Non-conventional Use of Smartphones: Remote Monitoring Powered Wheelchairs in MARINER Project

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Abstract. In this paper we will present the prototype of a system meant to quantitatively and continuously monitor the information measured during the daily use of powered wheelchairs, early adopted by severely impaired children. The system is based on a non-conventional use of a common smartphone, and it may represent an interesting application for long-term remote monitoring of health-related information.

Keywords: Quantitative remote monitoring · Powered wheelchair · Smartphones · Cloud

1 Introduction

Powered Wheelchairs (PWs) represent a fundamental aid to severely impaired people, especially children [1]. Because of their key role, there should be a careful pre-provision assessment and accurate follow-ups to verify the subjects' capabilities, as well as to adapt these devices to the users' changes. However, despite the high costs of these aids and their increasing demand, the assessments are usually limited to some pre-provision ones (not always performed by skilled professionals), and the follow-ups are seldom done, usually by means of phone calls to caregivers [2]. According to a recent review these assessments are, moreover, generally of qualitative nature [3]. The lack of post-provision quantitative evaluations, regarding "how long" and "how well" PWs are actually used, becomes particularly relevant when dealing with children, whose needs and capabilities are evolving with subjects' growth. Of course, without a continuous monitoring of the actual PW's use, such an important and sophisticated aid might turn into a less relevant support, or even useless and then abandoned, if it becomes difficult to be controlled or even dangerous to be operated by the user.

In 2014 we started a study (funded by Italian Lombardy Region), with the aim to assess the effects of early adoption (4–5 years old) of PWs in children with Cerebral Palsy, by evaluating changes in quality of life and in development of cognitive functions.

P. Perego et al. (Eds.): MobiHealth 2016, LNICST 192, pp. 138–143, 2017.
DOI: 10.1007/978-3-319-58877-3_18

Within this framework, we specifically designed a subproject (named Project MARINER – MonitorAggio Remoto carrozzIne ElettRoniche), to gather quantitative information about the real use of PWs in a non-invasive manner, without the need for parents or caregivers to fill in daily questionnaires or reports. The goal for this monitoring subproject was to remotely and automatically collect data, allowing the operators to have an insight in terms of the number of hours of actual motion with the PW, as well as other parameters that might result useful to better understand their daily use by the child.

We initially considered the control module already shipped with each PW, but such device is usually meant to operate the connected actuators only (i.e. motors, etc.), and it is designed to export raw data about PW's motion only for rare fine-tuning of the PW's parameters, performed by skilled technicians.

We then analyzed possible alternative solutions already on the market, without finding anything completely suitable for the purpose. In the growing areas of wearable devices and the Internet of Things, many products are able to continuously capture inertial data up to a few hours, but they have limited capacity to store and transmit this information to the Internet and to be connected with other electronic devices. Furthermore, among the industrial and fleet tracking solutions, despite the abundance of devices, these have very limited capacity of continuously recording inertial data. Since no available solution fully met the desired requirements, we finally opted to develop and integrate a custom designed system on the PW, to gather information from the motion, without interfering with the PW's controls.

In the following paragraphs we will briefly describe the system designed and integrated for the MARINER project, and we will highlight some possible future developments.

2 Materials and Methods

Nine children, 4 to 6 years old, were recruited, for an observation period of one year. Each of them was given a PW Skippy (Otto Bock Mobility Solutions GmbH, Germany), bundled with *seat modules*, to extend the low-level I/O capabilities. Every PW was then equipped with the custom developed remote monitoring system.

We wanted to collect three types of information: the actual number of hours each PW was actually used per day, quantitative data about "how well" the PW was operated, and finally issue some alerts in case of major problems (in particular empty battery and system overheating). While the first and the last types of information are rather straightforward to manage, respectively by monitoring the number of hours the motors are powered on and the presence of certain conditions (i.e. battery voltage drop under 20% of full charge, temperature raising above 50 °C), there is not a single way to assess the "how well the wheelchair is used" issue. For this preliminary study, we hence decided to simply collect all the available kinematic information (acceleration and angular speed), to be further analyzed in order to derive meaningful indexes, also by comparing these quantitative data with the qualitative impressions and considerations from the caregivers, by means of periodic phone calls.

Given these goals, we wanted the monitoring system to be energetically autonomous and rechargeable, equipped with inertial sensors (an accelerometer and a gyroscope) to measure the PW's use and an I/O interface to detect PW conditions. The monitoring system also needed to be firmly attached to the PW, and capable to autonomously transfer the acquired data to the Internet.

The final prototype of the monitoring system was thus built around a commercial smartphone (Galaxy S4, Samsung, Seoul, South Korea). The external information provided by each PW as pulse-width modulation signals (activation status of the electric brake) are low-pass filtered by a custom made RC filter (10 ms time constant) and acquired by a multi I/O board (Maxi I/O, Yoctopuce Sarl, Cartigny, Switzerland) connected to the smartphone through an USB cable (see Fig. 1).

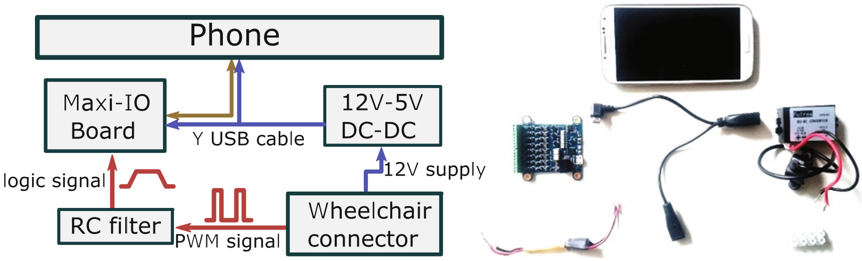

Fig. 1. Acquisition system scheme (left) and a photo of the actual elements (right).

During the PW's activity, the whole system is powered from the main PW's battery (12 V) through a common 12 V to 5 V DC-DC converter, which may provide up to 3A @ 5 V. This converter provides the required power supply either to the smartphone and the I/O board, thanks to a dedicated Y-cable (VAlarm, California, USA).

The smartphone is placed into a rugged plastic box, right above another enclosure hosting the DC-DC converter, the multi-IO board and the cables, as in Fig. 2.

Fig. 2. The Galaxy S4 smartphone running the app (left), a view of the devices placed in the plastic box and rugged enclosure (center). Final setup in the back side of the wheelchair (right) with the custom metal plate.

These boxes are set very close to the wheels' center of rotation, through a 3 mm thick metal plate designed and realized on purpose.

The overall cost of the hardware components is around €500.

The smartphone runs a custom Android app we developed to acquire, store and transmit data to the back-end architecture. The inertial measures are sampled @ 50 Hz from the smartphone's triaxial accelerometer and gyroscope, only during the movements of the PW, while the smartphone's temperature is continuously sampled, ten times per minute (@ 0.167 Hz). All of these data are stored as timestamped values in separate files on the smartphone (*tracings*).

Each single change in PW conditions (Power ON/OFF, Motor ON/OFF, battery level change, etc.) is timestamped and stored at the time of its occurrence, and considered an *asynchronous event*. The sequence of asynchronous events, as well as the tracings, are locally processed on the smartphone to extract some basic indexes. These basic indexes describing the PW's condition (percentage of activity, temperature of the smartphone, battery level, GSM/UMTS/4G signal level, etc.) are sent to the back-end architecture according two different timings: once every hour, the *Hourly Events,* to give a fast and synthetic view of the conditions, and once a day the *Daily Events*, which consist of a more thorough insight (including the number of hours of activity, number of daily power ON/OFF, number of daily motor ON/OFF and other data regarding the use of the wheelchair for that day). These latter data are sent every day, at 2:00 am, when the PW is not in use. At 2:0 am, furthermore, all the *tracings* acquired during that day are transferred to the appropriate back-end part (the blob repository).

In case a major problem or in case a major threat is detected (i.e. the temperature of the smartphone goes above a certain threshold – namely 50 °C, or battery below a certain threshold – namely 20% of full charge), this information is sent to the back-end architecture as an *Asynchronous Event*, the acquired data are saved locally on the phone, and a text message is directly sent from the smartphone to an operator.

The back-end side for collecting *Events* (simple set of few bytes of information) and *Tracings* (the files containing the signals acquired during the motion of the wheelchair) is briefly depicted in the scheme in Fig. 3. It has been developed using Microsoft Azure Cloud (Microsoft Corp., Redmond, USA), by using some of the key elements that have been specifically developed for the Internet of Things, like the Event Hub and the Stream Analytics, and using also a blob repository for the tracings and an SQL database for the final storage of the valuable information (indexes).

Once the tracings are transferred to the blob repository, they are further processed by the so called *workers* (custom developed algorithms coded in C#), to provide other indexes (min/max, mean, standard deviation, etc.) to the database. More sophisticated indexes (i.e. describing the distribution of accelerations and angular velocities and their asymmetries, etc.), which could be derived from the acquired tracings, will be further investigated and evaluated in the future.

The ultimate goal of this architecture is to provide both a simple lively overview of the current PWs' use by subjects, by accessing the SQL database, while allowing further detailed analysis and post-processing, once the tracings are available in the blob repository.

We have estimated to store up to 20 MB for tracings in the blob repository and some KB of data stored in the SQL database per day per wheelchair.

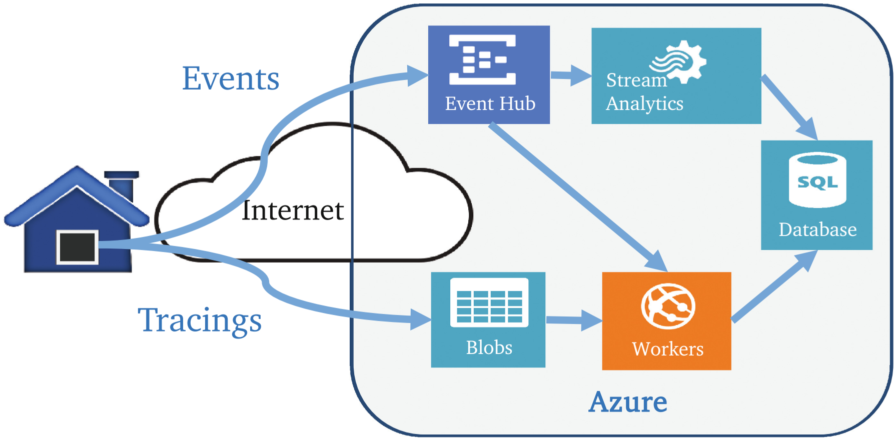

Fig. 3. Simple scheme of the dual data flow from the Power Wheelchair to Event Hub (events) and the blob repository (tracings), and after some processing steps, to the SQL database.

3 Conclusions and Future Perspectives

The prototype system described in the present paper is aimed at evaluating the feasibility and the clinical relevance in long-term quantitative monitoring of PWs' daily use, even going from some months up to various years.

To our knowledge, after the provision, there are no efforts in this direction regarding PWs, not only used by children, but also by adults and elderlies, unless (in some cases) diaries filled in by caregivers or phone/email contacts from operators.

Once this information and the related indexes will be thoroughly assessed and validated, this quantitative approach could give a significant contribution in the field of PW's use. Due to the high costs of the PWs (easily above €5000), and the increasing need of cost-effectiveness in the public healthcare systems, it is reasonable that such an approach, based on a minimally invasive and relatively low-cost "black box", could be used to derive more robust and useful measures of outcome in the provision of PWs.

Finally, since the project is based on a mobile Android app, it is foreseeable that almost the same backend architecture and a part of the front-end one could be easily adapted to gather quantitative information in a non-obtrusive manner on a broad spectrum of biomedical measures, valuable for the health conditions of patients (children, adult and elderly), directly from the smartphone or from other wearable devices (watches, etc.). This will allow a variety of novel forms of daily quantitative remote monitoring in a long-term perspective, not only limited to the use of PWs.

Further and larger studies will be of course required to foster the subject, because of the number of psychological, social and economic implications.

Acknowledgments. Authors would like to thank Microsoft Corp. for the provision of their Azure Cloud solutions to Fondazione Don Gnocchi, as a part of their support program for non-profit organizations. Authors would also like to thank Samsung Electronics Italia SpA for their support in the early stage of the project, by providing some mobile solutions to be tested and integrated.

Finally, authors would like to acknowledge Amper S.r.l. (Milano, Italy) who manufactured and provided all the mechanical components required for the proper system placement on the PWs.

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