e-PEMICU: an e-Health Platform to Support Early Mobilisation in Intensive Care Units

Antoni Martínez-Ballesté, Pablo Gimeno, Aleix Mariné,
Edgar Batista and Agusti Solanas
Smart Health Research Group, Dept. of Computer Engineering and Mathematics,
Universitat Rovira i Virgili, Av. Països Catalans, 26, 43007 Tarragona, Spain
antoni.martinez@urv.cat, pablo.gimeno@urv.cat, aleix.marine@estudiants.urv.cat,
edgar.batista@urv.cat, agusti.solanas@urv.cat

***Abstract*—Early Mobilisation routines aim at improving the recovery process of critically ill patients that are hospitalised in intensive care units. Such routines consist of passive and active progressive mobilisations aiming at reducing the side-effects derived from ICU stays. In this paper, we present e-PEMICU, an e-health platform to support early mobilisation programmes in intensive care units. Our solution is founded on motion sensors and smartphones, hence, it is affordable and easy to deploy in real scenarios. We present the design and implementation of a prototype that has been created to address real users needs. Our platform paves the way for a better and sustainable application of current early mobilisation routines.**

***Index Terms*—early mobilisation, smart health, motion sensors, intensive care units**

Fig. 1: A physiotherapist performing a passive mobilisation on a patient's arm.

I. Introduction

Early Mobilisation (EM) consists in applying passive and active mobilisation routines to critically ill patients that are hospitalised in intensive care units (ICUs) [1]. Physicians and physiotherapists struggle to shorten patients' stay in the ICU with the aim of decreasing their risks of suffering from *Postintensive Care Syndrome*, including physical issues (*e.g.* muscle weakness and other muscular disorders[1]), and mental or cognitive alterations [2]. These alterations, which may last for years, clearly jeopardise patients' quality of life. Moreover, according to several studies, half of the ICU surviving patients are not able to work for one year after being hospitalised, and 30% might suffer from life-long impairments with no chances of returning back to their normal, professional, active life [3].

EM of critically ill patients is beneficial and it should be incorporated into daily clinical practice [4]. Early passive, active, and combined progressive mobilisations allow for shortening ICU and hospital stays and reduce their side-effects. Passive mobilisation includes manual passive exercises (see Figure 1 for an example of passive mobilisation) and the use of a variety of passive motion machines. Active mobilisation can be done by patients while sitting on a bed or chair, and includes cycling, tilting up and ambulating (either with or without assistance, and even while mechanical ventilation is in place). Although EM is safe and beneficial (when properly applied by professionals), there is a lack of standardised frameworks and widely-accepted procedures. On the one hand, the optimal level of physical therapy (*i.e.*, intensity, duration, frequency) must be determined at different times (for fully sedated patients, first awakening patients, etc.) and it has to be adapted to each patient [1]. On the other hand, there are several barriers that EM programmes must face namely, patient-related barriers (symptoms and condition), barriers related to human and technical resources, as well as barriers related to the health institution policies and their view on EM convenience [5].

A. *Early Mobilisation in Practice*

Health professionals apply EM worldwide. To illustrate the case, let us take the example of health professionals of *Joan XXIII* Hospital in Tarragona (Catalonia, Spain). They have integrated EM routines into their daily practice in the ICU. Currently, the EM programme involves professionals such as physicians, nurses and physiotherapists. The physician responsible for the EM programme designs a series of routines for each of the following patients' levels:

- Level 1: for unconscious patients, includes passive mobilisation of extremities and postural changes.
- Level 2: for conscious patients, includes active mobilisation of extremities.
- Level 3: adds a sitting posture.
- Level 4: adds basic everyday movements.
- Level 5: adds walking exercises.

Physiotherapists and nurses put exercises into practice and apply the programmed mobilisation routines as scheduled, with a specific number of repetitions and intensities. Routines are usually defined session by session according to

[1]Up to a 40% loss in muscle strength can occur within the first week of immobilisation.

the progress of each patient. Once finished, physiotherapists and nurses take note of each patient's progress on paper forms or by using some basic software. To the best of our knowledge, there are no electronic tools to ease the monitoring of EM programmes neither to analyse patients, exercises and outcomes from a global perspective. Thus, it is difficult and cumbersome to detect similarities or trends among patients and, hence, to extract other high level knowledge on the evolution of patients.

Moreover, once patients are released from the ICU, there is no protocol in place to keep doing mobilisations and exercises beyond Level 5, which may not require the continuous presence/assistance of a physiotherapist.

B. Early Mobilisation and Smart Healthcare

As we have stated above, general practice considers minimal or no electronic devices to support early mobilisation programmes. However, a number of proposals to monitor physical activities related to rehabilitation can be found in the literature. The vast majority of those solutions are based on computer vision techniques applied in controlled environments with fixed cameras, and using visible markers in specific locations.

Instead of considering fixed cameras alone, we aim at following the paradigm of Smart Healthcare described in [6], and we augment the ICU (and the patients in it) with the proper sensing capabilities so as to be considered context-aware environments able to provide automatic feedback on a number of signals, which could be used to monitor the condition and activities of patients. In fact, many context-aware solutions have been used in healthcare [7], [8] but, to the best of our knowledge, this is the first application of this approach in ICUs.

Our approach to augment ICUs aims at being cost-effective and minimally intrusive. Thus, we base our solution on mobile devices and low footprint motion sensors, which use in this area is still in its infancy [9], [10].

Despite their potential privacy and security risks [11], [12], mobile devices have been previously used to determine patients movements in several platforms [13] and for many applications [14]–[16]. Moreover, several techniques have been suggested to protect patients location and data privacy [17]. All in all, the proposed solution has the technology to guaranty the safety of patients and can significantly contribute to improve their monitoring in EM programmes.

C. Contribution and Plan of this Paper

In this paper we present e-PEMICU, an e-health platform to support Early Mobilisation programmes in Intensive Care Units. We address the design and implementation of a platform that allows practitioners to monitor the achievements in the different phases of the programme. The rest of the paper is structured as follows: Section II describes the architecture of the platform, Section III presents the system functionalities, Section IV addresses some implementation details and, finally, Section V concludes the paper.

Fig. 2: A box in the ICU of Joan XXIII Hospital in Tarragona (Catalonia, Spain).

II. ARCHITECTURE

The core of the platform is a *hardware node*, which is comprised of an accelerometer, a smartphone and a tablet:

- The accelerometer is embedded in a wearable device and wrapped in a wristband. It can detect acceleration changes in the X, Y and Z axes.
- The smartphone links the wearable device (or devices) to the back-end using Bluetooth Low Energy to connect the devices with the smartphone, and the TCP/IP stack over WIFI to connect the smartphone with the back-end.
- The tablet runs a web browser to access the platform's front-end and interact with the provided tools.

An ICU is typically organised in boxes where patients receive treatments. Boxes (*cf.,* Figure 2), whose core is a hospital bed, re equipped with medical devices (*e.g.*, mechanical ventilation apparatus) and bedside monitors. Boxes are distributed around a control zone, where nurses can monitor patients remotely and in real time. It is expected that every box in the ICU is equipped with a hardware node. In the ICU, EM sessions will be managed by a physiotherapist.

Once patients finish their stay in the ICU, they are released to one of the hospital's room. In our proposal we count with a number of portable versions of the hardware nodes. Whenever an EM routine is scheduled, an orderly brings the portable node to the hospital room and connects the equipment. In the hospital room, the EM routines can even be managed by some relative or caregiver, after some training by the physiotherapist. Note that, under specific circumstances, even the patient could be able to manage the session on his/her own.

The back-end server logs the information on the movements and the routines performed by the patient. Also, it stores personal data about patients. Hence, two databases are considered: a movement log database for routines accounting (motion database, Figure 4) and a database with patients' data. Note that the server is deployed using web technologies so it can be accessed from virtually any device with Internet browsing capabilities and the right credentials. Figure 3 schemes the big picture of the e-PEMICU architecture.

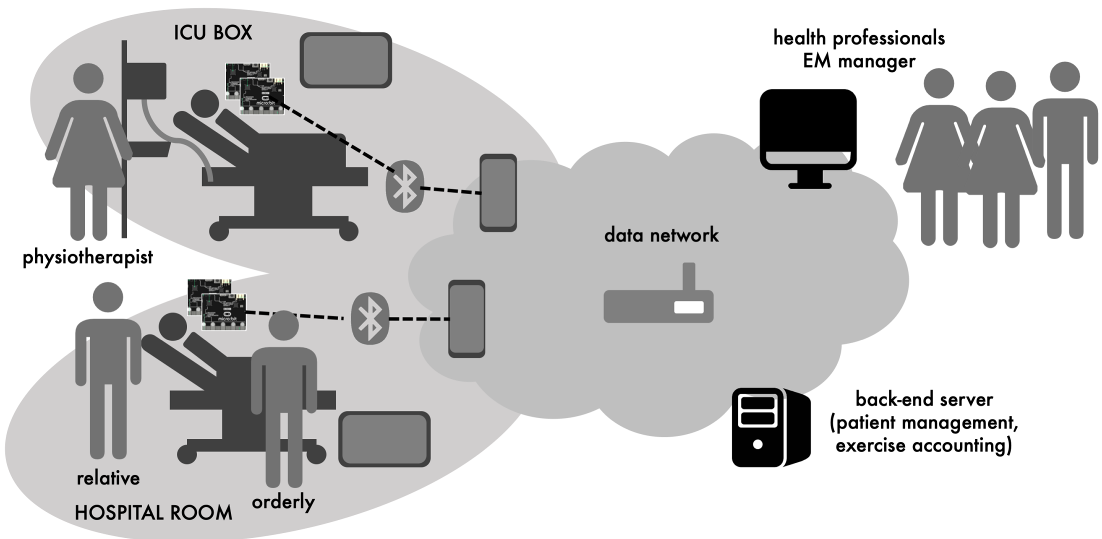

Fig. 3: The big picture of the e-PEMICU platform.

III. Functionalities, Roles and Modules

This section describes the functionalities of the e-PEMICU platform. We define the users' roles of the platform and, we describe its modules, namely the *Session Module*, the *Assessment Module*, and the *Management Module* (*cf.,* Figure 4).

A. Users' roles

The platform considers three kinds of users:

- 'Manager': typically a doctor responsible for the management of e-PEMICU. This user is able to add, edit and remove patients and setup other users. Moreover, he/she schedules the routine for each patient and is able to access the *Assessment Module*. Also, they are able to manage the devices of the platform (*i.e.,* smartphones and sensors).
- 'Professional': intended for physiotherapists and nurses of the ICU who manage EM sessions with a number of patients. They have access to the *Session Module* to work with patients, and are also able to assess the progress of the patients by using the *Assessment Module*.
- 'Sporadic': intended for those users supervising EM routines in regular hospital rooms, this is, nurses, physiotherapist, relatives, caregivers or the very patients.

B. Session Module

The main functionality of the system is to record data from the EM sessions. Users will setup the motion sensors and will assist patients in the performance of exercises. 'Professional' users will select the patient from their list of assigned patients.

Both 'Professional' and 'Sporadic' users will assist patients when doing the scheduled routines, either by performing mobilisations on patients or, in case of conscious and recovered patients, just making sure that they follow the routines. The interaction with the system is done by using the website front-end. Hence, the physiotherapist will log in the website and will select the patient to work with. Users will be shown the exercise to be performed, together with some setup information *i.e.*, the number of sensors needed as well as their specific placing (*e.g.*, wrist, elbow, ankle, etc.) and orientation. Additionally, users can read a precise description of the exercise to be executed and the details of the pattern to be followed (in terms of rate and intensity). Also, a video depicting the execution of the exercises is available.

Once the sensors are in the right place, the session starts. A "start session" button is pressed and, from that moment onward, movements detected by the sensors are stored in the motion database, until the "end session" button is pressed. Users can annotate the session when it ends.

C. Assessment Module

Both physiotherapists and administrators can use the assessment module: its goal is to measure the degree of achievement of the mobilisation routines for each patient.

This module shows the number of routines executed and the pending ones, as well as other statistics. In addition, for each performed session, an assessment indicator is shown. Since a session consists of a series of mobilisations, each one is assigned a colour that indicates how far the real mobilisation is from the intended one. For example, if a mobilisation consists in moving the hand up and down without moving the elbow, a red colour is shown if movement in the elbow is detected.

D. Management Module

This module contains additional functionalities, such as the management of users and patients. Also, it considers device registration and identification: adding new sensors to the system, setting up new smartphones, or disabling devices not being used. Regarding sensors, this module allows for the checking of sensors working order (*i.e.* detecting changes in acceleration, and level of battery). Also, this module allows to download and plot raw data from the *Motion Database*.

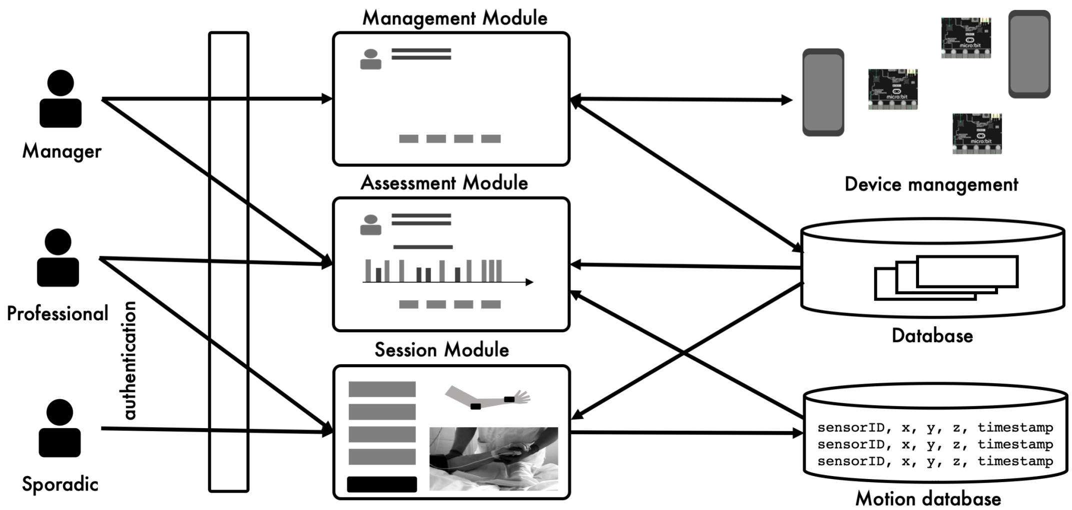

Fig. 4: Users, modules and databases of the system

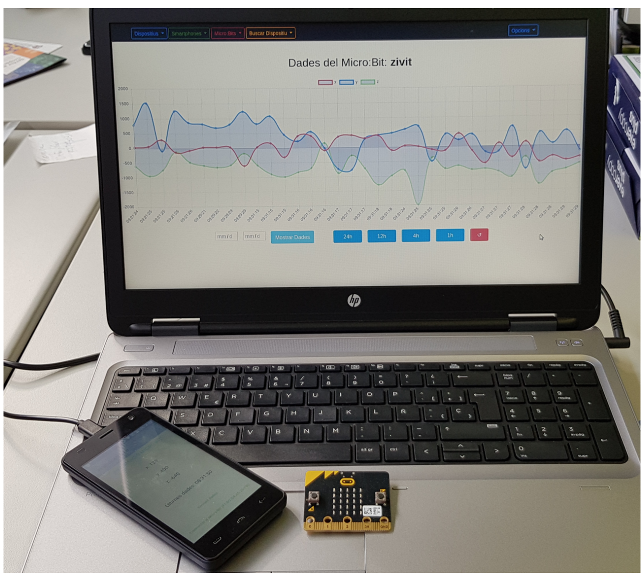

Fig. 5: Picture of the main components of the prototype, showing the raw motion data interface (May 2019).

IV. Implementation

We have implemented a prototype (*cf.* Figure 5) as a proof of concept of the platform. The current implementation is being tested in Joan XXIII Hospital. The hardware components of the prototype are the following:

- *Sensors:* We have selected the micro:bit device as motion sensor [18], [19]. It is inexpensive, small and can be used on patient's bodies in an almost non-intrusive manner. It can be inserted in a wristband. It contains an accelerometer and can be programmed to send a message as soon as a change in the acceleration is detected. It is attached to a pair of AAA batteries. Its low power consumption allows it to operate for weeks without being recharged. micro:bits are programmed using a C++ library [20] with drivers to access all their functionalities, *e.g.* from controlling the LED display to the peer-to-peer radio communication and secure BLE services.
- *Smartphone:* We use simple smartphones, capable of establishing BLE links with the micro:bit sensors. They also establish a WiFi connection with the data network.
- *Access Point:* We use an 802.11ac access point to create a wireless network so that all smartphones in the platform can communicate with the server.
- *Server:* A computer with an Intel i5 processor. It uses the XAMPP stack (Linux, Apache, MySQL, PHP, Perl) to run the back-end and front-end of the platform.
- *Tablet:* Used to access the front-end using Chrome through a WiFi connection to the access point.

A. Identification and Pairing

Each micro:bits counts with a pair of buttons. When button 'B' is pressed, the LED matrix shows the *Unique Derived Name* (UDN): a set of five characters that are unique to the device. Using this, sensors can be identified and users can know what sensors are used in each hardware node. For communications purposes, sensors must be paired with a smartphone. In the current prototype, up to three motion sensors can be paired in a hardware node. Note that, in order to prevent data related to *faux* movements from being stored, users will be able to enable and disable sensors in the *Session Module* and the motion information coming from disabled sensors will not be stored in the motion database.

B. Messaging

When a sensor detects a change in the acceleration in any of the axes, an event is triggered and a message is sent from the sensor to the smartphone, using the BLE link. The message contains the sensor's UDN, the acceleration values in X, Y and Z, and a timestamp. This tuple is forwarded by the smartphone to the back-end using an HTTP GET method over a TCP connection.

V. Conclusions and Further Work

The introduction of information and communication technologies and the Internet of Things [21] within the healthcare domain paves the way for novel, flexible and sustainable solutions that aim at enhancing the quality of life of patients. The adoption of the smart health paradigm [6] that advocates for the development and use of the capabilities of context-aware scenarios opens the door to innovative solutions with higher degrees of personalisation, adaptation and responsiveness.

This article has focused on Early Mobilisation (EM) programmes, whose goal is to enhance the recovery process of critically ill patients that are hospitalised in ICUs. Despite the benefits of incorporating EM into daily clinical practice, there are no technological solutions to specifically evaluate the success of these EM programmes and to ease and foster their use. With the aim to fill this gap, we have designed and implemented e-PEMICU, a platform to support EM programmes in ICUs, and we have presented a working prototype that is currently in use and under evaluation in a real ICU scenario.

By deploying our platform, practitioners, hospital managers, and researchers will be able to collect vast and invaluable data from patients. The collection of these data will allow for obtaining knowledge and wisdom [22] and will help to improve the management of EM programmes worldwide. For instance, our *Assessment Module* allows the easy monitoring of the degree of achievement and adherence to the scheduled routines, and accounting progress on mobilisation routines allows for the later analysis of data, for example, by using process mining techniques [23].

Future work will focus on concluding the development of the platform and on evaluating its suitability with more patients in ICUs. Also, the analysis of the data will play a key role in the next developments of this research. Specifically, we will pay attention to new models for predicting and learning from imbalanced data [24] such as those gathered with e-PEMICU.

Acknowledgments

This work is supported by the Government of Catalonia with project 2017- SGR-896 and Universitat Rovira i Virgili, with projects 2017PFR-URV-B2-41 and 2017R2B-07. A. Mariné is supported by a collaboration grant of the Ministry of Education (2018-19). E. Batista is supported by an Industrial PhD grant (2017-DI-002) from the Government of Catalonia.

References

[1] A. R. Miranda Rocha, B. P. Martinez, V. Z. Maldaner da Silva, and L. A. Forgiarini Junior, "Early mobilization: Why, what for and how?" *Med Intensiva*, vol. 41, no. 7, pp. 429–436, Oct 2017.

[2] C. A. Bautista, P. Nydahl, M. K. Bader, S. Livesay, A. K. Cassier-Woidasky, and D. M. Olson, "Executive Summary: Post-Intensive Care Syndrome in the Neurocritical Intensive Care Unit," *J Neurosci Nurs*, Apr 2019.

[3] S. Phelan, F. Lin, M. Mitchell, and W. Chaboyer, "Implementing early mobilisation in the intensive care unit: An integrative review," *Int J Nurs Stud*, vol. 77, pp. 91–105, Jan 2018.

[4] S. Cameron, I. Ball, G. Cepinskas, K. Choong, T. J. Doherty, C. G. Ellis, C. M. Martin, T. S. Mele, M. Sharpe, J. K. Shoemaker, and D. D. Fraser, "Early mobilization in the critical care unit: A review of adult and pediatric literature," *J Crit Care*, vol. 30, no. 4, pp. 664–672, Aug 2015.

[5] R. Dubb, P. Nydahl, C. Hermes, N. Schwabbauer, A. Toonstra, A. M. Parker, A. Kaltwasser, and D. M. Needham, "Barriers and Strategies for Early Mobilization of Patients in Intensive Care Units," *Ann Am Thorac Soc*, vol. 13, no. 5, pp. 724–730, 05 2016.

[6] A. Solanas, C. Patsakis, M. Conti, I. Vlachos, V. Ramos, F. Falcone, O. Postolache, P. Perez-Martinez, R. Pietro, D. Perrea, and A. Martinez-Balleste, "Smart health: A context-aware health paradigm within smart cities," *IEEE Communications Magazine*, vol. 52, no. 8, pp. 74–81, 2014.

[7] C. Patsakis, R. Venanzio, P. Bellavista, A. Solanas, and M. Bouroche, "Personalized medical services using smart cities' infrastructures," in *IEEE MeMeA 2014 - IEEE International Symposium on Medical Measurements and Applications, Proceedings*, 2014.

[8] E. Aguirre, M. Flores, L. Azpilicueta, P. López-Iturri, F. Falcone, V. Ramos, and A. Solanas, "Implementing context aware scenarios to enable smart health in complex urban environments," in *IEEE MeMeA 2014 - IEEE International Symposium on Medical Measurements and Applications, Proceedings*, 2014.

[9] A. C. Verceles and E. R. Hager, "Use of Accelerometry to Monitor Physical Activity in Critically Ill Subjects: A Systematic Review," *Respir Care*, vol. 60, no. 9, pp. 1330–1336, Sep 2015.

[10] A. J. Ma, N. Rawat, A. Reiter, C. Shrock, A. Zhan, A. Stone, A. Rabiee, S. Griffin, D. M. Needham, and S. Saria, "Measuring Patient Mobility in the ICU Using a Novel Noninvasive Sensor," *Crit. Care Med.*, vol. 45, no. 4, pp. 630–636, Apr 2017.

[11] D. Ding, M. Conti, and A. Solanas, "A smart health application and its related privacy issues," in *Proceedings of the 2016 Smart City Security and Privacy Workshop, SCSP-W 2016*, 2016.

[12] A. Papageorgiou, M. Strigkos, E. Politou, E. Alepis, A. Solanas, and C. Patsakis, "Security and Privacy Analysis of Mobile Health Applications: The Alarming State of Practice," *IEEE Access*, 2018.

[13] A. Solanas, A. Martinez-Balleste, P. Perez-Martinez, A. Pena, and J. Ramos, "m-Carer: Privacy-aware monitoring for people with mild cognitive impairment and dementia," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 9, 2013.

[14] E. Batista, F. Borras, F. Casino, and A. Solanas, "A study on the detection of wandering patterns in human trajectories," in *6th International Conference on Information, Intelligence, Systems and Applications (IISA)*, 2015.

[15] A. Solanas, E. Batista, F. Borras, A. Martínez-Ballesté, and C. Patsakis, "Wandering analysis with mobile phones on the relation between randomness and wandering," in *PECCS 2015 - 5th International Conference on Pervasive and Embedded Computing and Communication Systems, Proceedings*, 2015.

[16] P. Rashidi and D. J. Cook, "Mining and monitoring patterns of daily routines for assisted living in real world settings," in *Proceedings of the ACM international conference on Health informatics - IHI '10*. ACM, 2010, pp. 336 – 345. [Online]. Available: http://portal.acm.org/citation.cfm?doid=1882992.1883040

[17] A. Solanas, A. Martínez-Ballesté, and J. Mateo-Sanz, "Distributed architecture with double-phase microaggregation for the private sharing of biomedical data in mobile health," *IEEE Transactions on Information Forensics and Security*, vol. 8, no. 6, 2013.

[18] Micro:bit Educational Foundation. Micro:bit. [Online]. Available: https://microbit.org

[19] Wikipedia. Micro bit. [Online]. Available: https://en.wikipedia.org/wiki/Micro_Bit

[20] Lancaster University. Micro:bit runtime. [Online]. Available: https://lancaster-university.github.io/microbit-docs/

[21] L. Liu, W. Chen, A. Solanas, and A. He, "Knowledge, attitude, and practice about internet of things for healthcare," in *2017 International Smart Cities Conference, ISC2 2017*, 2017.

[22] A. Solanas, F. Casino, E. Batista, and R. Rallo, "Trends and challenges in smart healthcare research: A journey from data to wisdom," in *RTSI 2017 - IEEE 3rd International Forum on Research and Technologies for Society and Industry, Conference Proceedings*, 2017.

[23] E. Batista and A. Solanas, "Process Mining in Healthcare: A Systematic Review," in *Proceedings of the 9th International Conference on Information, Intelligence, Systems and Applications (IISA)*. IEEE, 2018, pp. 1 – 6.

[24] Haibo He and E. Garcia, "Learning from Imbalanced Data," *IEEE Transactions on Knowledge and Data Engineering*, vol. 21, no. 9, pp. 1263–1284, sep 2009. [Online]. Available: http://ieeexplore.ieee.org/document/5128907/