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An automated activity monitoring system for rehabilitation

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Abstract

Time lost due to injury or illness requiring rehabilitation is a major problem. Activity is an important part of rehabilitation, however compliance and adherence can be challenging. This paper addresses this issue by presenting an automatic system for monitoring activity allowing objective assessment of the activity. The system consisted of a smartphone based activity capture platform connected wirelessly to back-end server for analysis and storage and a web server to provide a user-friendly interface for feedback and education purposes. The system was validated by comparison with 3 accepted standard measuring devices and found to match their results well. The system also monitored the data of the participants over a continuous period of a number of days. It is evident that human factors play a part in both of the data collection strategies.

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1. Introduction

Time lost due to injury or illness is a major problem for the general community as well as the sporting community. It has been shown that strict adherence to a formalized physical therapy exercise regimen is

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crucial for both a speedy and successful recovery [1]. Typically the participant self-report the activities undertaken in the physical therapy which can range from a verbal report to a full written survey. The literature also reports that compliance in completing such reports is problematic [2, 3]. Monitoring technology can be used to improve this process by reducing or removing patient interaction whilst maintaining consistent and objective data collection. Web 2.0 and mobile platforms are powerful enablers that can be used to provide education and feedback about the rehabilitation process being undertaken whilst allowing interventions to be taken where required [4]. What is needed is an automated activity monitoring system to accurately and objectively measure activity, remotely store the data on a long-term basis, as well as use web servers to generate reports, educate and provide feedback to both the participants and the professional/s overseeing the recovery.

Smartphones are small computers with a useful array of capabilities that are now being applied to many different monitoring applications [5, 6]. They typically have many communication options such as 3G, WiFi, Bluetooth, and sometimes ANT. WiFi and 3G can provide connectivity to the Internet which allows access to external servers for data storage and analysis as well as access to websites for feedback and education. Communication protocols such as Bluetooth and ANT can be used to allow the phone to connect to external third party monitoring systems such as wireless fitness sensors which are useful for monitoring physical. In this case the smartphone is being used as a data aggregator [6] providing local storage and allowing connection to external servers to provide analysis, storage and web page access for feedback and education.

This paper describes an automated activity monitoring system using a smartphone as a data aggregator and remote servers for storage, feedback, and education purposes. The activity metric chosen to be monitored was footsteps. This paper will present the system concept and design, validate the system against other accepted activity monitoring methods and verify the operation of the system with a short 3 day trial.

2. System design

The basic conceptual model is illustrated in Figure 1. The concept is to automatically collect information about a person's physical activity using a smartphone-based platform and to send it wirelessly over the Internet to remote servers for storage and analysis. The person or health professional overseeing the rehabilitation can log into a web site and extract information about the activities undertaken and have access to material to educate participants about the activities undertaken.

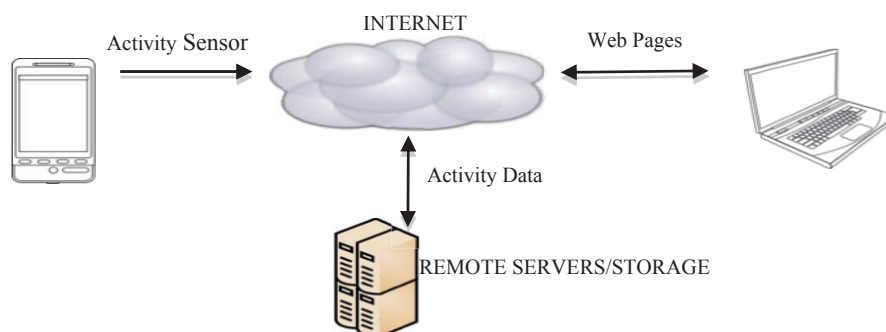


Fig. 1. Concept of the automated activity monitoring system

The system design is divided into 3 sections:

1. A smartphone platform for activity data collection and transmission
2. A remote server to receive, process and store the activity data
3. A website for reporting activity (feedback) and for education

2.1. Smartphone platform

The data collection is performed using an android based smartphone connected to a fitness sensor (Garmin Footpod) using the ANT+ protocol. The Footpod is attached to the shoe and transmits the step count, distance, and speed to the smartphone. Software was written for the smartphone that would operate as a service rather than as a visible activity thus removing any need for user. The software connects with the Footpod and collects the measured activity data and stores it in local memory and on an SD card. Periodically the software uses the WiFi to try to connect to the internet and if a connection is available it then uploads the data securely to the remote server for storage and analysis.

2.2. Remote server system

The remote server system has been detailed in previous work by the authors [6]. The remote server was implemented using PHP, JSON, and an SQL database. Basic security was implemented using SSL connections. The remote server consisted of a Data Receiver unit, a Data Processing unit, and a Web Server. Each of these could be implemented as separate processes on the one server or as separate physical servers. The purpose of the Data Receiver unit is to receive the incoming activity data and store it in the database. The purpose of the Data Processing Unit is to process the data using scripts in the Matlab language. The Web server is an Apache webserver to interact with the user and to serve the pages of the website. The feedback pages are dynamically generated from the activity data stored in the database. An SQL database is used to store the activity data and the Matlab scripts used in the data processing.

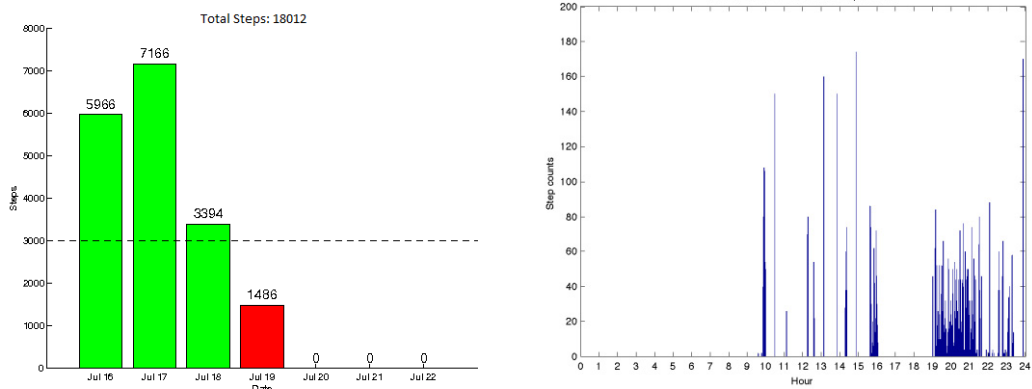


Fig. 2. Screen shots showing step counts for a (a) single week and (b) single day. The website address has been deliberately obscured in the screen shots.

2.3. Web interface

The web interface allows 3 modes of access. (1) A user mode which allows a user to read the educational material and view a dynamically generated report of their activity. (2) A professional mode to

allow health care providers to have greater access to a participant's data including generation of detailed reports for downloading in .csv format and (3) An administrator mode is used to perform website administration and tasks such as setting accounts and access etc. All modes require authentication since they have access to sensitive material.

Typical feedback outputs can be seen from the screen shots in Figure 2 which shows reports of step counts for: (a) a single week: and (b) a single day.

It is expected that the participant will typically use the weekly view as shown in Figure 2(a). The health professional can set a target daily step count which is indicated by the dashed line. Each bar represents a day's activity and is coloured green if the daily goal has been achieved and coloured red if the daily goal has not been achieved. The total step count achieved for the week can be seen in the title of the graph. The user can obtain more detailed data and examine a whole day as shown in Figure 2(b). The total step count achieved for the day can be seen in the title of graph.

3. Validation and verification

The operation of the system was tested using a validation test and a verification test. The validation test involved authenticating the accuracy of the stride counts measured by the system against other commonly used and accepted devices and techniques. The verification test verified the functionality of the system over a 3 day trial using multiple participants.

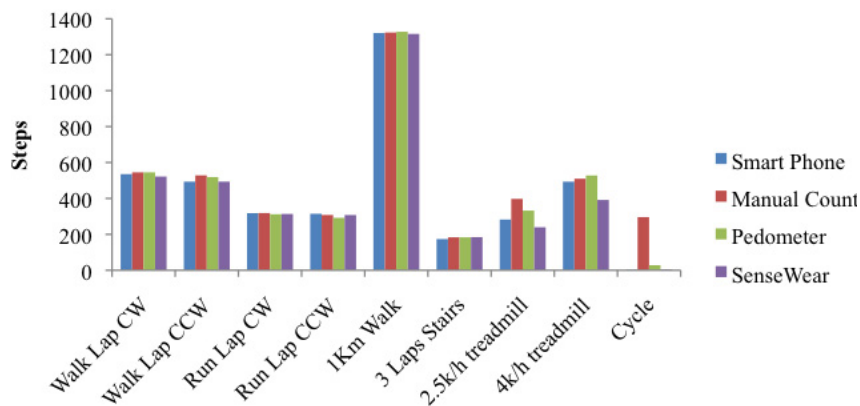


Fig. 3. Validation results showing the results from the smartphone compared to 3 other technologies/methods.

3.1. Validation

In order to validate the accuracy of the stride count measurements produced by the system, ten participants carried out a series of nine activities and were monitored by the smartphone and three other methods for the duration of the testing. The three comparison technologies were an electronic pedometer worn on the hip (Omron HJ-720IT-E2 pedometer, Omron Healthcare, Muko, Kyoto, Japan), a Sensewear Pro2 armband (BodyMedia, Inc., Pittsburgh, PA, USA) on the upper arm and two manual counters utilized by the researchers and operated alongside the participant to manually count each footfall. Values from each device were recorded in between each activity and compared at the conclusion of the testing.

The activities carried out were: One lap of a running oval at a walking pace, clockwise and counter-clockwise and then the same at jogging pace, a one kilometer walk, climbing three flights of stairs and

then descending one flight, 5 minutes on a treadmill at 2.5km/h and 4km/h and 5 minutes on an exercise cycle.

3.2. Verification

Figure 3 shows the results of each device for one of the participants. The system's results matched those obtained using the other devices within an acceptable tolerance. Manual counting was considered as the baseline standard since two counters were used independently and recorded values matched in most cases. The stationary bicycle is the obvious exception and is due to the fact that the Footpod requires impact with the ground to register a step and the cycling motion does not incorporate such impact. The device verification was based upon a trial performed over 3 continuous days. Each of the participants were provided with a preconfigured smartphone and a Footpod which they attached to their shoe for the duration of the trial. At the end of the trial, daily plots for each user were obtained from the website for each user. Figure 4 shows the results for 2 different users. The participant in Figure 4(a) had a total of 7678 steps for the day and the participant in Figure 4(b) had a total of 3376 steps for the day. The sleep periods can be easily inferred from the graphs and the periods of greatest activity can also be easily inferred from the figures. However, in order to explain the bursts of activity and inactivity the context needs to be included and such information was not available.

An informal debriefing of some of the participants after the trial and post hoc analysis of the data raised the following issues:

- The requirement to use a Footpod meant that socks or shoes needed to be worn at all times which did not suit all activities of daily living;
- The Footpod could not easily be attached to shoes without socks or laces;
- A Footpod was misplaced early in the trial meaning that data could not be collected for one participant;
- Data from two participants was unusable due to incorrect sensor placement;
- No diarized logging was performed so the context of the activity data could not be ascertained.

The issues outlined, highlighted that the use of a Footpod added an extra complexity and component to the system. It was also apparent that human factors continue to play a part in automated collection methods since there must be human interaction with the technology at some stage. Overall, the long-term monitoring of the participants was successful and the system upload, storage, and website worked as expected.

This work conformed to Griffith University ethical standards (GU ethics code: PES/20/11/HREC).

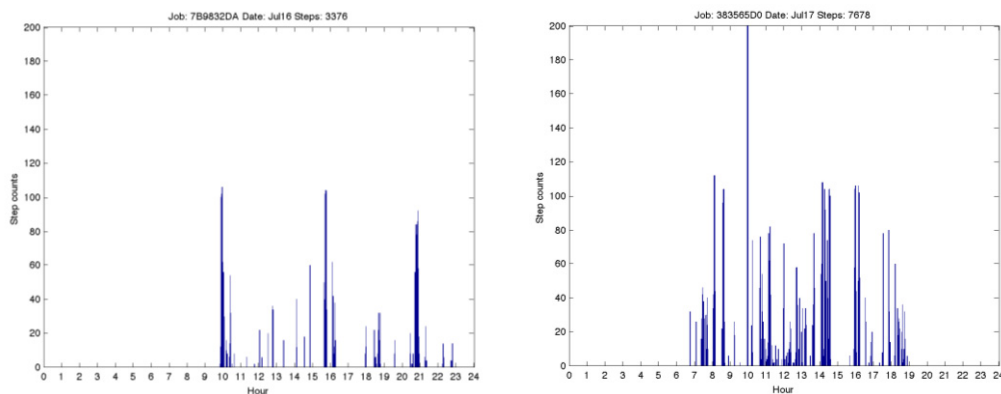


Fig. 4. Steps counts over 1 day for 2 different subjects. Subject (a) took 7678 steps and subject (b) took 3376 steps.

4. Conclusion

Activity is an important part of rehabilitation and disease prevention, however compliance and adherence can be problematic. This paper addresses this issue by presenting an automatic system for monitoring activity allowing objective assessment of the activity. The system comprised a smartphone and fitness sensor for activity data collection, a back-end server system for analysis and storage, and a web server.

The system was validated by comparison to three other technologies and the system was verified through a trial lasting three days. The data from the validation suggests that the system was logging and storing the activity correctly which means that the data collected is an accurate representation of the activity undertaken. The verification showed that the system could operate for an extended period with acceptable results. However, the testing highlighted that human factors continue to play a part in any automated system. Future work will involve removing the reliance on the Footpod as this factor appeared to be problematic for some of the users.

Overall the validation and verification studies demonstrated that the system was feasible and was functionally correct however work remains to be done on addressing the human factors which interface with the technologies.

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