SmartStuff: A Case Study of a Smart Water Bottle

Emil Jovanov, Vindhya R Nallathimmareddygari, Jonathan E. Pryor

Abstract— **The rapid growth of Internet of Things (IoT) and miniature wearable biosensors have generated new opportunities for personalized eHealth and mHealth services. Smart objects equipped with physiological sensors can provide robust monitoring of activities of daily living and context for wearable physiological sensors. We present a case study of an intelligent water bottle that can precisely measure the amount of liquid in the bottle, monitor activity using inertial sensors, and physiological parameters using a touch and photoplethysmographic sensor. We evaluate two system configurations: a smart water bottle integrated into a personal body sensor network and a cloud based device. This paper presents system organization and the results from preliminary field testing of the prototype device.**

I. Introduction

Exponential growth of the number of physical objects connected to the Internet, also known as Internet of Things or IoT, is expected to reach 50 billion devices by 2020 [1]. New applications include smart homes, transportation, healthcare, and industrial automation. Smart objects in our environment can provide context awareness that is often missing during monitoring of activities of daily living [2], [3]. Smart objects equipped with physiological and activity sensors, that we call SmartStuff provide new opportunities for unobtrusive physiological monitoring.

Integration of SmartStuff with wearable body sensor networks is facilitated with smartphones and smartwatches [4], [5]. New generations of smartwatches, such as Basis Peak or Apple Watch, feature continuous measurement of physiological parameters, such as heart rate, galvanic skin resistance (GSR), and temperature. Smartwatches can also receive messages and notifications that are very important for ubiquitous health monitoring applications.

Smart sensors and smart environments facilitate one of the main trends in big data science – the quantified self (QS) [6], [7]. The QS community is engaged in self tracking or group tracking of physiological, behavioral, and environmental information. New sensors and systems enable seamless collection of records and integration in databases that can facilitate data mining and new insights. This trend is further supported by establishment of the standard toolsets, such as Apple HealthBook, Google Fit, Samsung S.A.M.I, and Microsoft Healthvault. Big Data analytics can support personalized health monitoring and interventions [3], [7].

One of the most important factors for health and wellbeing is proper hydration. Water makes up 60% of our body, 75% of our brain, and 83% of our blood. An intelligent hydration monitoring and management platform can provide automatic, accurate, and reliable monitoring of fluid consumption and provide configurable advice for optimum personalized hydration management. A smart water bottle can satisfy the needs of a variety of groups, including athletes that want to enhance performance, dieters that want to achieve their weight goals, as well as elderly in group homes or living alone that often suffer from dehydration. While most users who seek to improve their wellness have insufficient liquid intake, some medical applications require limiting of water intake. Typical examples include kidney disease and congestive heart failure (CHF) patients that need to comply with recommended water intake protocols and limit the total amount of liquid taken during the day while still taking liquids regularly throughout the day.

An integrated hydration management platform enables users to receive alerts and reminders of when to drink, set goals for how much to drink, show current and previous consumption levels, and where they are vis-à-vis their individual hydration goals at any moment in time.

The first intelligent water bottle on the market was Hydra Coach. The bottle features a display that presents hydration information, but no wireless connectivity. The new generation of bottles, such as HydrateMe and Trago feature Bluetooth wireless interfaces and custom smartphone and smartwatch applications [8].

This paper presents preliminary results of the sensor enabled smart water bottle. We present system architecture, possible applications, and preliminary performance analysis of the implemented prototype.

II. Methods

We implemented several versions of a smart water bottle to evaluate user factors and performance of different configurations. Two main configurations include: a) body area network integration, and b) WiFi cloud system integration.

A smart water bottle integrated through a smartphone application is presented in Fig. 1. The controller communicates with the custom smartphone application through a Bluetooth Smart wireless interface. The smartphone application processes data from the smart water bottle and sends processed information to the backend server. Limited range of the Bluetooth wireless interface may be an issue for some applications.

In the case of collective monitoring, such as monitoring in hospitals and assisted living facilities, it is not practical that every user keeps a smartphone platform with them most of the time. Therefore, we implemented a cloud based solution with WiFi connectivity as presented in Fig. 2.

E. Jovanov V. R. Nallathimmareddygari, and J. E. Pryor are with the Electrical and Computer Engineering Department, University of Alabama in Huntsville, Huntsville, AL 35899, USA (Phone: 256-824-5094; fax: 256-824-6803; e-mail: emil.jovanov@uah.edu).

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Fig. 1. Smart water bottle integrated into a personal body area network.

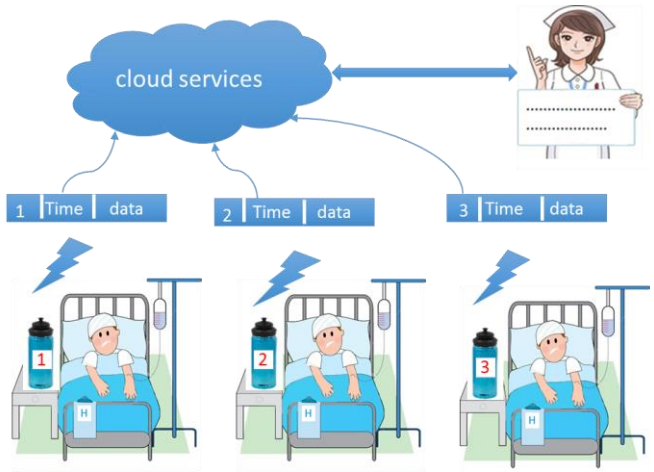

Fig. 2. A cloud-based intelligent water bottle implementation.

Nurses or physicians can access information from each bottle directly through the cloud and retrieve current status and history of hydration for each user. The system can also send alerts and notifications to the users, staff, or caregivers.

The controller is implemented using Photon WiFi platform for IoT applications from Particle [9]. Photon uses the Broadcom Wi-Fi controller that supports 802.11b/g/n and direct support for cloud services. This approach allows a large number of intelligent devices integrated through existing WiFi infrastructure. In our application, individual users use their own water bottles that all communicate to the cloud through the WiFi interface. This configuration is particularly important for nursing homes and hospitals.

We implemented several sensors on the smart water bottle to evaluate possible use of sensors for monitoring of activity and physiological monitoring of users. We use a 3D accelerometer to detect the use of the bottle.

Physiological monitoring is implemented using a custom developed Touch and Pulse Sensor (TAPS). The sensor uses capacitive sensing to detect when user touches the bottle and physiological monitoring using a photoplethysmographic sensor (PPG), as presented in Fig. 3. In the current prototype, TAPS sensor is controlled by the dedicated controller, Teensy 3.2 [10].

The PCB of the TAPS sensor is a 2-layer board (0.625 by 0.92 inches) that features the Maxim MAX30100 heart rate and pulse oximeter sensor [11] and power management circuit on the bottom of the board. The MAX30100 is an integrated pulse oximetry and heart-rate monitor sensor solution that combines two LEDs, a photodetector, optimized optics, and low-noise analog signal processing to detect pulse oximetry and heart-rate signals.

Fig. 3. PPG sensor on the smart water bottle

The main controller communicates with the MAX30100 via I2C. It is a very compact sensor with a size of 5.6 mm by 2.8 mm. The I2C commands allow for granular control over the sensor, including low power mode control, FIFO control, LED power usage, and temperature measurement control. The user can choose to measure red, infrared, or both PPG signals. Digital PPG signal is read by the main bottle controller. PPG signal can be sampled at sampling frequency of 50Hz to 1,000 Hz with resolution of 13 to 16 bits per sample. Typical PPG signal recorded on the sensor is presented in Fig. 4.

As an alternative, we evaluated the analog Pulse Sensor [12] for monitoring of heart rate only. Analog signal is digitized using a 16-bit integrated AD converter of the microcontroller, but MAX30100 was much better solution for our application.

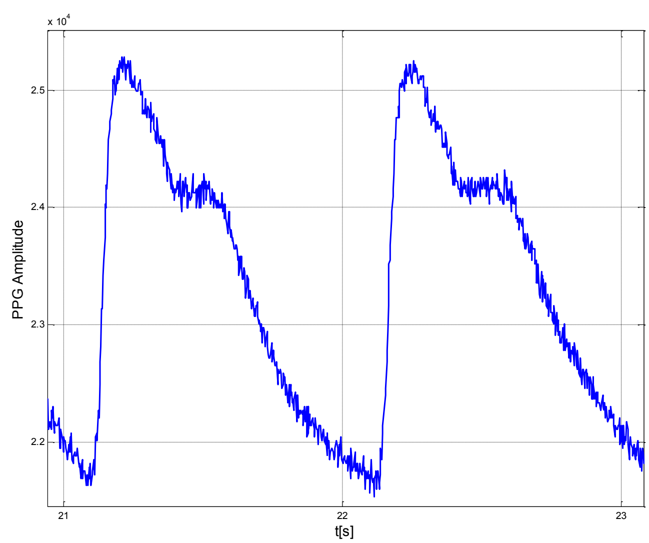

Fig. 4. PPG signal from the pulse sensor; Sampling frequency Fs=1,000Hz

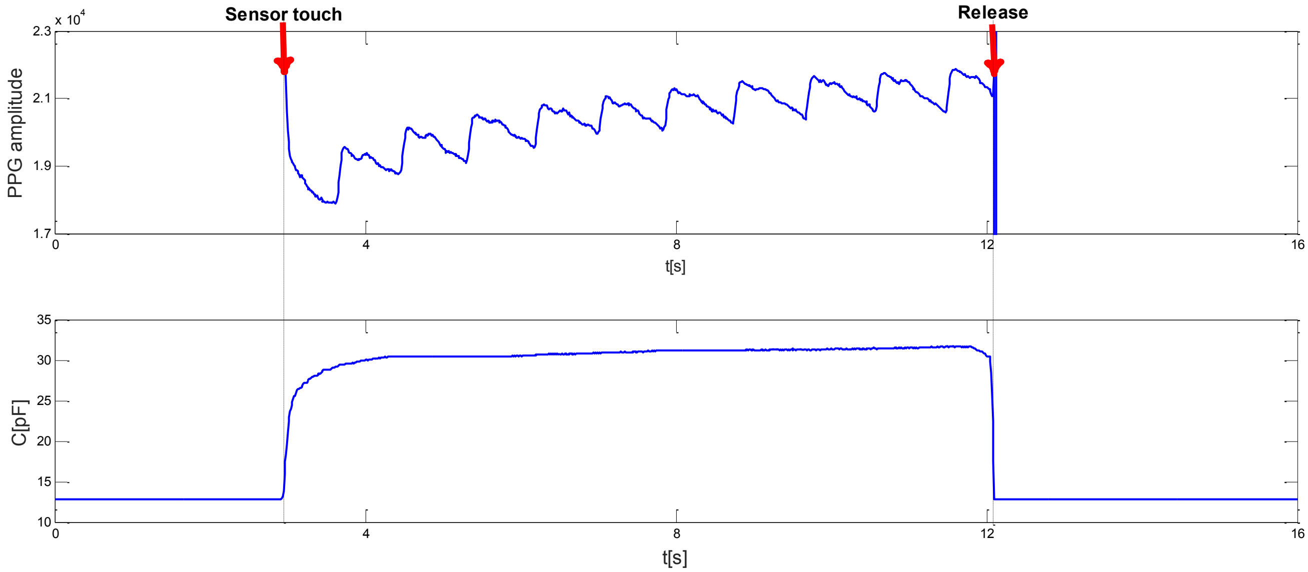

Fig. 5. PPG signal and sensor capacitance from the pulse sensor on the smart water bottle.

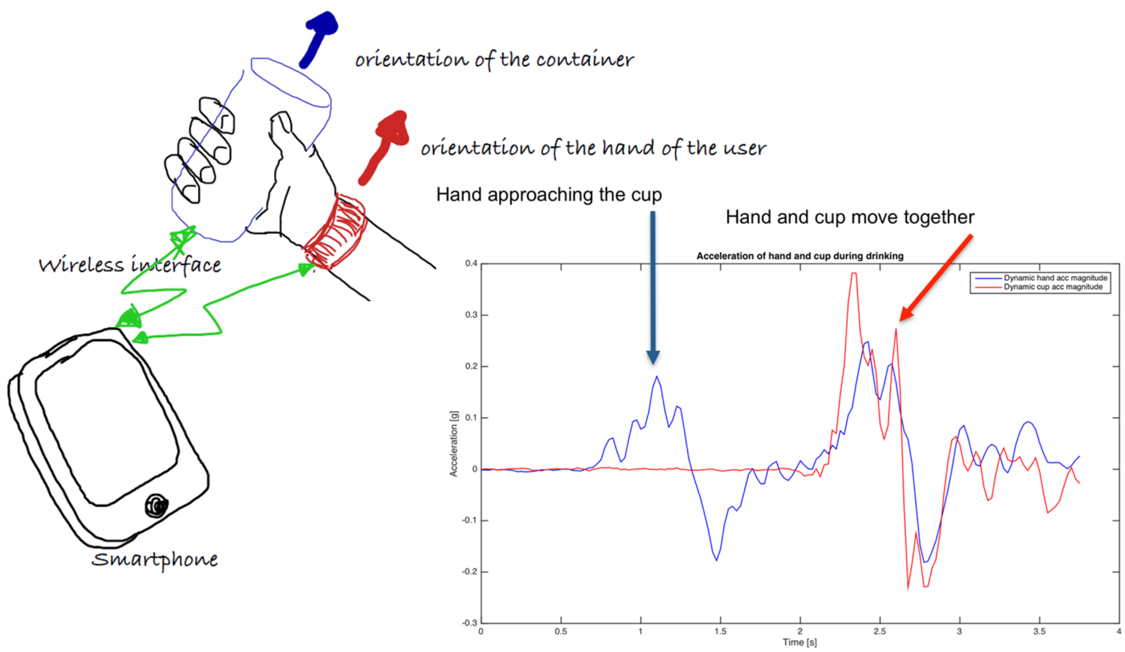

Fig. 6. Context awareness using collective processing from inertial sensors on the water bottle and the smartwatch.

TAPS features a capacitive sensor implemented on the PCB that is used to detect touching of the sensor. This touch sensor provides detection of the use of the bottle. That information can be used to significantly optimize power consumption and extend battery life of the device by turning off PPG sensor when bottle is not used. In addition, driving current of the PPGs can be adjusted in software according to the contact with the bottle. Typical LED current of the sensors can be set between 4.4 mA and 50 mA, or turned off when the bottle is not used, as indicated using the touch sensor.

III. Results

Preliminary testing of the physiological sensors on the smart water bottle indicates a very good quality of signals that can be used for non-invasive physiological monitoring. A sample of the PPG signal from Pulse Sensor on the bottle is presented in Fig. 4, and change of capacitance caused by touching the sensor is presented in Fig. 5.

SmartStuff with sensors integrated in objects of everyday use allows synergistic processing of signals from multiple sensors that facilitates understanding of context of measurements and unique insights. We evaluated the use of sensors to identify the user.

Inertial sensors on the bottle and the smartwatch of the user can be used to detect the same pattern of activity as a means of identification of the user. A typical pattern of activity recorded during the bottle use is presented in Fig. 6. Dynamic component of the 3D magnitude of acceleration on wrist (collected by the smartwatch) and the bottle (accelerometer on the bottle) is very similar when the bottle is held on the same hand.

In addition, heart rate from the PPG sensor on the bottle and from the smartwatch can also be used to identify the user, which is useful if the opposite hand is used to hold the bottle.

Touch sensor can be used to assess the contact between the finger and the PPG sensor. We investigated quality of the PPG measured as peak-to-peak amplitude of the PPG for each heart beat as a function of the capacitance of the touch sensor. The results are presented in Fig. 7. It can be seen that the light touch, indicated as measured capacitance between 10 and 27 pF provides good signal with amplitude around 450 units for the 13-bit precision of the PPG. The amplitude is significantly better with more pressure (28-33pF), but drops significantly with high pressure due to the loss of pulsation in the finger.

We analyzed dynamic power consumption using Battery Simulator NI PXIe-4154 by National Instruments. Power consumption of the Photon ranges from 320 mA (searching for Internet) to 450 mA (communicating with the server) in the active mode. During standby mode power consumption is 4 mA, and during deep sleep mode it is 76.5 µA.

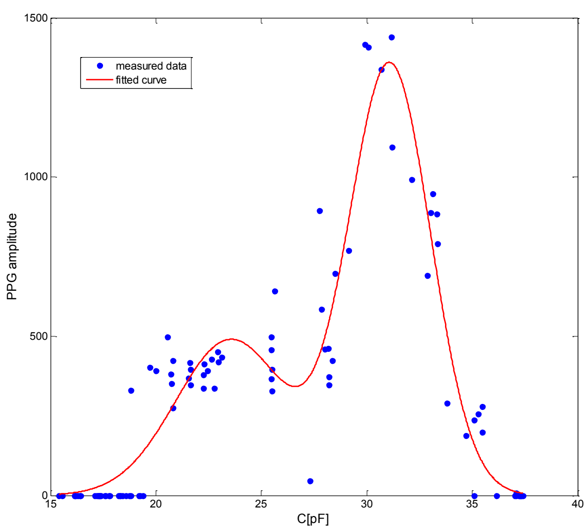

Fig. 7. PPG amplitude (peak-to-peak) as a function of the capacitance of the sensor.

IV. Discussion and Conclusion

Increased intelligence of objects of everyday use implemented in SmartStuff presents opportunity for new applications and services. Synergistic processing of data from the SmartStuff and smartwatches and other wearable sensors may significantly improve the field of mHealth and longitudinal monitoring.

Multisensory integration is a very promising approach for robust monitoring and for the understanding of the context of measurements.

In this paper we presented preliminary results of analysis of two implementations of the smart water bottle. Each approach has advantages for specific applications. Integration using a personal body area network is more power efficient, but requires personal gateway (smartphone) in the vicinity of the device, at least periodically throughout the day. A cloud based solution allows seamless integration for a large number of users using a standard infrastructure, but requires higher power consumption and significantly decreases battery life of the system.

Challenges and issues and our future work include service discovery, heterogeneous system integration, power-efficient system implementation, and robust processing and detection algorithms.

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