FRADE: Pervasive Platform for Fall Risk Assessment, Prevention and Fall Detection

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Abstract: The ageing of the global population has an impact on the elderly quality of life, as the reduced mobility and balance contribute to the increasing of falls. Fall detection solutions can trigger emergency alerts and reduce the negative effect of falls. Fall risk assessment strategies can help to early identify fall risk factors and tailor strategies to revert those risk factors, by means of fall prevention exercises. However, most technological solutions do not simultaneously address these three aspects of the falls management cycle. *FRADE* platform will allow to pervasively detect falls using a wearable device, that can also be used to monitor fall risk assessment tests and recommended individual exercises, that can be performed at home with a tablet and two wearables.

1 INTRODUCTION

The worldwide population aged over 65 is rapidly growing and the consequences are simultaneously social, health-related and economic. The process of ageing impacts mobility, muscle strength and balance control which contributes to the increase of falls occurrence in this population. Currently, there are a variety of solutions to address only specific stages of the fall management lifecycle: assessing multiple fall risk factors, detecting falls automatically, and providing strategies for falls prevention that focus on attenuating specific fall risk factors (Rajagopalan et al., 2017). However, most technological solutions do not allow to close the falls management loop by simultaneously addressing fall detection (FD), fall risk assessment (FRA) and prevention (FP).

Among the elderly population, falls are one of the major causes of death and injury. More than 30% of people over 65 falls each year and the prevalence increases for people above 80 (Bergen et al., 2016). Besides social and personal consequences, falls also play an important role in healthcare costs. Centers for Disease Control and Prevention estimate approximately 645 fall-related emergency visits for every 10000 elderly. In the USA in 2015, the direct costs for fatal and nonfatal fall injuries were 637,5 million and 31,3 billion dollars, respectively (Burns et al., 2016). The Personal Emergency Response Systems (PERS) market is valued at 6245 million in 2018 and expected to reach 9452 million dollars by 2025 (Bergen et al., 2019).

Even a minor fall can severely affect the physical and mental health of an elder and increase the fear of falling again. Thus, the elderly quality of life and of their caregivers can be severally affected. For community-dwelling elderly, the problem affects mostly the elder and his family. However, given the high demand for specialized care due to aging and falls, most of the older adults need to be institutionalized, and thus the problems also affect daycare centers, retirement homes, nursing homes, and healthcare facilities. Fall detection solutions can trigger emergency alerts and reduce the negative effect of falls. FRA strategies can help to early identify fall risk and tailor strategies to revert those risk factors.

Currently, there are a variety of solutions to address only specific stages of the fall management cycle: assessing multiple fall risk factors, detecting falls

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automatically, and providing strategies for falls prevention that focus on attenuating specific fall risk factors. However, current solutions fail to provide a complete system for fall detection, fall risk assessment, and fall prevention, which would enable value-based healthcare. Most commercial solutions available in the market target only one specific functionality.

Personal emergency response systems (PERS), or medical alert services, provide prompt access to emergency help for elderly who fall. PERS are usually in the form of a pendant or wrist band, and enable the users to press a button, to transmits a signal to a call center or caregiver, who contacts emergency help. Most PERS are not automatic, instead, the user must press a button. PERS are stigmatizing since they should be attached to a specific on-body position, and most of them do not allow the user to select different levels of sensitivity for FD. The main competitors are Philips Lifeline [1], Medical Guardian[2], AlertOne Services [3], Tunstall [4] and Life Alert Emergency Response [5]. These companies provide PERS with an emergency button, but few detect falls automatically.

FRA solutions fail to address multiple risk factors and only provide an estimation of FRA based on a limited number of risk factors evaluated in specific periods. There are several commercial solutions for FRA that can use wearable devices or pressure sensors to evaluate standard tests, such as QTUG from Kinesis[6], Go from GaitUp[7] and MoveTest from McRoberts[8].

FP solutions do not combine the assessment of fall risk factors with personalization of FP strategies. There are a variety of solutions that provide technological support to gamify physiotherapy exercises, either with wearable devices, pressure sensors or Kinect, such as Sword Health[9], Biosensics[10] and SilverFit[11].

Considering that there are no existing solutions that close the falls management loop, *FRADE* will be unique in that perspective. Such level of integration comes with benefits in the acquisition and maintenance costs, which can be cheaper than acquiring individual solutions. It also brings a broader view of the elder status, where all the information is available in a single platform, which should improve the efficiency of healthcare for the elderly population. The FD system is a standalone wearable device that supports multiple body positions. The FRA is composed of a multifactorial set of questionnaires and instrumented functional tests, which allow recommending individual exercises.

[1] https://www.lifeline.philips.com/medical-alert-systems/fall-detection.html
[2] https://www.medicalguardian.com/
[3] https://www.alert-1.com/
[4] https://www.tunstall.co.uk/resources/product-datasheets/vibby-fall-detector/
[5] http://www.lifealert.com/
[6] https://www.kinesis.ie/qtug/
[7] https://clinical.gaitup.com/gait-up-go/
[8] https://www.mcroberts.nl/products/movetest/
[9] https://swordhealth.com/
[10] https://biosensics.com/
[11] https://silverfit.com/en/

2 *FRADE* PLATFORM

FRADE is composed of a bundle of components (wearable sensor, desktop application, Android application, data storage, and data visualization web interface) to perform FD, FRA, and FP. The elder will use the wearable sensor to monitor falls automatically, based on movement analysis. It sends an alarm to the backend server and an SMS to a caregiver whenever a fall is detected. The wearable device will also be used to monitor the elder's movements and communicate with the desktop and Android application while he performs FRA tests and FP exergames. All the monitored data is stored in the data storage and can be accessed through a web interface, by a caregiver or an healthcare provider.

2.1 Fall Detection Wearable Device

Kallisto is an hardware module with sensing, communication and power management capabilities. It includes a set of inertial and ambient sensors, Bluetooth Low Energy (BLE) and NFC radios, as well as USB and Qi inductive charging systems. It is supplied as a module and can be used as standalone or as part of a more complex device. To build the wearable device, the COMM mainboard was used that comprises Kallisto as its core block and complements the system by providing extra sensing and communication functionalities. It includes GNSS, Narrow Band-IOT (NB-IoT) and RFID radios[12].

The wearable device casing was conceived from a user-centered perspective in a way of making it easy to use whilst accommodating the HW platform. The design approach was to make the device almost part of the user clothes, as a simple shirt button for example, as represented in Figure 2. When attached to the clothes the device will provide automatic fall detection, and occasionally, when attached on an accessory to the users' thighs or feet, it will provide data stream for movement analysis.

[12] https://demo.sensry.net/

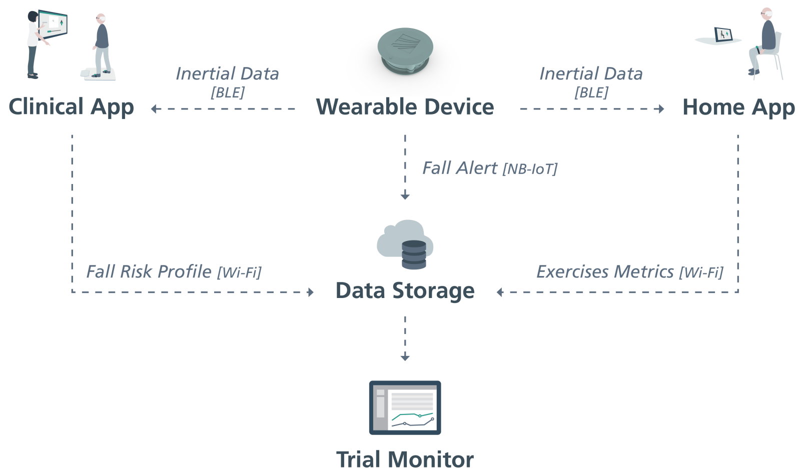

Figure 1: Hardware and software components of the *FRADE* platform.


Figure 2: Wearable device Kallisto placed in the clothes as a button.


Figure 3: Elderly performing the fall risk screening using the Clinical App.

This wearable device integrates an automatic fall detection algorithm and offers features such as alarm sending, through the wearable device, which can be used discreetly by the user in the belt, pocket or in the chest. The fall detection algorithm is embedded in the firmware of the wearable device. This algorithm analyses the inertial sensors data and detect whenever a fall incident occurs, as previously described in (Alves et al., 2019). In case of detection of a fall event, a notification will be sent to a data storage that in turn sends an SMS and e-mail to a set of predefined emergency contacts. The communication between the device and the data storage is made through NB-IoT. The device also triggers an audible alarm to attract the attention of people nearby, featuring an emergency button that allows the cancellation of false alarms. The device works independently of a smartphone or other resource and only needs to be charged via an induction charger, which is made available with the device.

2.2 Fall Risk Assessment Clinical Application

The Clinical app is a Windows desktop application that was designed for the healthcare providers to allow the creation of questionnaires and functional tests to screen the elderly regarding the fall risk. The exercise monitoring algorithms are based on the analysis of movement and balance (Martins et al., 2018) using sensor data from two wearable devices and a PhysioSensing pressure platform, as can be seen in Figure 3. This application also allows healthcare providers to prescribe exercises for the home application. The application was developed in Unity 2019.3.3 and requires a laptop with BLE to connect to the wearable devices and a USB port to connect to the pressure platform[13].

The Clinical App extracts information about the movement and balance of the user while he is per-

[13]https://www.physiosensing.net/

forming the functional tests Sit-to-Stand Test (Cho et al., 2012), Timed-Up and Go Test (Kojima et al., 2015), and 4 Stage Balance Test (Thomas et al., 2014), as shown in the main screen of Figure 4. The application also allows the insertion of the personal profile of each participant and the answer to several questionnaires for the assessment of several risk factors for falls, such as activities of daily living (Araújo et al., 2008), fear of falling (Figueiredo and Santos, 2017), and home hazards (Watson et al., 2014) questionnaires. In addition, the application allows the prescription of Otago Exercise Program (OEP) exercises and their schedule for each participant through a dedicated exercise prescription interface. This exercise prescription will be sent automatically to the Home application.

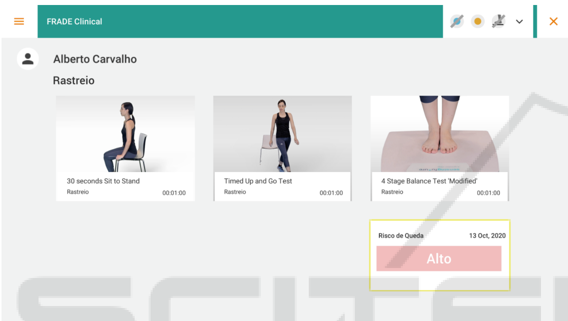

Figure 4: Screening exercises in the Clinical App.

2.3 Fall Prevention Home Application

The Home App is an Android tablet-based application for the elderly to perform fall prevention exercises based on the Otago Programme, an evidence-based program for reducing falls (Campbell et al., 1997). The application provides interfaces with instructions on how to perform the exercises, as in Figure 5, and interfaces with feedback during the exercises, which are based on the movement analysis algorithms provided by the inertial sensors of a wearable device, as previously described in (Silva et al., 2018).

The interactive Home application, based on the Otago exercise program, aims to improve physical functionality. The application features 8 exercises from the program, i.e., knee flexion, knee extension, hip abduction, knee bending, toe raises, calf raises, sit to stand, and one leg standing, that are static, easy and well accepted exercises with interactive feedback on the execution of the movement, as depicted in Figure 6. The application could also be a source of motivation for the participants who perform the exercises at home. The use of the application requires an Android Tablet, a support for the tablet, two wearable inertial devices, and the respective chargers. The application only requires internet connectivity once at the app setup and occasionally to synchronize the exercises metrics with the cloud (on follow up appointments with the clinician). The application is compatible with any tablet with Android version above Android 4.4 (API 19). The user will be guided through a weekly exercise plan, which he/she will be able to select through the tablet interface where the instructions for executing each exercise will be presented, as well as an interface with visual feedback during the execution of each exercise.

Figure 5: Example of one interface of the Otago exercises using the Home App.

Figure 6: Execution of one exercise using the Home App.

2.4 Data Storage

All the information collected through the aforementioned components is stored on Firebase Cloud Firestore. Cloud Firestore is a non-relational database that enable developers to safely store and sync data across multiple devices and applications. Firebase is certified under major privacy and security standards and follows the GDPR rules. All the data in Firebase is also encrypted on the tablet side. Cloud Firestore is also used to manage the authentication of users with the home and clinical applications. Only registered users can have access to the data, i.e., the healthcare providers or caregivers. Data from the clinical app, home app, as well as from the wearable device are stored on the database to be made available to the other applications in the system (Fig. 1). For instance, plans generated on the clinical app by healthcare providers are available for the elderly to follow in the mobile app. Cloud Firestore stores the profile data, such as height or clinical condition, the answers to the questionnaires for risk assessment, plans created by the healthcare providers, and session and exercise data detailing the measurements of individual exercises. Besides allowing developers to synchronize data across applications, it enable us to monitor the elderly during the trials, and to keep a detailed log of participants measurements for further analysis of the trials results.

2.5 Trial Monitor

Trial Monitor is a web application created with the purpose of supporting researchers monitoring participants remotely during field trials (Vasconcelos et al., 2019). The tool enables researchers to create personalized data visualization dashboards with the data generated by participants during the trials (Fig. 7). The web application connects to the data storage (i.e. Cloud Firestore) to retrieve users data, and generates visualizations for health providers to follow the elderly remotely.

The platform enables nursers to understand how participants are progressing during the trial, by providing a system for monitoring the results of the prescribed exercises and how they evolve over time. Healthcare providers can use the platform to visualize and analyse the results of the Otago exercises, or the fall risk assessment questionnaires. The platform displays the number of sessions completed and the results from individual exercises (e.g. number of repetitions, range of motion). Moreover, the platform allows researchers to easily export data (i.e. *CSV* file) from the system for further analysis after the end of the trial.

3 VALIDATION TRIALS

We have produced 20 units of system to be used during the validation trials. The participants are being recruited. The trials to be conducted will allow to evaluate the performance of the FD and to assess the fall risk of the elder population in the North region of Portugal. The trials will also provide insights on the effectiveness of the FP exercises using this technological platform.

The study will bring the objective measure of fall risk factors and movement-based metrics extracted during the Otago exercises. The technological platform allows the centralization of all relevant variables in a unified and secured database, that is accessed through a web portal, that will be available for the healthcare providers that will supervise the study. Besides the aforementioned variables retrieved by the Clinical app, i.e., personal profile, medical conditions, medication, answer to the questionnaires, and scores of the three functional tests, the Home app will allow to measure range of motion, number of repetitions and duration of ascending and descending movements for eight exercises of the OEP, i.e., knee flexion, knee extension, hip abduction, knee bending, toe raises, calf raises, sit to stand, and one leg standing.

4 CONCLUSION

The use of technological devices for early detection and prevention of falls is a key strategy to minimize the consequences of this event, namely the permanence on the ground for long periods after the fall and hypothermia, which often leads to the death of the elderly. This reality is verified not only in the elder's home but also in nursing homes. To respond to this, the scientific production in this area has been proliferating, both in the technological sector and in the academic and clinical context. The synergies created by the joint work of these areas, allow this project to contribute to the development of more effective strategies for prevention, reduction of falls and their physical, psychological and economic consequences.

In technological terms, we consider that the technological literacy of each participant could impact the way each one will use the platform and we are aware that some limitations may raise during the course of the eight weeks of intervention, considering that in some of the sessions the elderly will perform the exercises alone at home. To try to overcome these limitations, we foresee frequent contacts between the healthcare providers and the elderly, as well as remote guidance whenever possible.

At the end of the validation study, we will have a system for fall management composed of a wearable device and a bundle of applications. The system can be used to i) pervasively detect falls and assess fall risk factors in daily life; ii) monitor movements during fall risk assessment tests to estimate a risk of falling using a desktop application, with the supervision of a healthcare provider; iii) monitor movements during the execution of fall prevention exercises using by a tablet application. The trials conducted will

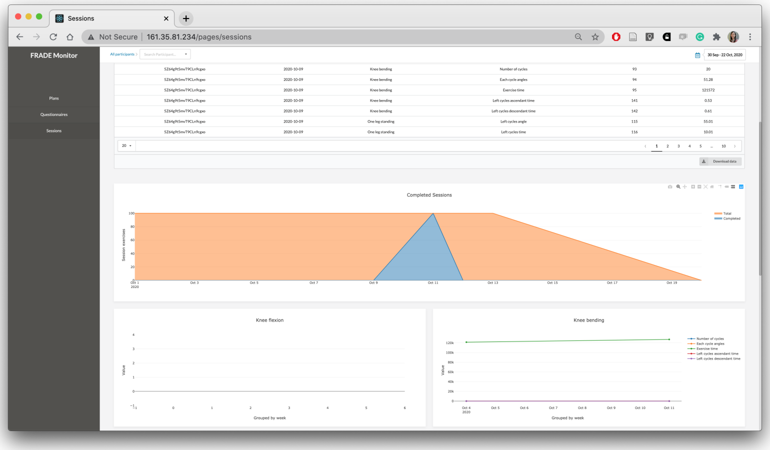

Figure 7: Trial monitor web platform displaying the metrics of the Otago exercises.

allow us to evaluate the performance of the FD, and to screen part of the institutionalized population in the North region of Portugal. The FD, FRA will provide insights on the effectiveness of the fall prevention exercises.

This validation study aims to evaluate the effectiveness of the technological solution for detecting falls and the identification of the risk of falling in the elderly at their homes, as well as validating a technological solution for fall prevention. The primary economic buyer will be companies that sell healthcare equipment, mainly to nursing homes and daycare centers. The secondary economic buyer will be the nursing homes and healthcare institutions and the tertiary economic buyer will be the final consumer, the elderly since the solution can also fit a home scenario.

The main obstacles for our solution to reach the market are mainly related to the user and market acceptance. The technological solutions that will be integrated into this system were previously developed based on user-centered design and all the prototypes were tested with the elderly in usability tests using a network of end-users and institutions. The fact that the same wearable can be used for FD, FRA and FP, will require less devices to be bought and maintained. The same applies to the monthly fees normally associated with these services, there will be a single fee for a system that covers all components, instead of a fee for each component. We can also mitigate the risks of poor market acceptance by providing only parts of the system.

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