A TELEMEDICINE APPLICATION OF AN EMBEDDED SYSTEM FOR REMOTE MONITORING OF BALANCE

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Abstract: The aim of this study is to present a solution for remote surveillance of elderly at risk of falling. This study presents a technological solution installed in the home of the elderly person being assessed by a remote monitoring unit. The system assesses the balance of an elderly person using a force plate linked with a local processing unit, which analyses the data provided by the force plate. The solution chosen needed to be both non-intrusive and low-cost. In order to achieve this aim, the system chosen needs to use readily available equipment, such as the mobile phone using Bluetooth™ communication for the force plate and GSM communication with the remote monitoring system. In order to allow easy adaptation of the software in the mobile phone, JAVA™ was used. This solution ensures that the local system is able to make the decision based on the data recorded, and to transmit the results to the remote system via GSM. The parameters related to the decision-making process are able to be modified remotely. The local installation part of the system has been tested successfully in a laboratory setting for both internet and GSM communication. The next step will to be to evaluate telecommunications, in particular the update facility, after which a field trial of remote assessment of balance in elderly subjects will begin. Such data is needed to adapt the treatment algorithms, and to evaluate the efficacy of the system.

Introduction

Falls in the elderly are one of the biggest concerns for healthcare services, in terms of medical and social consequences, as well as the associated financial cost. In France alone, more than 9000 people die each year from falls, at an estimated cost of 2 billion euros [1]. The most effective strategy to decrease the risk of falling is to adopt an exercise programme, however in order for such an intervention to be cost effective, only those people with a high risk of falling must be targeted [2]. Although many risk factors for falls have been identified, a recurrent factor is a balance problem [3], which can also be affected by other underlying conditions. Detection of individuals with balance problems and high risk of falling can be done using either biomechanical or clinical tests [4]. Biomechanical tests use a force plate to measure centre of pressure (COP) displacement over time, which can be used a measure of postural stability. However, the application of these tests to a large population is costly and time consuming [5]. The aim of this article is to describe a system that can perform non-invasive home-based balance tests as part of a remote monitoring system.

Measurement Protocol

The measurement protocol can be broken down into three phases (see Figure 1): the first phase, which corresponds to the subject stepping onto the force plate; the second phase, which corresponds to the period "stable" when the subject is stationary on the force plate; and the third phase, which corresponds to the descent backwards off the force plate.

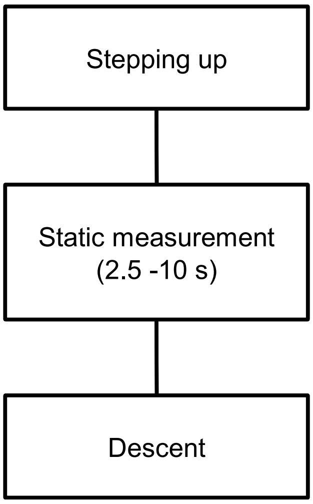

Figure 1: The three phases of the measurement protocol

The stepping up and descent phases can be classed as dynamic measurement [6], with the duration of these phases depending on the person measured. The "stable" phase can be classed as static measurement, with the duration, which would be fixed for all subjects, between 5 and 10 s. This duration, which could be reduced to as little as 2.5 s [7], needs to be long enough to evaluate the postural equilibrium of the subject using standard stabilogram analysis.

Thereafter, the pertinent parameters will be extracted from the recorded data, in order to determine a signature

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that permits the identification of the subject, and to analyse the evolution of this signature in order to determine the risk of falling.

System Architecture

The system needs to be not only non-intrusive, it also needs to be low-cost. In addition, as the criteria for detecting fall risk evolve over time, the system needs to be able to adapt to this evolution. Any change in the detection parameters need to be performed remotely, without necessitating an intervention in the home of the elderly person being assessed. Thus, the system needs to be accessible remotely.

The system consists of a local installation of a sensor and a local processing unit (LPU), which can communicate remotely with other parts of the surveillance network (see Figure. 2).

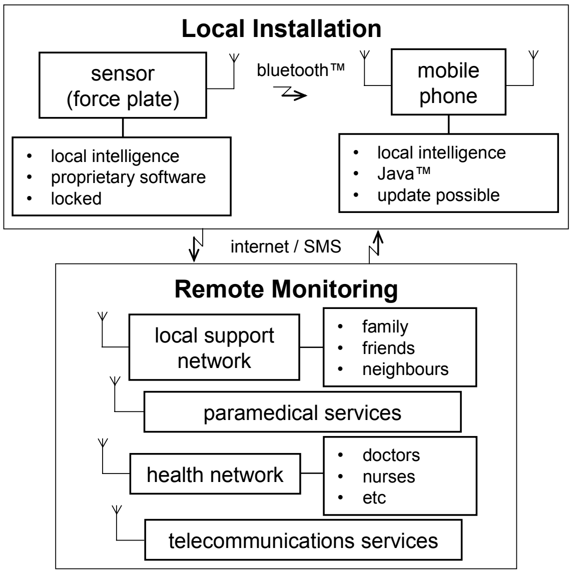

Figure 2: Schematic diagram of a remote monitoring system for balance assessment

Local Sensor

Although the final system needs to be low-cost, the initial design used an expensive high-technology solution. The sensor was a force plate (4060-80, Bertec Corp., USA) fitted with a wireless Bluetooth™ data transmission module. The force plate measured COP data, and had local intelligence in order to choose the information to send to the local processing unit. The software in the force plate was proprietary, and was unable to be modified remotely.

The force plate enables measures to be performed using four force sensors. The mediolateral and anteroposterior displacement signals of the stabilogram are then extracted from the raw data, before subsequent transmission to the embedded system.

The force plate needs to be energetically autonomous (battery powered). The measurement time, which should be less than 10 s, is able to be modified.

The management of the energy resources is very important, with the force plate activating as the subject approaches, in order to record the data for dynamic analysis. In order to aide energy conservation and to avoid perturbation of the measurement, wireless data transmission is performed at the end of the recording period, before being transmitted to the mobile phone.

The functioning of the force plate is explained by the algorithm shown in Figure 3. In order to conserve energy, the force plate needs to remain on standby, and be activated by the approach of the person. This can be achieved using a presence sensor, such as an optical sensor.

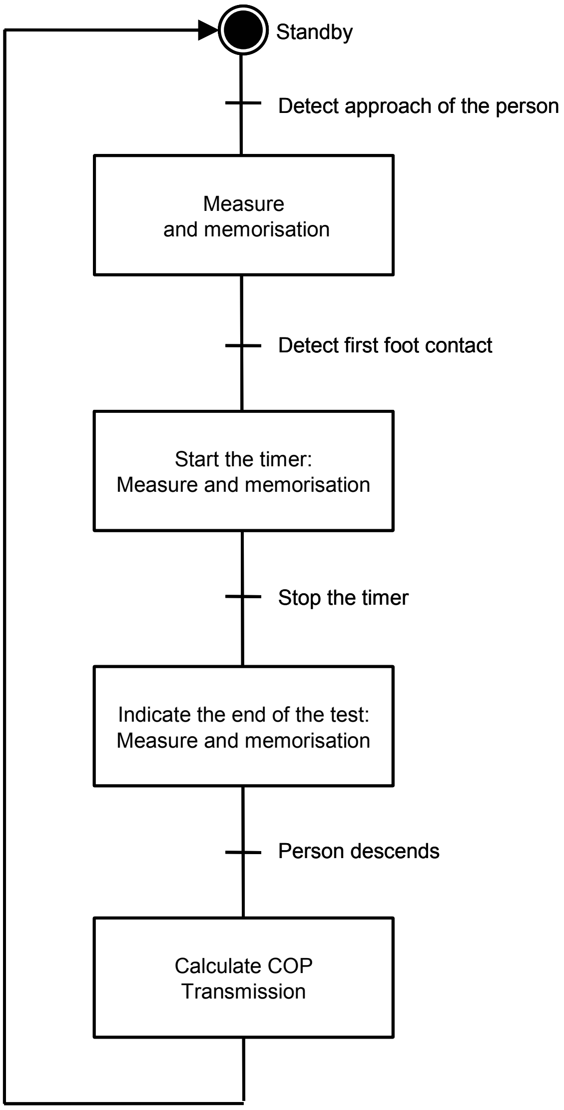

Figure 3: Algorithm of the functioning of the force plate

When the force plate is activated, it starts the measurement and memorisation of the values from the four force sensors. As soon as these values pass a threshold indicating that someone is one the force plate, the timer starts for the static measurement. At the end of the pre-determined duration for static measurement, an indicator is activated to signify that the person can descend from the force plate. After the end of the measurement period, data recording stops and the centre of pressure signals are calculated. Thereafter, the force plate establishes a Bluetooth™ connection with the mobile phone, transmits the data, before disconnecting and returning to standby.

Local processing unit

The functions contained in the LPU included signal processing, extraction of relevant parameters using algorithms based on clinical data [6,7], and a decision making capability. The LPU also communicated with both the sensor, and the rest of the surveillance network. The LPU had to be capable of transmitting the decision outcome by SMS or internet using GSM technology. In the current example, the role of the LPU was performed by a mobile phone (6600, Nokia, Finland), with programs written in Java™. The LPU possesses the following characteristics:

- Bluetooth™ interface,
- JAVA™ with multi-task operating system, and
- memory extension.

The LPU also performs the following functionalities:

- processing the data received via Bluetooth™,
- sending an SMS,
- updating of the decision-making parameters via GSM, and
- connection and transmission of data via internet.

These different functions are integrated in two processes that survey the arrival of the data. The first surveys Bluetooth™, in order to detect the arrival of the data from the force plate, and integrates the data processing functions, sending the SMS to the network, and sending the data via internet for storage. The second process surveys the telephone connection in order to respond to any modification of the detection parameters by the remote system. The priority is given to the first process in terms of the access to the parameters previously cited. The data processing algorithm for the first process is shown in Figure 4.

This process waits for a request for a Bluetooth™ connection. When this connection is established, the data transmitted are stored in memory and the connection is closed. The process then calculates the signature from these data, then compares the signature with the previous data to determine if there has been an evolution towards a risk of falling.

If there is a risk of falling identified, an SMS is sent to a neighbour, a friend, a family member, or a possible socio-medical network. Thereafter, a connection can be established with a remote server in order to transmit the latest results that are stored in the database.

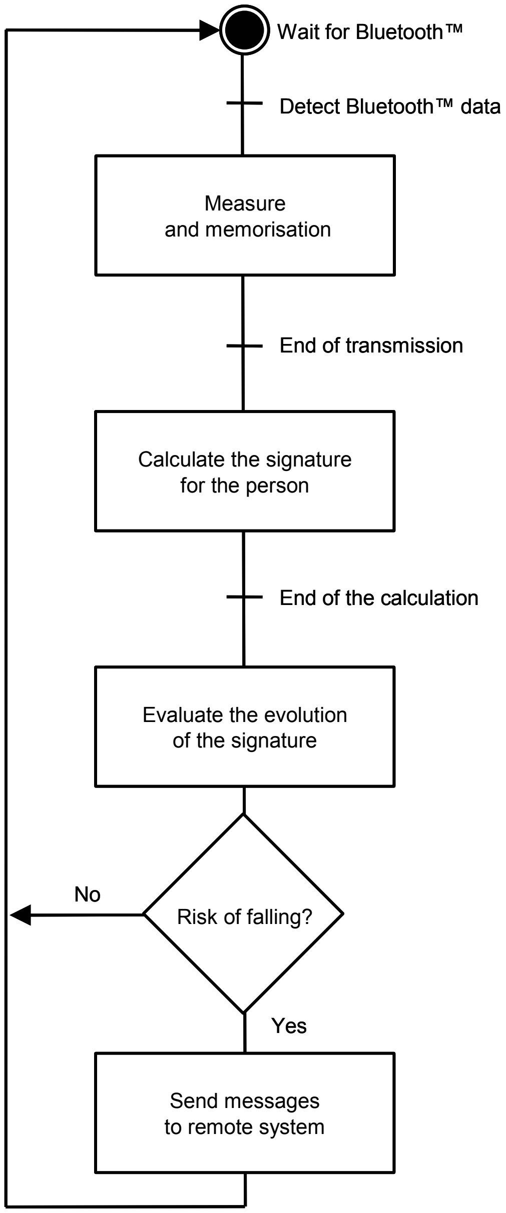

Figure 4: Algorithm of the functioning of the first process of the mobile phone

The detection of the risk of falling from the current signature and the previous signatures requires the previous results to be stored in the memory of the telephone or in the memory extension. The detection parameters common to the two processes are also stored in the memory extension.

The medical service is able to verify if there is a real risk of falling, in order to modify the detection parameters in case of a false alarm.

When the server receives a demand for an update from the medical service, a connection is established with the mobile phone via GSM and the parameters are updated.

The update algorithm for the second process is shown in Figure 5.

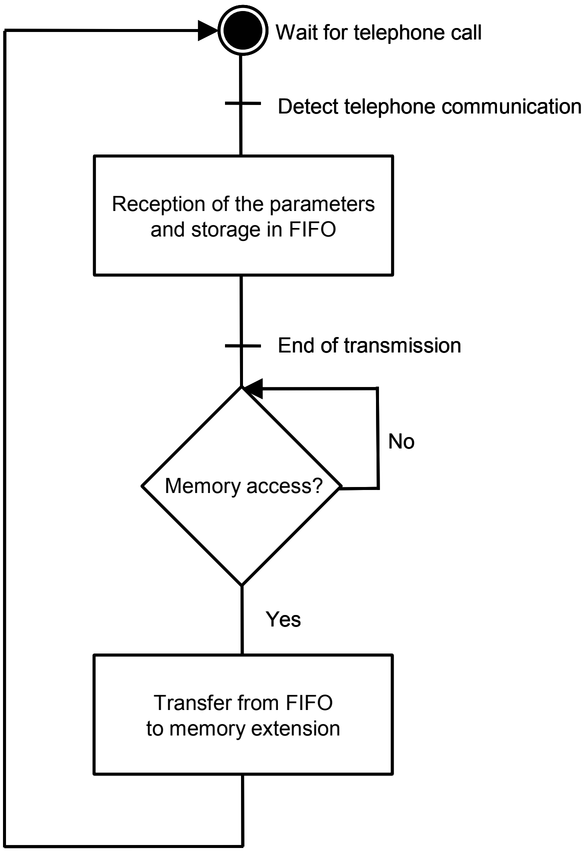

Figure 5: Algorithm of the functioning of the second process of the mobile phone

The parameter update process waits for the telephone call from the remote server. After the call, a connection is established, and the new parameters are stored in a FIFO (First Input First Output), before the telephone is disconnected. When it is possible to access the common memory, the new parameters are stored. Finally, the process returns to its initial state, waiting for a new call.

Surveillance network

All actors in the network are linked to a dedicated server. The four different types of actors in the network use a communication type that varies according to their function. The local supportnetwork (family, friends, & neighbours) and emergency services receive information via phone or SMS, whereas the medical support network (doctors, nurses, etc) receives more detailed information by internet. The telecommunications service communicates with the LPU to verify functioning and update programs and decision parameters.

Results and discussion

The system created is non-intrusive and low-cost, as it utilises readily available technology. It is easily adaptable, thanks to the JAVA™ technology, while it is also able to evolve, and be controlled remotely.

It is also possible to work with only the first process of data treatment with the data received via Bluetooth™, without using the second process of parameter modification, by including the parameter modification in the first process. In order to perform such a step, it is necessary to add a request function for new parameters in the transmission function. After having transmitted the results relative to the risk of falling, it is simply necessary to request the server if any new parameters are available. This method would greatly simplify the ensemble of exchanges and processing. By removing a telephone communication and the associated programs, it is possible to reduce the telecommunication cost of the system.

The local installation part of the system has been tested successfully in a laboratory setting for both internet and SMS communication. The next step will to be to evaluate telecommunications, in particular the update facility, after which a field trial of remote assessment of balance in elderly subjects will begin. Such data is needed to adapt the treatment algorithms, and to evaluate the efficacy of the system.

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