Assessment Test Framework for Collecting and Evaluating Fall-Related Data Using Mobile Devices

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Abstract. With an increasing population of older people the number of falls and fall-related injuries is on the rise. This will cause changes for future health care systems, and fall prevention and fall detection will pose a major challenge. Taking the multimodal character of fall-related parameters into account, the development of adequate strategies for fall prevention and detection is very complex. Therefore, it is necessary to collect and analyze fall-related data.

This paper describes the development of a test framework to perform a variety of assessment tests to collect fall-related data. The aim of the framework is to easily set up assessment tests and analyze the data regarding fall-related behaviors. It offers an open interface to support a variety of devices. The framework consists of a Web service, a relational database and a Web-based backend. In order to test the framework, a mobile device client recording accelerometer and gyroscope sensor data is implemented on the iOS platform. The evaluation, which includes three mobility assessment tests, demonstrates the sensor accuracy for movement analysis for further feature extraction.

Keywords: fall detection, fall prevention, mobile devices, restful Web service.

1 Introduction

The demographic change by [8] shows that the average age of the European inhabitants will increase. A recent projection by [9] shows that in 2060, the number of people aged 80 or over is three times larger than in 2008 and the rate of people aged 65 and over will double. With the rising age of the population also the

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number of falls and fall-related injuries rise [10]. According to [10] approximately 28-35% of people aged 65 and over fall each year about 2 to 4 times while 32-42% of the people aged 70 fall. Therefore, falls are a relevant factor in the society especially in the in group of older and disabled people and will raise new challenges for the healthcare, care systems and retirement plans.

Therefore, fall prevention and fall detection will become a major challenge. To perform fall detection, it is important to distinguish between activities of daily living and a fall. Current approaches deal with the fact that a fall-like behavior has a higher acceleration than normal activities [12]. Consequently, it is possible to define an acceleration threshold where a fall is detected [12]. According to [11], also the position of the sensor leads to different body accelerations which makes it more difficult to identify a fall-like behavior. Taking all the facts into account, fall prevention and fall detection is a complex task.

With the growing success of mobile devices, especially smartphones, it can be observed that such devices are becoming more accepted among older people. Moreover, modern mobile devices are equipped with the necessary hardware sensors as well the required software capabilities for performing automatic fall detection. Using smartphones has the advantage of cost effectiveness, robust and stable hardware as well as the form factor, which makes them well-suited for pervasive fall detection.

In order to develop an adequate algorithm for automatic fall detection and prevention by using smartphones, an assessment-based test framework has been implemented. The purpose of the framework is to collect (fall-related) motion data in order to evaluate and analyze them regarding fall detection, taking different activities and positions of the smartphone into account. The framework uses an open and easy to use interface while supporting different devices with their sensors. This paper shows the development of a Web-based test framework, used by a variety of mobile devices in order to record motion data. Furthermore, the architecture and the poof-of-concept is discussed.

2 Related Work

Fall detection methods are divided into three main approaches using a wearable device, camera-based or ambience device [4]. This paper focuses on the wearable device approach by using mobile devices and its embedded sensors such as accelerometer and gyroscope for measuring body movement. The advantage of this approach is that it is independent of the user's location and a fall-like behavior can be directly assigned to the user.

[5], [6] and [7] use mobile phones equipped with accelerometers to detect a fall. The application by [5] monitors the X, Y and Z acceleration in order to detect a fall. [6] developed an application running on Google's Android mobile platform and presented a fall detection algorithm. The system proposed by [7] focuses on the advantages and disadvantages of using mobile phones for fall detection.

Fall prevention is a wide research topic and varies in the ways a fall is prevented or predicted and differentiates between usage based on context such as nursing home, hospital, home or living in the community. According to [14], [15], [16], [17], and [10] the following most common fall prevention methods can be identified:

- Assessment tests: By performing common clinical mobility assessment tests, the fall risk of a user can be determined.
- Adjustment of environment and walking aids: Potential tripping hazards can be removed and by using walking aids the risk of falling can be reduced.
- Gait Analyses: Based on the analysis of the gait pattern, a potential fall can be predicted and the user is alarmed.
- Education: By clarifying the fall risk factors to the involved parties, fall risks can be reduced.
- Exercise/training: Specifically developed training sessions and exercises strengthen the patient's body and thus reduce the risk of falling.
- Medications: The use of the wrong medication can lead to reduced alertness, balance and gait.

3 Framework Architecture

In order to evaluate and analyze fall-related data gathered by devices during assessment-based tests, a framework for collecting motion data is required. The described framework provides an open interface to support a variety of devices. The framework is designed to offer great flexibility and extensibility in order to integrate different types of devices and sensors. The recorded motion data is saved in a consistent way on a consolidated database backend and analyzed afterwards.

The framework consists of three main components: database, interface and client as depicted in Fig. 1. A client-server architecture based on a 3-tier architecture is chosen. This architecture offers a clean separation of the presentation, application and data layer.

The data layer consists of a database for storing test-related data as well as the device types with their configured sensors. The relational database ensures integrity and consistency of the data. The application layer resides on the server side and implements the Application Programming Interface (API). The interface is implemented as a Web service according to the Representational State Transfer (REST) architectural style [13]. This approach offers best flexibility for implementing the client regardless of the programming language. Therefore, different kinds of devices used for measuring motion can be integrated into the framework. The client layer is responsible for recording motion data and uses the Web service API for storing test-related data.

3.1 Features of the Framework

The framework features an assessment test-based approach. With an assessment test, the following properties are assigned:

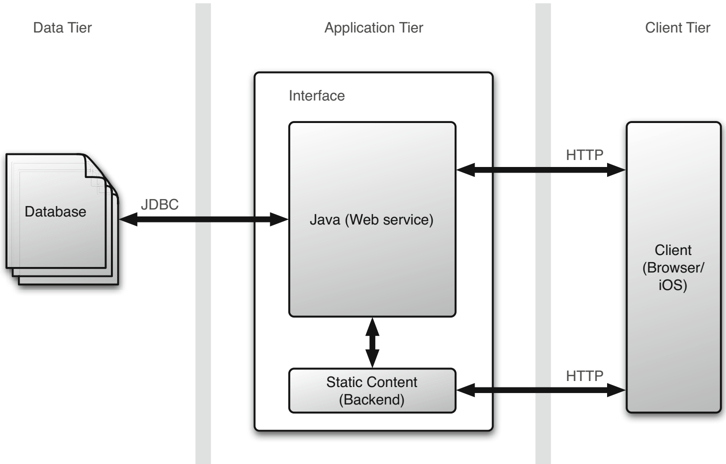

Fig. 1. 3-tier Framework Architecture

- the user who actually performs the test;
- the researcher who observes the test;
- location, start and end time of the test;
- the performed test type, e.g., “Timed Up and Go”;
- the device sensors and their data types;
- the used devices with its position and sample rate.

After the test is finished, the client transfers the recorded motion data to the database backend using the Web service and is assigned to the performed assessment test. This allows to access the recorded data later on for performing the required evaluation. The framework offers the possibility to assign various results of different evaluation methods to the test. This makes it possible to compare the result of the performed evaluations.

To provide a better user experience, a Web-based administrative tool has been developed. This tool allows the creation of tests, users, devices and their related sensors.

4 Mobile Device Client

A mobile device client for the iOS platform, especially the iPhone 4, has been implemented. The client is used to demonstrate the functionality of the framework as well as the capabilities and sensor accuracy of the iPhone 4. The application uses the possibility to receive high-rate continuous motion data with the “Core Motion” framework. The framework provides access to raw accelerometer data, raw gyroscope data, and processed device-motion data. Motion data is obtained by requesting the data at the given interval and saved locally on the device during the assessment test.

The communication with the Web service API is achieved by using HTTP requests. First, the user is authenticated and the current device information is loaded to identify the used device. Subsequently, the client periodically requests for the currently running tests issued for the current user and device. After a running test has been found, the device starts recording motion data and periodically requests the status of the test in the background. If the test is finished, the recorded data is transmitted to the Web service.

The iOS application depicted in Fig. 2 consists of several easy-to-use interfaces which are designed to require as little user interaction as possible. Fig. 2a shows the main view and displays current user and device information. A running test is indicated by the green background in the first cell with the appropriate status description as seen in Fig. 2b. Moreover, the device settings used (position and sample rate) for the current test are shown.

(a) Main View **(b)** Active Test View

Fig. 2. Screenshots of the iOS Client

5 Evaluation

The framework and the iOS client were evaluated by running three common clinical mobility assessment tests. The "2-Minute Walk" (2MWT), "Sit-to-Stand 5" (STS5) and "Timed Up and Go" (TUG) tests were performed [3], [2], [1]. The evaluation proved the flexibility, availability and integrity of the framework as well as the recorded gait data of the iPhone 4 regarding movement analysis and feature extraction.

The test scenarios comprised creating the tests and their dependencies using the administrative backend. For each test two iPhones using the implemented client were used for recording the motion data during the test to demonstrate the capabilities of the framework. During the assessment, the motion data was stored locally on the devices and was transmitted to the Web service after the test was finished. Finally, the recorded data was analyzed.

5.1 Test Settings

The tests were performed in a well equipped room for assessment testing. A notebook using the Mozilla Firefox browser was used for performing backend relevant tasks such as creating assessment tests, users, devices and its sensors. The notebook as well as the two mobile phones were connected though Wi-Fi with the Internet. As mobile devices running the client application, an iPhone 4 (using accelerometer and gyroscope) and an iPhone 3 (using accelerometer only) have been connected to the Web service using the proband's user credentials. Both devices were running all the tests with a sample rate of 50Hz. The iPhone 4 was located on the right hip and the iPhone 3 on the left hip height.

5.2 Analysis

The gait data recorded by the iPhone 4 has been visualized and analyzed regarding movement analysis and feature extraction.

In Fig. 3, data recorded during the performance of a classical *2-Minute Walk* test can be seen. The test was performed on a 10 meter straight walk passage. During the test, the test-subject had to walk with "normal" (self-chosen) speed. As depicted in Fig. 3, the iPhone 4 data promises a good base for ongoing data analysis and movement feature extraction (based on simple peak detection as well as more sophisticated feature analysis, such as knowledge-based methods and statistical analysis). Single movement passages (for example 10m straight walk, turn around) are distinguishable by performing a simple Support Vector Machine

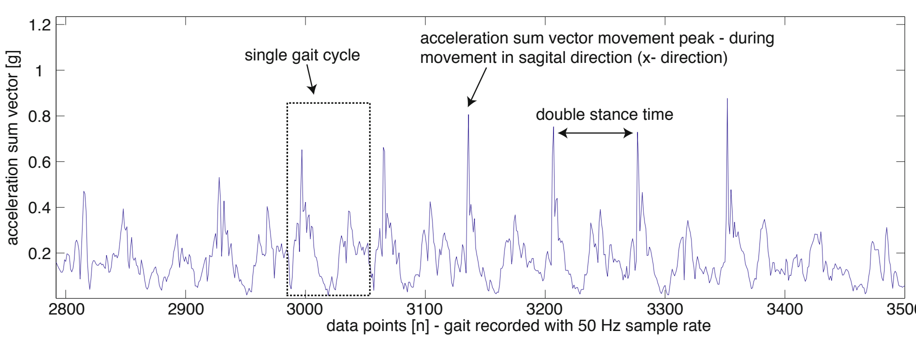

Fig. 3. Detailed Gait Signal During 2-Minute Walk with Normal Gait Speed (Single Steps)

(SVM) calculation and following peak detection. A calculation of peak distances offers the opportunity to extract important and fall risk describing parameters (for instance gait cycle times, variances over time) in the time domain.

After the 2 minutes of normal walking, a walking phase with an increased speed can be seen, which is characterized by a well increased value of the acceleration sum vector peaks during the movement in x-direction (sagittal plane).

The evaluation of the *Sit-to-Stand* test shows a good base for feature extraction of classical assessment parameters like STS5 performance time as well as an expanded set of features like single movement times. The *Timed Up and Go* test evaluation shows a base for feature extraction. Moreover, parameters for classical assessments like TUG performance time can be extracted as well as an expanded set of features (single movement times, gait cycle times, variances over time).

6 Conclusion

Developing a fall detection algorithm is a complex task. A fall must be differentiated from activities of daily living. Moreover, also the position of the used motion tracking device influences the fall detection behavior. In order to perform fall detection and fall prevention analysis, an assessment test framework has been developed. The framework is based on a 3-tier architecture consisting of a data layer for storing motion data, an application layer which implements an open interface and the client layer for recording motion data.

The application layer offers a RESTful Web service with the ability to integrate various devices with their sensors into the framework. This approach makes it easy to create new assessment tests taking all the different fall parameters into account. The collected data is analyzed after the test with the possibility to save and compare results.

In order to demonstrate the functionality of the framework, a mobile device client was implemented. This proof-of-concept implementation runs natively on iOS devices, particularly the iPhone 4, and records motion data using accelerometer and gyroscope sensors. The evaluation was done by performing three clinical assessment tests. The visualization and evaluation of the recorded iPhone 4 motion data showed that the framework fulfills the requirements for data storage and processing as well as flexibility regarding the integration of new devices into the framework. Moreover, the iPhone 4 is well-suited for movement analysis regarding the sensor data and accuracy.

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