A model to develop frailty diagnosis tools through mobile devices and a service-oriented approach

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Abstract. Frailty is a health condition related to aging and dependence. A reduction or delay of frailty state can improve the quality of elderly life. However, providing a frailty assessment is difficult because many factors must be taken into account. Most of the time, measurement of these factors is performed in a non-centralized way, encouraging physician to make a wrong diagnosis or not as objective as it should be.
In this paper we propose a general model as a guideline to develop systems focused on elderly frailty assessment by using mobile phone capabilities and service-based approach. The proposed model uses a set of identified elements, facilitating the deployment of relevant services to support physicians in frailty decision-making. From this model, accelerometer sensors are entities used to get data of physical activity, while the mobile phone is responsible for service deployment.

Keywords: Frailty, elderly people, mobile phone, accelerometer, healthcare services.

1 Introduction

Human aging is a natural process characterized by a progressive loss of multiple abilities, including physical and cognitive ones. Normally, aging leads to a frailty state, and possibly a dependence condition. In 1988, Woodhouse [1] defined frail elderly people as those more than 65 years old who dependent on other people to perform their basic needs. Gillick [2] defined frail elderly people as "old debilitated individuals who cannot survive without substantial help from others", emphasizing the social consequences of frailty. Therefore, frailty is a condition which increases the risk of disability and dependency in the elderly.

In recent years, the concept of frailty has taken on a new topicality. Hamerman [3] shows its importance, due to the large number of parameters to be considered. In fact, detection and diagnosis of frailty must be studied on the following domains: medical, functional, socio-economic, cognitive and institutional. Functional domain have been classically appreciated to measure the independence level of a person. This includes the performance of activities of daily living (ADL) [4][5]. In this case, frailty is often equated with functional dependence in these activities, although frail elderly people are sometimes described in predominantly medical terms. However, it is difficult to standardize an operational definition of frailty taking into account this broad perspective.

Fried [6] proposes a phenotype of frailty according to the symptoms and signs from the clinical syndrome of frailty. Thus, Fried sets out five general criteria to decide whether an elder is frail or not.

Nowadays, the results for frailty detection and diagnosis are based on the following:

- Global scores from standard questionnaires filled by physicians.
- Overview of the elder and his environment.
- Measures from medical instruments.
- Analysis of lab reports from the elderly patient.

Moreover, doctors do not take into account all the previous items at the final assessment, but their decision is based only on some of them. Besides, the first two items depend on the physician viewpoint affecting the final result. For example, the assessment of gait and balance, one of the main indicators for frailty diagnosis, is obtained by several questionnaires. In this sense, the use of mobile phones with built-in accelerometers as a medical instrument during gait and balance activities, in combination with other factors, can be a useful method to generate more accurate and centralized results of frailty.

This paper is organized into 6 sections. Section 2 presents a set of relevant related work about frailty detection and diagnosis, including the use of new technologies for that. In section 3, we detail the risk factors for frailty diagnosis. Then, in sections 4 and 5 the proposed model is described in detail. Finally, section 6 presents the conclusions of our work.

2 Related Work

Study of frailty has been aided by the inclusion of new technologies, especially in the last decade. However, frailty detection and diagnosis is a complex process which takes into account many factors, as discussed above. In this sense, Martin [7] presents an overview of tools (tests and scales) used by relevant researchers in the field of frailty, studying the importance of each tool and the provided information. Jones [8] proposes a method to determine a frailty index from a detailed geriatric assessment which is focused on studying a set of variables including: balance, communication, cognitive state, nutrition, continence, ADLs and comorbidity among other. However, he says the best way to measure frailty remains unresolved. On the same line, Searle et al. [9] propose a quantification procedure for creating a fraility index from a dataset of variables. In this case, non-numerical variables were coded.

On the other hand, Gobbens et al. [10] define a conceptual framework to group the most important factors related to frailty, detected through an experiment. These ones include cognitive factors, strength, balance, nutrition, physical activity and mobility; while social and psychological factors were less important.

Most authors agree that physical assessment is the most important domain in frailty analysis because it offers plenty of information about a person. The emergence of new technologies and the development of Accelerometry field, facilitates an objective analysis of the physical condition in the elderly. In this case, accelerometer sensors can provide much more information than current tests.

So far, accelerometer mechanisms have been used in activity recognition, falls detection and lately, in physical rehabilitation work. But studies of frailty detection from physical exercises are not so numerous. Tehou [11] performs a comparison between the use of different devices and frailty levels. This includes the use of the following: accelerometer device, heart rate monitor, portable electromyography unit, GPS[3] system and serveral questionnaires. When these devices are used in combination, provide important information about physical condition. However, in most of cases it is an unaffordable solution in daily work of health environments.

In recent years, the use of mobile devices in healthcare systems has increased significantly. In this sense, accelerometer sensors attached to the patient's waist are commonly used to measure simple parameters related to gait and other physical exercises. Auvinet [12] and Foerster [13] concluded the suitable use of a single accelerometer is sufficient and acceptable for general gait analysis. Today, growth of mobile phones capabilities allow us to improve certain tasks in healthcare environments not only related to physical activity monitoring, without using specific devices. In this case, a complete assessment of elderly frailty can be performed. In [14], Fontecha develops a mobile frailty detection architecture based on the model proposed in this paper.

3 Factors for frailty assessment

According to the state of art, there are a set of relevant factors to be taken into account when a physician carries out a frailty diagnosis. Espinoza [15] identifies a group of possible risk factors from the frailty phenotype and a sistematic review. Also, physical characteristics of frailty are presented. However, the importance of each one is not mentioned, at least in a quantitative way.

Clinical variables related to frailty come from the patient record. The score of tests and scales, results of lab reports, general information, etc., are stored by physicians to be studied as needed. Meanwhile, social and psychological indicators are not considered because they have not a direct relationship with the patient record. The most common indicators are associated with the following clinical groups (all these items can be quantified easily): -*Anthropometric and general data*- Including gender, age, size, weight, BMI, lean mass, fat mass, total water and drug number. -*Functional assessment*- Including Tinetti gait and balance score, Barthel index, Lawton&Brody score, Get-Up and Go score, need help in physical activities, etc. -*Independence in ADL*- Choosing an option from the following: independent, mild dependence, moderate dependence, great depen-

[3] http://www.gps.gov

dence or serious dependence. -*Geriatric syndromes*- Checking dementia, depression, incontinence, immobility, recurrent falls, polypharmacy, comorbidity, sensory deprivation, pressure ulcer, malnutrition and terminally illnes. -*Nutritional assessment*- Including results from total protein, serum albumin, cholesterol level triglycerides, blood iron, ferritin, vitamin B12, serum folic acid, serum transferrin, leukocytes, lymphocytes, hemoglobin, calcium, etc. -*Cognitive assessment*- Including Mini Mental Status MMS) score, CRP test, etc. -*Pathologies and diseases*- Chronic diseases can be divided into several groups. The number of diseases from each group provides important data about the patient.

New parameters can be identified to take part in the final assessment.

Functional assessment is the most important group to determine frailty and the first to be studied. In this sense, physician applies two gait and balance tests to assess several features: Tinetti test [16] and *Get-Up and Go* test [17]. The use of an accelerometer attached to the elderly waist during these activities collects relevant data about gait and balance. In [14], the following indicators were identified from the movement analysis as a accelerometry indicators: *arithmetic mean, standard deviation, absolute mean difference, acceleration mean, variance, amplitude and Pearson's coefficient of variation.* This new group of parameters is also considered part of the frailty assessment.

4 Conceptual Design

We have created a general model for supporting a frailty diagnosis based on the analysis of frailty risk factors, previously identified in section 3. The main goal of the model is to facilitate the implementation of an automated system to be run on mobile devices such as smartphones in order to get a centralized and objective frailty assessment. Obviously, the technology used to implement our model depends on developers.

4.1 Entities and Role Definition

The first step is to identify the set of entities which form our model. In this case, the mobile phone is the crux of the model and the most important entity. These entities have been grouped in four classes: *Devices, Users, Procedures/Services and Artifacts* (see table 1). Each entity is responsible for one or more actions (this is known as entity role).

Procedures and services are software components which must be previously implemented unlike tangible entities (from devices, users and artifacts). In section 5 the features of software services are described in detail.

4.2 Entity Relationship. Onthology-based model

The previous entities are related to each other in a mobility and ubiquitous domain. In this sense, the Fig. 1 shows a graphical representation of the model according to the Table 1 in which relations between entities represents the model assumptions and these are defined as follows:

Class	Entity	Role
Device	Mobile phone	Service deployment, facilitating interaction, visualization, accelerometer data acquisition
	Accelerometer	Accelerometer data acquisition
	Server	Serve requests from mobile phone, process deployment
User	Elderly patient	Carry mobile phone / accelerometer to the waist during physical activity, provide the patient record
	Pysician	Assess frailty state of the elder, interact with mobile phone
Artifact	Questionnaires	Provide one or more measures for a general assessment based on clinical indicators from physician viewpoint (e.g. Barthel Index test)
	Medical instrument	Providing accurate measures of clinical indicators from clinical equipment (e.g. IMC scales)
Procedure^P/Service^S	Patient record (P)	Providing values of risk factors for frailty
	Patient stack (P)	Frailty data storage from studied patients
	Acquisition (S)	Acquisition services get data from the corresponding entities, including accelerometer data, patient record data and patient stack data
	Processing (S)	Analysis and processing of accelerometer data, patient record data and patient stack information
	Storage (S)	Data storage used by entities and processing tasks
	Result (S)	Creating a structure for visualization of frailty results on mobile phone screen

Table 1. Model entities and roles

- Physician-*Treats to*-Elder. Physician is responsible for tretaing an elder.
- Elder-*has*-Patient record. The elder has a patient record.
- Elder-*carries*-Mobile device. The elder carries an accelerometer-enabled mobile device during gait and balance tests.
- Physician-*interacts*-Smartphone. The physician interacts with the smartphone to know the patient state.
- Accelerometer-*has*-Smartphone. The accelerometer can be integrated in the own smartphone.
- Smartphone-*provides*-Service. All identified services (acquisition, storage, result and processing) are provided by the smartphone.
- Service-*Request to*-Server. The service is requested to a server.
- Server-*Communicates with*-Mobile device. The server sends the corresponding result to the smartphone.
- Server-*obtains*-Patient record. Also the server obtain the patient record as a medical resource.
- Server-*stores*-Patient stack. The server stores the patient stack entity.
- Patient record-*stores*-Clinical parameter. Besides, the patient record stores a set of frailty clinical parameters.
- Artifact-measures-Clinical parameter. An artifact (questionnires and medical instruments) measures a clinical parameter.

So far, we have described *"Which"* elements are necessary (structure), but we have not discussed *"How"* these items work according to their roles (functionality).

5 Functional Design

To develop the procedures and services included in the model as software components, we propose a service-oriented approach. Thus, functionalities of proposed

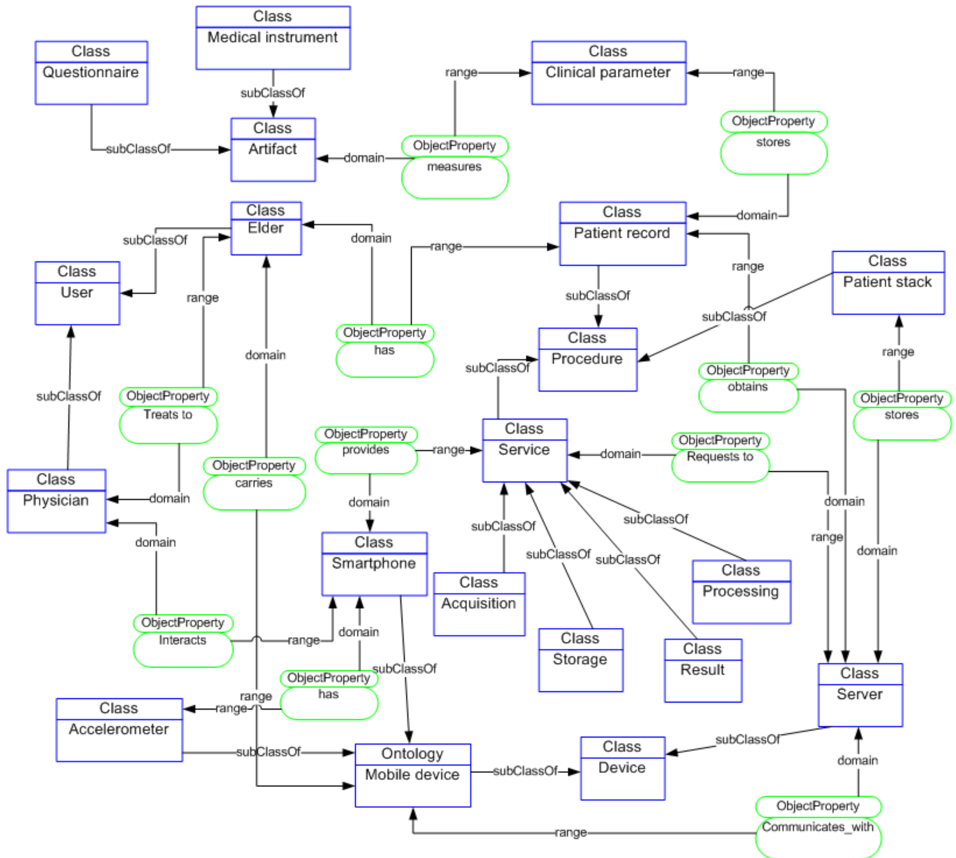

Fig. 1. Ontology. Representation of the model

model are offered by means of software services. Their implementation features depend on the system and the used platform. In this section, we propose a guideline about services requirements and their functions.

Firstly, we have identified two kinds of services according to the running device: mobile and web services. The first one includes the internal services which can be deployed by the mobile phone or smartphone. The second one is related to services hosted in a server as web services. For that, a network connection (via wireless) between mobile device and server is needed.

Assuming a real scenario, the services are runned in order according to the table 2, with their inputs and outputs. Inputs represent needed objects or procedures for service running. And the outputs are the results provided by the services.

For example, the comparison procedure to get a *frailty assessment output* can include the use of data mining and classification algorithms, or mathematical formulas based on similarity and distance. In the same way, the *frailty assessment*

Service	Type	Description	Inputs	Outputs
Accelerometer data acquisition	mobile	Responsible for accelerometer data gathering and storage at run time, when elderly people perform a specific gait and balance test. This also includes mobile communication between smartphone and accelerometer sensor.	accelerometer signal	accelerometer values in x,y,z axes)
Accelerometer data processing	mobile	Responsible for carrying out accelerometer data handling through the data filtering and segmentation as well as accelerometry indicators calculation.	accelerometer values (x,y,z axes)	accelerometry indicators
Patient record extraction	web	It defines the mechanisms to obtain frailty risk factors from the patient record. The use of clinical standards could be necessary.	patient record, accelerometry indicators	frailty risk factors
Comparison procedure	web	This service is responsible for performing a comparison between frailty risk factors from the elderly patient studied and each of the patients stored into the patient stack	frailty risk factors, patient stack	frailty assessment
Setting up a built result	web	Parsing of comparison results in a formal language, easily readable by the mobile phone.	frailty assessment	frailty assessment formalized
Visualization of frailty assessment	mobile	Services which define the method for frailty results preparation and visualization on the smartphone screen, after receiving data from the server.	frailty assessment formalized	information, tips and charts for the physician
Storage into Patient Stack	web	Service related to the storage of the new patient data in the patient stack structure, increasingly patient stack size and improving the accuracy for frailty assessment in the future.	risk factors from a new patient	patient stack with new patient

Table 2. Inputs and outputs of identified services

formalized output may consist of XML files, structures or programming objects. These are some ideas to develop the corresponding services, but that are not part of this work.

6 Discussions

In this work we have presented a model to support the elderly frailty diagnosis in a ubiquitous environment by using mobile devices such as mobile phones and accelerometers. Nowadays, physicians do not have a centralized method which provides a frailty assessment based on the results of existing tests and clinical information.

On the other hand, we can take advantage of smartphone features to develop frailty diagnosis tools. Accelerometer sensors and wireless communication capabilities are essential in our model which aims to lead the developer in implementing mobile software systems for frailty assessment based on services, providing a conceptual and functional frame.

Ongoing work is to evaluate the efficiency and usability of the model on a group of software developers considering the proposed entities and services. Besides, in the future, we would like to make a comparison between frailty assessment mobile tools which make use of our model and other systems that do not take into account.

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