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Physical Activity Monitoring and Sharing Platform for Manual Wheelchair Users

Dan Ding, *Member, IEEE*, Soleh Ayubi, *Member, IEEE*
Shivayogi Hiremath, *Member, IEEE*, and Bambang Parmanto

Abstract— **Unlike able-bodied ambulatory population, wheelchair users do not have adequate access to technologies that monitor and motivate physical activity (PA). We developed a physical activity monitoring and sharing platform (PAMS) especially suited for capturing PA that are part of the lifestyle in wheelchair users and motivating them to be physically active via social networking based applications. This paper describes the general infrastructure and components of the prototype PAMS. The monitoring unit is designed to capture the activity type, amount, and associated energy expenditure of wheelchair users. The sharing unit consists of a web-based application and an Android-based mobile application built on top of Facebook platform and allows wheelchair users to self-monitor and share their PA information with their community of interest. The prototype PAMS is being evaluated for its reliability in capturing PA, validity in measuring PA parameters, and usability of the sharing applications among wheelchair users. We expect the PAMS will enable wheelchair users to track their own PA participation and become more physically active, leading to better overall health, greater community participation, and higher quality of life.**

I. Introduction

Regular participation in physical activity (PA) is often identified as a leading health indicator [1, 2]. Yet research has shown that people with physical disabilities, especially those who rely on manual wheelchairs as their primary means of mobility, are less likely to be physically active when compared to the able-bodied population [3, 4]. Low levels of PA in this population have been associated with decreased aerobic capacity, muscular strength and endurance, and flexibility, all of which have the potential for restricting their functional independence and increasing their risks for chronic diseases and secondary complications [5]. In fact, this population reports a high number of chronic conditions (e.g., diabetes mellitus and cardiovascular disease) and secondary complications (e.g., fatigue, weight gain, pain, and depression) [6-8].

One of the prerequisites as well as strategies to promote regular PA participation is to obtain accurate estimates of everyday PA [9-11]. The general population nowadays has access to a plethora of body monitoring devices ranging from simple pedometers to complex multi-sensor platforms that automatically track PA and provide feedback to increase user understanding and consciousness of their PA participation [12]. However, manual wheelchair users have no equivalent means to self-manage their PA participation. Only a few studies looked into using activity monitors to measure physical activity among wheelchair users [13-16]. These studies either measured time of travel and distances to indicate gross PA levels or examined correlations between wrist-worn accelerometer counts and energy expenditure of wheelchair users. None of them have provided direct estimation of energy expenditure associated with physical activity and given real-time feedback to wheelchair users on their PA levels.

Wheelchair users also face more barriers in participating in regular PA than the general population [17-19]. In addition to the barriers related to their physical limitations such as pain, lack of energy, and lack of accessible facilities and exercise equipment, several studies also indicated that social influence from friends and family is an especially important determinant of PA participation for this population [17, 18]. Warms et al. found that social environment variables including social support from family and friends and healthcare providers discussing exercise were more important factors than physical environment variables for promoting PA in wheelchair users [17]. Kerstin et al. found that the ability to share with others and give support in the process of participating in PA strengthens one's own ability to participate in PA among a group of people with spinal cord injury [19].

This paper describes our preliminary work on developing a physical activity monitoring and sharing platform (PAMS) especially suited for capturing PA that are part of the lifestyle in wheelchair users and motivating them to be physically active via web-based or mobile social networking applications.

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D. Ding is affiliated with the Department of Rehabilitation Science and Technology and Department of Bioengineering, University of Pittsburgh, Pittsburgh, PA 15260, and Human Engineering Research Laboratories, VA Pittsburgh Healthcare System, Pittsburgh, PA 15206 (phone: 412-822-3684; fax: 412-822-3698; email: dad5@pitt.edu).

S. Ayubi is affiliated with the Department of Health Information Management, University of Pittsburgh, Pittsburgh, PA 15260 (phone: 412-383-6646; fax: 412-383-6655; email: soa8@pitt.edu)

S. Hiremath is affiliated with the Department of Rehabilitation Science and Technology, University of Pittsburgh, Pittsburgh, PA 15260, and Human Engineering Research Laboratories, VA Pittsburgh Healthcare System, Pittsburgh, PA 15206 (phone: 412-822-3705; fax: 412-822-3698; email: svh4@pitt.edu).

B. Parmanto is affiliated with the Department of Health Information Management, University of Pittsburgh, Pittsburgh, PA 15260 (phone: 412-383-6649; fax: 412-383-6655; email: parmanto@pitt.edu)

II. SYSTEM DESIGN

A. General Architecture

The architecture of the PAMS is shown in Figure 1. It consists of a monitoring unit, a personal gateway, a secure server, and a sharing unit. The monitoring unit consists of multiple sensing devices that can be worn at different parts of the body and attached to a wheelchair. These devices communicate with the personal gateway (e.g., a mobile phone) using Bluetooth. The personal gateway stores the sensor data temporarily, analyzes them, and transmits the most recent data to the remote server where the data are stored. Because HTTP protocol is used for data transmission from the personal gateway to the portal server, the personal gateway must have internet connection services such as GPRS, 3G, or WLAN. The server uses distributed database architecture to store the data mapped with personal profiles. The sharing unit consists of a web-based application and an Android-based mobile application built on top of Facebook platform and allows wheelchair users to self-monitor and share their PA information. The Facebook open application programming interface (API) provides all the functions to perform necessary online interactions needed in social support of physical activity participation, and allows our applications to use the Facebook authentication, security setting, and privacy/confidentiality setting.

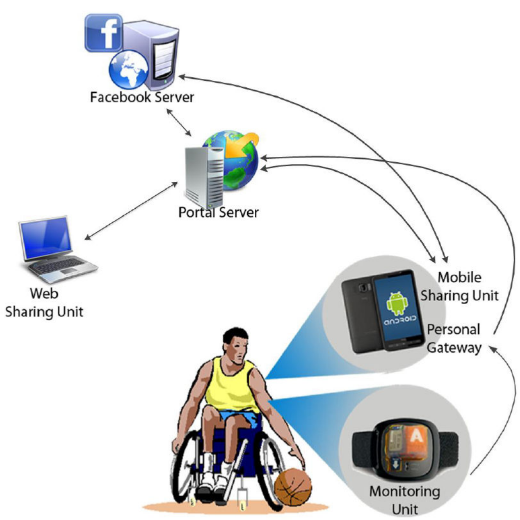

Figure 1 The Architecture of PAMS

B. Monitoring Unit

The monitoring unit of the PAMS integrates a wheel rotation monitor (WRM) clipped to the spokes of a wheelchair and an accelerometer-based monitor (i.e., wocket) worn around the dominant arm of the user (Figure 2). The WRM and wocket provide complementary information about physical activity in wheelchair users, and allows more comprehensive and accurate assessment of multiple PA measures in this population.

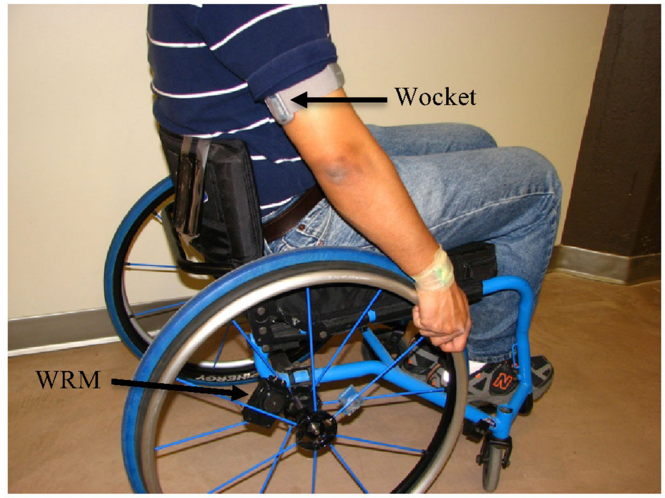

Figure 2 The monitoring unit

The WRM is a small, lightweight, and self-contained device that easily attaches to a wheelchair via two zip ties without any modification to the wheelchair. The WRM tracks the wheelchair motion by sensing the distance and velocity of the wheelchair user while in motion. The underlying technology is based on six reed switches and a magnet mounted at the bottom of a pendulum that detects wheel rotations and a gyroscope sensor that senses angular velocity. In addition, the WRM includes a Bluetooth® module that wirelessly transmits the wheelchair motion information to an Android phone in real-time. The variables that can be obtained from the WRM are the total distance covered, average speed, and total wheelchair travel time. Further, we can also obtain information such as number of movement bouts and movement time at different speeds. The sampling rate for the WRM can be varied from 1Hz to 64Hz.

The wocket was developed by researchers at the Northeastern University as part of an open source effort to create very low-cost motion measurement devices for researchers in the field of activity monitoring [20]. Wockets are small, wireless 3-dimensional accelerometers that collect and wirelessly send data about body motion via Bluetooth in real time. The current sampling rate for the wocket is 40Hz.

The data from the WRM and wocket are collected by the personal gateway (i.e., an Android phone) via the Bluetooth. To evaluate the reliability of data transmission between the personal gateway and the WRM/wockets, we have conducted multiple bench tests. Table 1 shows the mean percentage of data loss in four wockets and one WRM when sending raw data continuously to an Android phone. The time durations for the tests ranged from 10 minutes to 3 hours with three tests for each testing period.

We are currently testing subjects who rely on manual wheelchairs for primary mobility in the laboratory and home settings. Subjects wear the monitoring unit and portable metabolic cart while performing a variety of physical activities in the laboratory and home settings. The video recordings and energy expenditure from the portable metabolic cart are used as references for predicting activity type and associated energy expenditure using the monitoring unit. The study procedure follows our previous work for activity classification [21] and energy expenditure prediction [22, 23].

Table 1: The mean (standard deviation) percentage of data loss for the WRM and wockets when transmitting data to an Android phone

Sensor	Time duration of the test				
	10min	30min	1 hour	2 hour	3 hour
Wocket0	-1.2(0.2)	-1.3(0.0)	-0.6 (0.1)	-1.3 (0.0)	-1.2 (0.0)
Wocket1	0.1(0.7)	0.0(0.2)	-0.4(0.1)	0.1(0.1)	0.1(0.0)
Wocket2	-0.4(0.3)	-0.6(0.1)	-0.5(0.0)	-0.6(0.0)	-0.5(0.0)
Wocket3	-0.7(0.1)	-0.9(0.1)	-0.5 (0.1)	-0.8 (0.1)	-0.8 (0.0)
WRM	-0.1(0.1)	-0.1(0.0)	-0.1 (0.0)	-0.0 (0.1)	-0.1 (0.0)

C. Sharing Unit

We have developed two applications for information sharing including a web-based application (Figure 3) and a mobile application (Figure 4). Both applications incorporated the following strategies that have been proven to be effective in promoting positive PA behaviors.

- Goal setting: Users can formulate an activity goal such as time spent in activities of moderate intensity, or accept the goal recommended by the application based on their current PA levels.
- Self-monitoring: Users can monitor their PA levels and progress towards the goal.
- Social comparison: Users can compare their own PA goal and status with aggregate data from their group (e.g., group average and group maximum) or data from individual user(s) in their group if permission is granted. The system can also set and post PA challenges and users can choose to accept the challenges.
- Social support: Users can support each other in participating in PA by giving rewards or greetings for reaching the targeted goal, sharing experience or activities, and doing "like this status" or commenting on other people's activities.

The difference between the two applications lies in how often and extensive PA parameters are provided. The mobile application provides more immediate feedback than the web-based application, while the web-based application provides more extensive summaries and views of PA participation for individual users and group aggregates. These differences are mainly caused by the nature of the technologies (smartphone and computer) by which PAMS is accessed. The mobile phones are carried on the person, always turned on, personal, and portable; but are limited on computation power and screen size. On another hand, computer has better computation power and larger screen size.

Figure 3 The web-based application

In terms of security and confidentiality, the authentication process requires a combination of the device's phone number, International Mobile Equipment Identity (IMEI) number, and a Facebook account. Only devices and Facebook accounts registered to the applications will be able to connect to, send data to, and download information from the PAMS. The communication framework between the applications and the server handles the encryption and authentication. The confidentiality setting of the applications is inherited from the Facebook confidentiality setting. Users have choices to make their page public or private. By default, data from individual participants are protected but summary data such as group maximum, minimum, and average are available for all group members. We are currently conducting an iterative usability testing of the two sharing applications with wheelchair users by observing their interaction with the applications and asking them "think out loud". The two applications will be revised iteratively through rounds of testing.

Figure 4 The Android-based mobile applications

III. Discussion

The paper describes a prototype system for monitoring and sharing PA among wheelchair users. One of the challenges lies in the lack of monitoring devices that can provide valid and accurate PA information for our target group – wheelchair users. The development of a monitoring unit that is capable of providing accurate information about the type, frequency, duration, and intensity of PA for our target group requires a large sample size and extensive testing and validation. Another challenge lies in the battery life of the monitoring unit and the mobile phone. Based on our preliminary testing, the monitoring unit needs to be charged on a daily basis, and the mobile phone can last for a day under light use. The feasibility for wheelchair users to use PAMS on a daily basis to self-monitor their PA needs to be explored. Finally, even though the integration of our applications with Facebook could increase the likelihood of user adoption, it could also potentially compromise user privacy. As physical activity and other health related data are attached to the social interaction using the Facebook functions, they can be exposed to the public if used inappropriately. Future work on the sharing applications could include features such as live news feed showing current 'best performer' based on specific category such as a user with the highest energy expenditure of the week/month. Another potential content for this live news feed is a list of users currently performing physical activity. We also aim to conduct clinical studies to evaluate the effectiveness of the PAMS in promoting PA among wheelchair users in the near future.

IV. CONCLUSION

The PAMS is a new activity monitoring system with seamless connectivity and interactivity that not only provides wheelchair users with accurate estimates of their everyday PA but also leverages the power of social influence to motivate positive PA behaviors among this group who ranks at the lower end of PA spectrum. The PAMS could also be a useful tool for assisting researchers and clinical professionals to collect *in situ* PA data to advance PA research in this population. The concept and design of the PAMS could potentially be extended to other populations.

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