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CONNECTED WELLNESS - An Approach for Cloud Connected Sensing for Healthcare and Wellness

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Abstract

Connected wellness and healthcare can be the next generation revenue earner for telecommunication service providers who can provide these services as bouquet of value added services (VAS). This might involve patient and elderly people monitoring by indoor localization and recognition of activities of daily living (ADL),connected physiological sensing and remote monitoring of health trends, calorie and workout management. Emergency features like fall detection can also be added to the suite. The advent of Smartphones has ensured connectivity to the masses and with peer-to-peer (P2P) connections like Bluetooth ensures connectivity to personal healthcare devices. Further, Smartphone sensors can themselves be used to elucidate activity and certain physiological parameters. Finally, cloud connectivity ensures remote monitoring and intervention and data integrity. This can further lead to opportunities like telemedicine and tele-rehabilitation.

This paper discusses a connected application suite available via the TCS Connected Universe Platform (TCUP). The TCUP connected applications are showcased on a Mobile Platform (Android device) which includes HeartSense, Aktrak and Fall Detection applications. HeartSense is a robust non-intrusive real time heart-rate (HR) and blood pressure (BP) measurement application from Photoplathysmograph (PPG). The second application is Aktrak that is used for activity classification, step counting and calorie estimation. The novelty of this application is that it can work independent of any personalization and the phone can be kept in any placement and orientation with respect to user's body. The third application is a fall detection application, which can detect user fall from phone inertial sensor data. The major issue with detecting falls using accelerometer is the number of false positives that get generated; we have developed an algorithm that provides appreciable precision as well as recall thereby reducing false positives.

TCS Connected Universe Platform offers a set of services that allow enterprises to easily develop, deploy, and administer Internet of Things(IoT) software applications such as web apps, real-time analytics (complex event processing), and batch analytics programs. The application programming interfaces (APIs) provided by the platform can be used by software programmers, while administrators can use the Connected Universe portal, along with another set of APIs, to manage IoT services. Healthcare and wellness is therefore provided as a service on top of TCUP, which can use underlying features of TCUP like data-storage, visualization, time-series analysis of data and predictive analytics. Such services can be used in future for risk assessment and trend analysis of patients as well as demography.

Introduction

Prevention is better than cure - Medical practitioners often suggest that dire consequences of a major disease may be avoided only if detected at an early stage. The insurance companies of the developed countries are also keen to monitor physiological parameters of people, round the clock, as the early detection of abnormalities may potentially reduce the cost of treatment. As the demographic age is increasing in both developed and underdeveloped countries and the medical ailments are naturally higher in elderly people with their physical movement often restricted, thereby requiring 24x7 physiological monitoring. Moreover, in the developing nations, the cost of regular health checkup is not affordable for a large section of the society and the lack of expert professionals who measure the health conditions makes the situation worse. Though there exists stand-alone devices to measure physiological parameters, these devices incur additional hardware cost. Mobile phone based healthcare systems are getting popular in both developing and developed nations. Such applications provide the users with an opportunity to monitor their health condition at home regularly, as part of preventive health care. While some of these devices are approved by medical fraternity (e.g. FDA approved), the rest are mostly intended for preventive indicative healthcare i.e. alerting the user for a doctor visit before it's too late. Hence, the digital healthcare trend has got further extended to hardware add-ons of smartphones (iPhone/android/windows), and in extreme cases - a simple clutter-free smartphone app without any need of external hardware whatsoever.

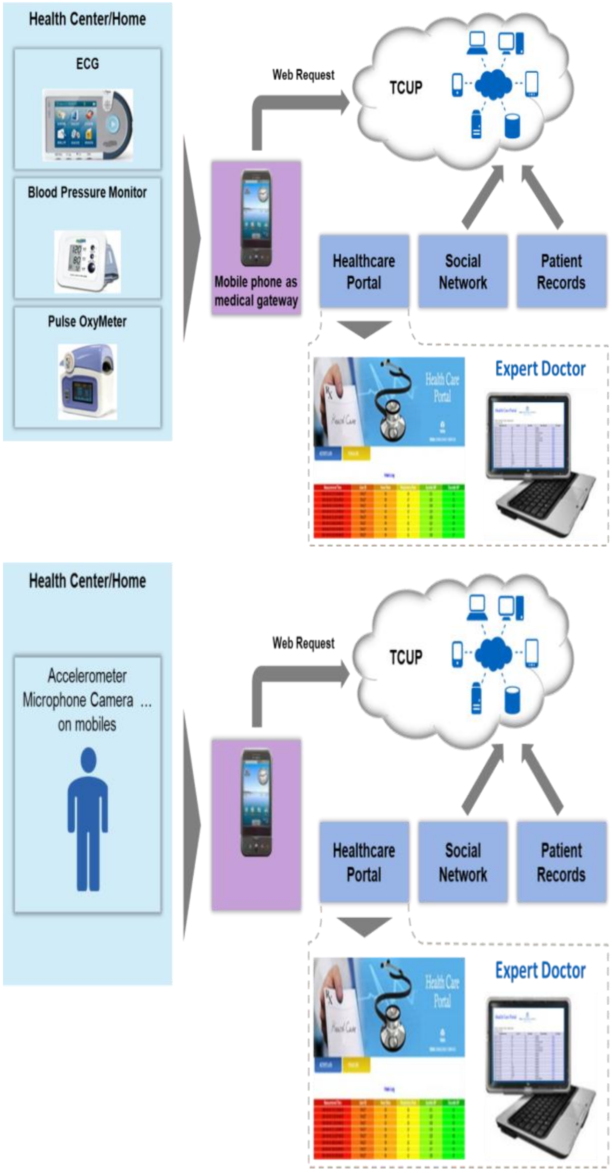

Figure 1 TCUP Health Service Components

The connected wellness healthcare service includes three components, mobile sensing applications, mobile gateway applications and the TCUP platform. The system architecture is provided in Figure 1, where the personal healthcare devices connect to a mobile device and followed by our TCUP agent which sends data to TCUP cloud [9] where it gets stored. This data can then be visualized and analyzed on the platform portals [1]. As such, the TCUP platform itself, is used to store, analyze and visualize the personal health data [1, 7].

The novelty of the solution is discussed in the mobile sensing component, where we have achieved a user friendly way for non invasive and continuous measurement of some wellness and physiological parameters using mobile phone sensors only [3, 4, and 5]. The parameters include activity, step count, calorie, heart-rate and blood pressure.

Our algorithm can be ported on any mobile phone platform or wearable, suggesting interoperability. We have ported our solution on Android 4.2.2 OS platform and iOS 7 and tested on Nexus 4, Nexus 5,

iPhone 4, iPhone 4S and iPhone 5 mobile phones. We are working on building a wearable system and porting our code into the same with no or very minimal changes to the algorithm.
By empowering patients and normal people to better manage their health and wellness through our Connected Wellness solution, healthcare organizations can improve outcomes and lower the cost of care, pharmacies and pharmaceutical manufacturers can increase medication adherence, employers can achieve employee peak performance, and policy payers can lower premium amount.
We discuss the salient features and innovations in the TCUP platform, HeartSense, Aktrak and Fall Detection componets of our solution in the following sections.

TCUP Platform

TCS Connected Universe Platform (TCUP), which was earlier, code-named RIPSAC, enables end-to-end management of smart healthcare devices and provides several benefits.
A holistic offering: A unified, flexible solution, based on open source platforms and components that address the needs of diverse operating environments and stakeholders. The platform enables role-based access control, thus augmenting security and privacy.
An offering that is product agnostic: The solution can be deployed across heterogeneous and interoperable devices, sensors, and applications.
The ability to manage large volumes of data: The offering helps enterprises better manage network communication loads by leveraging M2M communication protocols. It also enables businesses to address complexities related to data storage by using Big Data enabled architecture and distributed computing.
Deep domain expertise: The solution is backed by over 18 patent-pending sensor and wireless technologies, including an Integrated Sensor Cloud Platform, as well as solutions for distributed computing on edge devices, and secure communication and privacy.

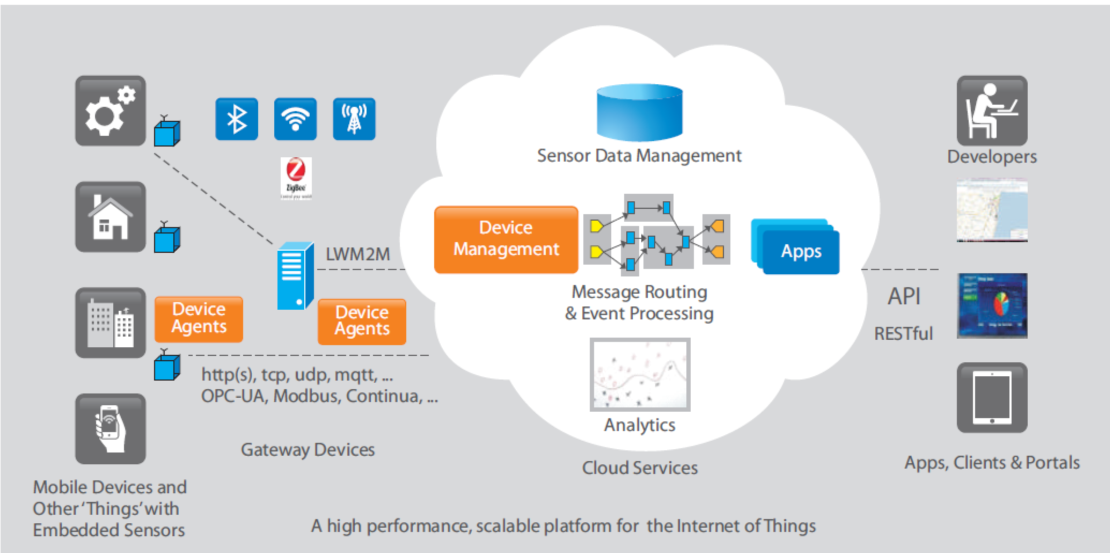

Figure 2 TCUP Platform Overview

The TCUP platform is used to store, analyze and visualize the personal health data, the HeartSense, Aktrak and Fall Detection components of the solution use the TCUP platform for data storage, analysis and visualization over the cloud which is discussed below.

HeartSense

Photoplathysmograph (PPG) technique can be used to detect a wide range of physiological parameters and/or conditions e.g. heart rate, respiratory rate, SpO2, blood pressure to rather intricate health issues such as Premature Ventricular Contraction (PVC) in a subject. The smartphone camera can be used to capture video from a user's fingertip at rest position, which is later digitally processed in order to extract reflective PPG, Fig. 3.

Like Heart Rate (HR), Blood Pressure (BP) is a very important vital parameter for human beings. In abnormal conditions, it can vary drastically within a very short span. Hence continuous monitoring of BP is required for patients under treatment. It is also desired to keep an eye of the same for normal people as part of preventive healthcare, which can be further extended to fitness programs, e.g., during an exercise session. However, today's available technologies do not enable the continuous monitoring of BP, since an external pressure cuff is required to measure the same. Recent development of estimating the BP from the PPG shows a possibility of continuous monitoring of BP.

We use a combination of machine learning and model driven system, which results in enhanced accuracy and more consistent output. The Windkessel model represents the human cardiovascular system in terms of an electrical circuit containing lumped electrical components. The electrical analogy of 2-Element Windkessel model is shown in Fig.4. Total peripheral resistance is considered as a resistance (R). Elasticity of the major artery is modeled as a capacitance (C). The blood flow from ventricles to artery symbolizes a sinusoidal electrical current I (t) and arterial pressure, generated due to blood flow is represented by the time-varying electrical potential P (t). So the systolic and diastolic pressures will then be the maximum and minimum values of the simulated pressure wave, implying one complete cardiac cycle.

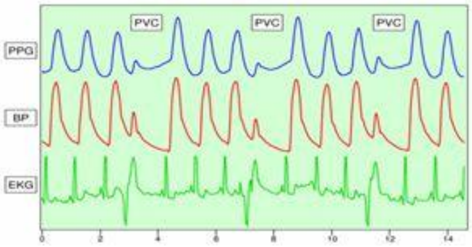

Figure 3 PPG Details

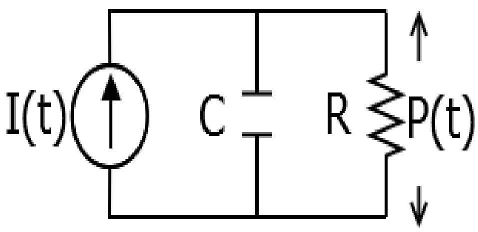

Figure 4 Electrical analogy of 2-ElementWindkessel model

Fig. 5 explains the BP measurement steps. During the training phase, models of R and C are created by extracting features from the PPG signal, obtained from the video stream by placing the finger on the phone camera, in combination with the BP measured using a standard medical instrument. During the testing phase, which is a real time smart phone application that is distributed to the users for BP monitoring, systolic and diastolic pressures P_s and P_d are calculated using the values of R and C models created during the training phase. Heart rate of the subject is also calculated using 512 point Fourier transform analysis and displayed.

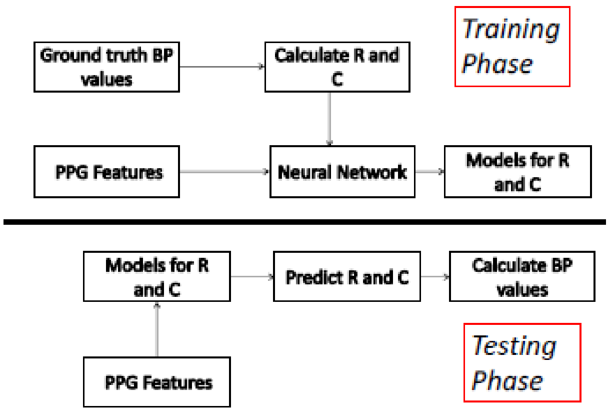

Figure 5 Block Diagram of proposed methodology for BP estimation

So far, the proposed methodology has been successfully implemented and tested in Nexus 4, Nexus 5 and iPhone 4 smart phones, with an accuracy error of 10% of the actual BP values (measured using sphygmomanometer in mmHg) for both Ps and Pd, with a 82% accuracy. Since the accuracy of a learning based system strongly depends on the diversity of training, we are still trying to improve our learning models for R and C in an incremental way, by introducing new subjects of different age, sex and BP.

This BP measurement application, ‘HeartSense: Smart Phones to Estimate Blood Pressure from Photoplethysmography’, was awarded the ‘best demo award’ at The 12th ACM Conference on Embedded Networked Sensor Systems (SenSys 2014)- http://sensys.acm.org/2014/

Aktrak

Step signatures can be found clearly in mobile micro electromechanical system (MEMS) based specific force sensors or accelerometers. Since these sensors fundamentally sense force, the step signature is clear when the foot hits the ground. However, there are some signal processing steps like removal of gravity using a high pass filter, mean-shifting the signal and doing a Fast Fourier Transform (FFT) to determine a single fundamental frequency involved. These steps are required to determine steps (footsteps) in noisy environments like phone movements due to regular usage. Hence we have got a robust mechanism for accurate step detection. On top of this we use step-frequency based classifier to classify user activity into walking, brisk-walking and jogging/running [5].
In addition to basic activity detection and step counting, we have developed a novel adaptive stride-length estimation algorithm that is able to determine the user's stride length based on his height and the activity class like walking, brisk-walking and running. Once we have a good measure of both step frequency and stride length, we obtain a very accurate estimate of speed which is fed to a standard Metabolic Equivalent table [MET] [8] to achieve calorie and distance measurements for walking/running based workout sessions. A mean accuracy of 85% was achieved for activity classification, while a 7% maximum error was noted for step frequency and count.

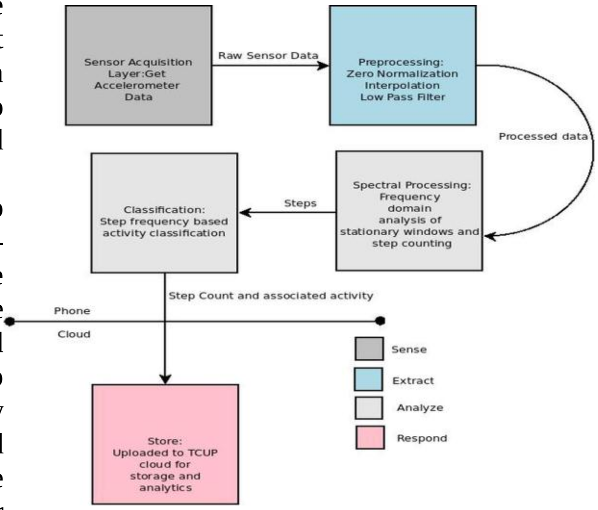

Figure 6 AcTrak blocks

Fall Detection

The aim of this application is to detect when a user has undergone a sudden fall, avoiding false positives, using the inertial sensors present in user’s mobile device.
When a subject falls, there is a substantial and a sudden displacement in her body’s center of mass in vertical direction. Such changes in displacement can be detected using accelerometer and gyroscope. Also these sensors suffer from a huge drifting problem. But since we are concerned only about detecting the anomalistic change in displacement, which is relative in form, this problem can be ignored, and combining this detection with proper heuristics, a robust fall detection algorithm can be designed.
It is observed that when a fall occurs, the displacement graph shows a distinct kink which we detect by the relative change in the variance, obtained by a running mean. This observation is important as it helps to

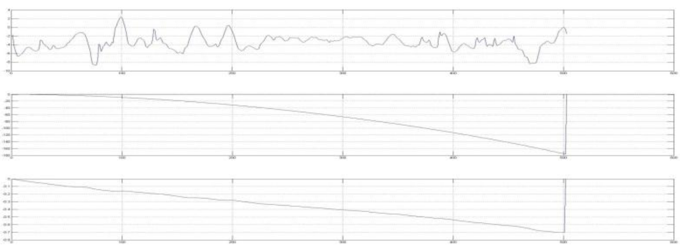

Figure 7 False drop: Dropping a mobile phone on table

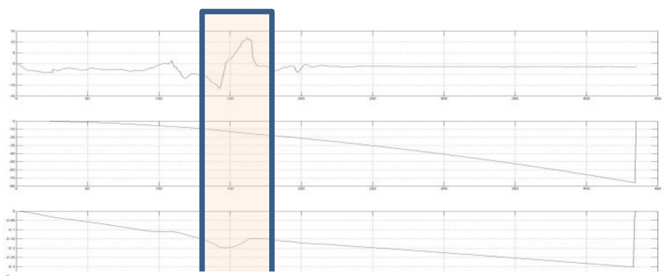

Figure 8 Real fall

differentiate false positives (like acceleration changes due to normal activities like running etc., where acceleration is also prominent in other axes as compared to perpendicular component). Also we apply a heuristic that a fall is declared if such a change in vertical displacement is observed and there is a certain time of stationary activity after the impact of fall. This may signify that the subject has fallen and was unable to recover instantaneously, and should be helped.

Figure 7 shows false drops of the mobile phone, where clearly the relative variance in the vertical displacement is not much, as compared to Figure 8 which is the case of a real fall. Our solution has been tested on the mobifall dataset [6] to provide a 93% precision and 92.4% recall. This signifies much lower number of false positives reaching to the server whereby reducing the number of emergency interventions.

Conclusion

Controlling the rise in chronic disease requires that people actively participate in the self-management of their own health and wellness. When this is achieved, outcomes will improve and the cost of care will be lower. While many of the solutions and concepts for connected wellness today focus on digitally connecting doctors and patients using mobile phones and using separate devices to measure their health and activity, the work presented by us is different in the way it measures the health and activity of the person using only a mobile phone which is then used to communicate to doctors. This solution can be extended to wearable computers too. Such a solution shall always be the focus in research and market as long as staying fit and keeping well is a challenge in our busy lives.

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