- €	...	15.000 €
Total Expenses	- 50.000 €	...	- 1.000 €
Cash flow (CF)	- 50.000 €	...	14.000 €
Cumulative cash flow	- 50.000 €	...	90.000 €
i = discount rate	8,0%	...	
Discounted cash flow	**- 50.000 €**	...	**9.528 €**
PbP (Pay Back Period)	**3,57**		
NPV (Net Present Value)	**63.989 €**		

Tab. 1 Financial analysis

10 CONCLUSIONS

The basic idea can be defined as an application of Engineering 4.0 to the medical sector. To cope with the problems related to bedridden patients, the authors invested efforts in designing a low-cost system and architecture that would represent a real solution. The outcomes of the study, as certified by the management of the testing facility (section 7), proved that the application of the system brought both the indisputable humanitarian benefits for the hospitalized and the favorable economic implications for the institution.

References

1. Blockchain's coming to hospital to digitalize healthcare services: Designing a distributed electronic health record ecosystem (Roberto Cerchione, Piera Centobelli, Emanuela Riccio, Stefano Abbate, Eugenio Oropallo). Technovation, Article in press, ISSN: 0166-4972
2. A decision support simulation model for bed management in healthcare (E.A. Cudney, R. Anvesh Baru, I. Guardiola, T. Materla, W. Cahill, R. Phillips, B. Mutter, D. Warner, C. Masek). International Journal of Health Care Quality Assurance Vol. 32 No. 2, 2019 pp. 499-515 © Emerald Publishing Limited 0952-6862
3. Adoption of Industry 4.0 and lean concepts in hospitals for healthcare operational performance improvement (Tharushi Sandunika Ilangakoon, Samanthi Kumari Weerabahu and Premaratne Samaranayake, Ruwan Wickramarachchi). International Journal of Productivity and Performance Management © Emerald Publishing Limited 1741-0401 DOI 10.1108/IJPPM-12-2020-0654
4. Modeling decisions for hospital bed management; A Review (Joaquim Matos, Pedro Pereira Rodrigues). In Proceedings of the International Conferenceon Health Informatics (HEALTHINF—2011) pages 504-507, ISBN: 978-989-8425-34-8
5. Health 4.0: On the Way to Realizing the Healthcare of the Future (Jameela Al-Jaroodi, Nader Mohamed, Eman Abukhousa). Received October 4, 2020, accepted October 30, 2020, date of publication November 18, 2020, date of current version December 7, 2020. Digital Object Identifier 10.1109/ACCESS.2020.3038858.
6. Healthcare 4.0: A Voyage of Fog Computing with IOT, Cloud Computing, Big Data, and Machine Learning (A. Kumar Sarangi, A. Gajendra Mohapatra, T. C. Mishra, Bright Keswani). © Springer Nature Switzerland AG 2021. S. Tanwar (ed.)
7. Fog Computing for Healthcare 4.0 Environments, Signals and Communication Technology, https://doi.org/10.1007/978-3-030-46197-3_8
8. Heart Failure Analysis Dashboard for patient's Remote Monitoring Combining Multiple Artificial Intelligence Technologies (G. Guidi, M. C. Pettenati, R. Miniati and E. Iadanza). 34th Annual International Conference of the IEEE EMBS. San Diego, California USA, 28 August - 1 September, 2012. 978-1-4577-1787-1/12/$26
9. Hospital 4.0 roadmap: an agile implementation guideline for hospital manager (M. Unterhofer, E. Rauch, D. T. Matt). Int. J. Agile Systems and Management, Vol. 14, No. 4, 2021
10. Importance of Fog Computing in Healthcare 4.0 (Jasleen Kaur, Richa Verma, Nawaf Rasheed Alharbe, Alka Agrawal, Raees Ahmad Khan). © Springer Nature Switzerland AG 2021. S. Tanwar (ed.), Fog Computing for Healthcare 4.0 Environments, Signals and Communication Technology
11. Artificial Intelligence and Internet of Things Based Healthcare 4.0 Monitoring System (Amit Kishor, Chinmay Chakraborty). Wireless Personal Communications. https://doi.org/10.1007/s11277-021-08708-5.

12. Role of emerging technologies in future IoT-driven Healthcare 4.0 technologies: a survey, current challenges and future directions (Sreelakshmi Krishnamoorthy, Amit Dua, Shashank Gupta). Journal of Ambient Intelligence and Humanized Computing. https://doi.org/10.1007/s12652-021-03302-w
13. A survey of group decision making methods in Healthcare Industry 4.0: bibliometrics, applications, and directions (Keyu Lu, Huchang Liao). Applied Intelligence. https://doi.org/10.1007/s10489-021-02909-y
14. An exploratory study of bed management (Ruth Boaden, Nathan Proudlove), Journal of Management in Medicine · February 1999 DOI: 10.1108/02689239910292945
15. Active Bed Management by Hospitalists and Emergency Department Throughput (Eric Howell, Edward Bessman, Steven Kravet, Ken Kolodner, Robert Marshall, Scott Wright), Annals of Internal Medicine 2008;149:804-810
16. Aging, patient-bed management and overcrowding in the medical departments (Aldina Gardellini, Roberto Nardi *, Vincenzo Arienti, Domenico Panuccio, Raffaella Bernardi, Vincenzo Pedone), Italian Journal of Medicine 2009;3(1):35-43
17. An Internet of Things Based Bed-Egress Alerting Paradigm Using Wearable Sensors in Elderly Care Environment (Muhammad Awais, Mohsin Raza, Kamran Ali, Zulfiqar Ali, Muhammad Irfan, Omer Chughtai, Imran Khan, Sunghwan Kim, Masood Ur Rehman), Sensors 2019, 19, 2498; doi:10.3390/s19112498
18. Supervisory Control System for Hospital Rehabilitation Beds (Bruno Santos, Daniel Martins, Tarcisio Leao, Eduardo Bock), 2021 9th International Conference on Control, Mechatronics and Automation (ICCMA) | 978-1-6654-1073-1/21/$31.00 ©2021 IEEE
19. Convergence of Automation Technology, Biomedical Engineering, and Health Informatics Toward the Healthcare 4.0 (Z. Pang, G. Yang, R. Khedri, Y.T. Zhang), IEEE Reviews In Biomedical Engineering, VOL. 11, 2018