StandUp: An Automated Guide for Improving Physical Activity of People using Their Handheld and Desktop Devices

Student Name: Abhishek Kumar

IIIT-D-MTech-CS-12-002

Jan 29, 2015

Indraprastha Institute of Information Technology
New Delhi

Thesis Committee
Dr. Vinayak Naik (Advisor)
Dr. Ojaswa Sharma (Internal Examiner)
Dr. Nischal Piratla (External Examiner)

Submitted in partial fulfillment of the requirements
for the Degree of M.Tech. in Computer Science,
with specialization in Mobile Computing

Keywords: Activity Tracking, Multi-modal Sensing, Workplace Healthcare, Triggered Sensing,

Certificate

This is to certify that the thesis titled **"StandUp: An Automated Guide for Improving Physical Activity of People using Their Handheld and Desktop Devices"** submitted by **Abhishek Kumar** for the partial fulfillment of the requirements for the degree of *Master of Technology* in *Computer Science & Engineering* is a record of the bonafide work carried out by him under my guidance and supervision in the Mobile Computing group at Indraprastha Institute of Information Technology, Delhi. This work has not been submitted anywhere else for the reward of any other degree.

Dr. Vinayak Naik
Indraprastha Institute of Information Technology, New Delhi

Abstract

The number of desk jobs have increased phenomenally with the evolution of computers, especially in the last few decades. A modern day worker who is indulged into desk job spends nearly one third of her daily time sitting at work. Excessive sitting has been identified as a major health-risk factor and can lead to several health problems like diabetes, heart attack, cancer, increased mortality etc. Researchers have found out that sitting and physical activity are two separate behaviors and even regular exercising cannot negate the adverse affects of excessive sitting. Taking regular breaks from sitting has been identified as the most effective remedy to curb down the harmful effects of sitting. This justifies the need of a ubiquitous system which tracks user activity and sitting time of a user and provide her with appropriate alerts and notifications to guide her activity for a better and healthy lifestyle.

Existing solutions include costly wearable devices and battery draining smartphone applications which are not prefered by the users. There also exists a category of desktop applications which alert users to take breaks when they are working on workstations, but the coverage of such systems is limited to the time spent by user on workstation only. We propose and develop a system StandUp which leverages on existing workplace infrastructure to provide sensing hints to detect user's presence which are complemented with the activity monitoring capabilities of a smartphone to track user's activity and sitting time throughout the day. It also issues alerts and notifications to guide the user. StandUp system comprises three main components namely a mobile application, a desktop application and a cloud service which acts as a intermediary and also aggregates the activity related data coming from both desktop and mobile application.

We developed a fully functional prototype system which includes desktop application build on top of .NET framework for workstations running Windows OS, native mobile application for Android smartphones and a django based cloud service which runs on top of an Apache server. We also give an elementary evaluation of the system and present some interesting statistics and activity patterns from the data collected by our system for nearly four weeks among few users. We also record the compliance of the notifications issued from the system by the users. We also evaluate our triggered sensing approach and present the daily tracking coverage of the system for a single user over a span of nearly two weeks. We compare the power characteristics of our mobile application with a well known activity tracking application available on Google Play Store. We plan to further improve the system and aim to build a more robust and effective system, and deploy it on a larger scale , which we scope as our future work.

Acknowledgments

I would like to thank Dr. Vinayak Naik for his invaluable support and guidance. He has always bestowed his faith in me and has been a continuous source of motivation and inspiration. I also take this opportunity to thank Dr. Kuldeep Yadav from Xerox Research Centre India for mentoring and guiding me throughout this research work. Special mention for the people at Xerox Research Centre India who helped and participated at every stage of the project.

Abhishek Kumar

Contents

List of Figures

List of Tables

Chapter 1

Introduction

With the proliferation of computers and information technology in the modern day scenario, the number of desk jobs have increased at a phenomenal rate, especially in the last two decades. In the United States, less than 20% of private sector jobs have moderate levels of physical activity, decreasing by nearly 30% compared to the early 60s [25]. Nearly 4 out of 5 people have desk jobs in the United Kingdom. A survey done in United States [23] reports that a typical American spends 7.5 hours sitting at work, 8 hours sleeping, 4.5 hours watching television or at home computer including leisure time, 1 hour eating and only 3 hours active or standing, i.e. sedentary for 21 hours out of 24 hours daily. There are many large scale studies which show that prolonged sitting is a high risk factor for health problems such as diabetes, cancer, heart attack and stroke and increased mortality, among others. For instance, [24] reports that adults reporting moderate-to-high amounts of sitting time (four hours or more) had significantly higher cardio-metabolic risks compared to those adults in the lowest category of sitting time (less than three hours). Another long-period study suggests that sitting for excessive hours can increase the risk of prostate or breast cancer. An analysis of existing research by American Institute for Cancer Research suggests that nearly 49,000 cases of breast cancer and almost 43,000 cases of colon cancer might be avoided if people simply spend less time being sedentary [18]. It has been found that the production of enzymes which burn fat declines by as much as 90% after one hour of sitting interval [20]. Also, excessive sitting results in depression, lower life expectancies, larger waist circumference and slower metabolism and over a lifetime, the harmful effects of sitting keep increasing.

It has been found out that even exercising or running regularly cannot inhibit the health related risks imposed by prolonged sitting [19]. A study done at Australia [22] provides evidence of the fact that short breaks from sitting can tackle most of the health related risks as discussed above. Taking regular activity breaks from sitting is one of the most recommended remedies. The above listed facts and findings strengthens the need of system or methodology to continuously track user activity and provide alert and notifications to guide the user accordingly.

One of the prevalent solutions to track user activity and issue alerts is the use of wearable devices. There are many such products available in the market like FitBit [1], Nike Fuel Band

[2], Jawbone UP [3] etc., most of them are very costly. Also for the users, it is more like an overhead to carry, wear and maintain an extra device. It has been found out that the users don't prefer such devices, more than half of U.S. consumers who owned an activity tracker stopped using them after some time [21]. Yet another solution which has gained popularity especially in countries like United States and Canada, is the use of Sit-Stand workstations, which are again not cost-friendly. Also researchers have found out that use of such desks imposes the risk of musculoskeletal injuries [26]. Also the use of sit-stand stations rapidly declines and it is reported that most of the users generally start sitting only after 1 month of use [17]. The above solutions require use of additional hardware and machinery to handle the problem of prolonged sitting. Also there exists a number of desktop applications like Workrave [10], Breaker [11] (Windows platform), Timeout [12] (Mac) etc. which issue alerts to the users to take breaks at regular and configurable intervals when the user is working on the workstation. The coverage of such systems are limited to the time spent by the users on workstation only and it is not feasible for such systems to track any physical activity during the break intervals. Similarly, there are a few Android and iOS apps such as MotionX 24/7 [13], Moves [14] etc. which use accelerometer sensors to track a person's activity. However, mobile-based apps also have limited coverage because many users tend to put their mobile phones on desks in workplace environments which prevents the apps from getting the required data. Also, these apps sample accelerometer values continuously, which results in high energy consumption. Hence, there is a need for ubiquitous, energy-efficient, as well as effective systems to track a user's activity in workplaces and provide personalized notifications.

This work includes proposal and design of a system StandUp which leverages on the users existing workplace environment and infrastructure to track their sitting and sedentary time especially during work hours, issue alerts and notifications to suggest them to take small breaks and track their physical activity as well. StandUp is based on a multi-modal sensing phenomenon in which the sensing hints from the user's desktop/laptop at their workplace is coupled with the sensing and activity tracking capabilities of the smartphone carried by the users to effectively and efficiently track the user's activity as well as inactivity. The StandUp comprises three main components namely Mobile Application, Desktop Application and Cloud Instance. Similar to the traditional and prevalent motion tracking applications, the StandUp mobile application uses the mobile sensors like accelerometer to track the user's activity. The desktop application uses the keyboard strokes, mouse events to detect that the user is working at his workstation. It also uses webcam capture and tries to detect the presence of the user in front of the workstation in case of missing keyboard strokes/mouse events for a specific interval of time. The cloud instance is designed to aggregate and store user's activity related data coming from the desktop and mobile application. It also acts as an interface between the mobile application and the desktop application to ensure that they work in an integrated and synchronized manner. It facilitates the triggered-sensing mechanism in which different sensors are triggered at appropriate time to minimize the energy consumption of the smartphone.

The main features of the StandUp system are listed below:

1. Multiple sensors in the workplace infrastructure (desktop, webcam, keyboard and mouse) are used in conjunction with mobile-based sensors to accurately track a user's activity, thereby enhancing the coverage of the activity monitoring system
2. Triggered-sensing based scheme to minimize redundant observations, thus minimizing energy consumption of battery-constrained mobile phone sensors
3. Personalized alerts to the users whenever they sit for a longer time
4. User-specific and rich visualization of activity patterns on both desktop and mobile phones

A prototype for the above proposed StandUp system has been implemented. The StandUp mobile application has been built for Android platform and supports Android (3.0W+) devices equipped with accelerometer. The desktop application is built on Microsoft .NET framework for Windows desktops/laptops. The cloud instance has been implemented using Django and runs on an Apache server.

We also carried out a controlled deployment of the prototype system among three workplace users for nearly four weeks. We present some interesting activity patterns of these users and also record the compliance of system-issued notifications by them to measure the effectiveness of the system. We evaluated the triggered-sensing approach of the proposed system and present the triggering-related statistics and the activity tracking coverage of the system for nearly two weeks. We also give the battery drain characteristics of a smartphone with StandUp mobile application running in triggered sensing mode and compare it with a popular activity tracking application available on Google Play.

Chapter 2

Prior Art and Related Work

The advancement of the concept of ubiquitous and pervasive computing along with the enhancement in the sensing capabilities of computerized devices has led to the evolvement of many healthcare and fitness applications. Physical Activity Recognition is one of the key application areas which has been into great focus in recent times. Wearable devices have emerged as a key tool to track and guide users physical activity. There are many commercially available Wearable devices like FitBit [1], Nike Fuel Band [2], Jawbone UP [3] etc. These devices have embedded accelerometers and inertial sensors to monitor and track users activity. Many of these devices interact with a smartphone over local bluetooth radio for storage, communication with the cloud and data visualization. These devices are generally very costly, for instance Nike Fuel Band is priced at $99 [15]. Also it has been observed in a study conducted in United States that more than 50% of the consumers who bought such activity tracking wearable devices stopped using them after some time [21].

Smartphones with their enhanced sensing capabilities have been used widely for user activity recognition. . Kwapisz et. al. [27] proposed and developed a system for android devices which could recognize simple physical activities like walking, jogging, sitting, standing etc. Activity Recognition systems for Nokia Devices have been designed and implemented as well [28] [29] . Hache et. al. [30] used an accelerometer integrated with a smartphone for detecting changes in the state of the subject caused by starting/stopping and postural changes in activities. Khan et. al. [31] used kernel discriminant analysis while Zhang et. al. [32] used SVM for recognizing physical activities using smartphones.

There is no dearth of commercially available activity-tracking smartphone applications on Android and iPhone app stores. Some of the most popular activity tracking applications are MotionX 24/7 [13], Moves [14], RunKeeper [4], RunTastic [5] etc. Such smartphone applications which continuously use and sample sensors like accelerometer and gyroscope for activity recognition are not battery friendly. Yet another limitation of using a smartphone-only dependent activity tracking system is the coverage period of tracking, especially in workplace environments. In workplace environments, some people generally have the tendency to keep their phones on office desks, or on charging which prevents these applications to gather required information to recognize user's activity.

There exists a number of desktop applications which reminds the user to take breaks at regular intervals. For instance EyeLeo [6] dims or disables the screen after a long interval of working time. WorkRave [10] is a highly configurable break reminding tool available for Windows and Linux platforms. PC WorkBreak [7] is yet another tool which offers multi-type break reminders such as micro-break, stretch, eye exercises and walk, based on user's PC usage model. Most of these tools do not differentiate between system turned on and user actually sitting. Also coverage of such systems are limited to the time spent by the users on workstation only and it is not feasible for such systems to track any physical activity during the break intervals. Similarly, there are some smartphone applications like StandApp [8], BreakTime [9] which reminds user to take breaks at configurable intervals of time.

Chapter 3

System Design

StandUp is designed with a focus that the existing infrastructure available in the end user's environment can be used effectively in order to track the user's activity as well as inactivity. In modern day scenario, it won't be an exaggerated assumption to perceive that people indulged in desk jobs possess a smartphone and a desktop/laptop on which they work. These two smart computing devices equipped with their associated capabilities are the two key foundations which helped us realize the aim of designing and implementing the architecture of an effective and ubiquitous system for Physical Activity Monitoring and Notifications using the prevalent infrastructure in Workplace Environments. Figure 3.1 below gives a broad view of the system.

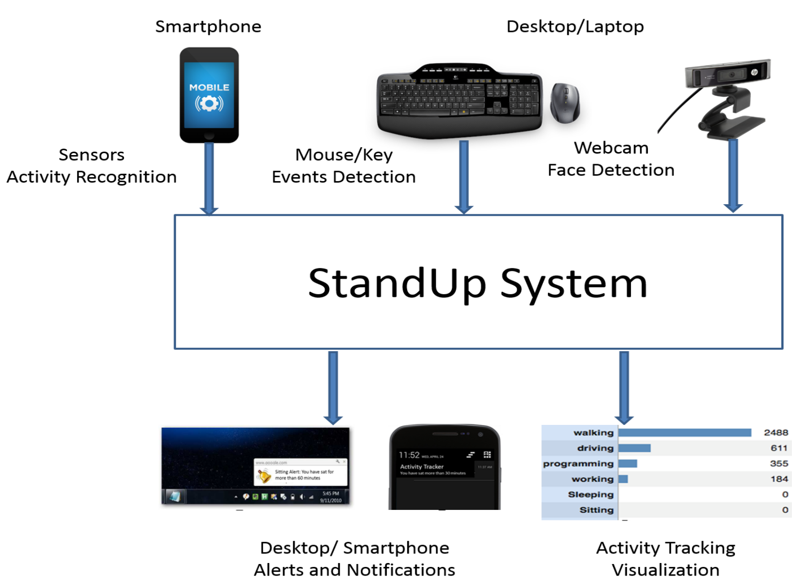

Figure 3.1: StandUp System basic design

StandUp is based on a multi-modal sensing mechanism. The system has been designed with two main components which are responsible for tracking the user's activity which are the desktop/laptop and the smartphone, ensuring maximum coverage especially in workplace environments. Smartphones nowadays are equipped with multiple sensors like accelerometer, gyroscope, proximity sensor etc. which can be used to detect user's activity with precision. StandUp uses state-of-art activity recognition modules to detect user's activity. The user activities are classified mainly as still, on-foot, on-bike, in-vehicle etc. We also use accelerometer readings to detect walking and make a count of steps whenever the activity recognized is on-foot. These sensing services run as background services on the smartphone and is complemented by an Activity Dashboard which allows user to see the current activity as well as previous activity track record. All the activity related data is cached locally on the mobile-phone and also stored at the cloud. Whenever the user is detected still for more than a threshold time (which can be customized), alert is issued to the user encouraging him to stand up and move. All these services and features are bundled as a mobile application.

On the desktop-end we use mouse and key events to detect the user working. A background service continuously monitors the keyboard and mouse events to log user's working period. There is a possibility of a case in which the user watches a video or reads a long document and thus do not use keyboard or mouse while still being sitting in front of the workstation. To handle such a case, the background opportunistically switches on the webcam after a fixed interval of time since the last keyboard/mouse event. The webcam capture is analyzed in real time to detect the face of the user. If the user is captured sitting in front of the workstation then the system marks her working, or else after trying detecting user's face for a specified period of time the system marks the user away. The webcam capture and face detection feature is an additional as well as optional functionality, thus making the system compatible with majority of systems irrespective of availability of a webcam. Similar to the smartphone application, desktop application also have a UI component to visualize activity record, the data is cached locally as well as synced on cloud. The desktop application also alerts the user in case user is detected working more than a threshold time (customizable).

The StandUp applications on mobile and desktop are designed to work as standalone applications as well as in an integrated manner. StandUp system can run in the following four modes of operation:

1. **Mobile phone only mode:** In this mode, the user just has the StandUp mobile application running on her smartphone. The activity recognition service runs throughout the day to detect and log user's activity. The user also has the flexibility to specify a fixed period of time-interval for which the user's activity is to be tracked, for instance the user can instruct the system not to track her activity during the night time, say from 2200 hours to 0600 hours. In this mode an active Internet connection is not required for the system to work, as the activity related data is locally cached on the mobile phone and then can be synced with the cloud when an Internet connection is available, as per the user specified configuration. The user receives alerts on her smartphone only. This mode of operation which relies only on the smartphone to detect the user's activity is subject to some limitations. Firstly it is not battery-friendly, as the sensors and the activity recognition modules continuously run and drain battery significantly. Yet another limitation is the limited coverage of the system due to insufficient collection of required data especially

in workplace environments where people tend to place their phone on desks.

2. **Desktop only mode:** In this mode, user has the StandUp desktop application installed and running on her workstation. This mode of operation can classify user's activity as working and away. Similar to the Mobile phone only mode, an active Internet connection is not required for the system to work, as the activity related data is cached locally on the workstation and is uploaded opportunistically to the cloud as per the user specified configuration. In this mode the StandUp is unable to detect any physical activity of the user and can only track the user working when she is available on her workstation. The alerts about excessive sitting and working are issued to the user on the desktop only.

3. **Dual Sensing Mode:** Dual Sensing mode can be perceived as the union of the Mobile phone only mode and Desktop only mode. In this mode both the mobile application and desktop application run throughout to detect and record the user activity from smartphone and working time from desktop respectively. Both the smartphone and desktop upload the activity related data periodically to the cloud. The cloud instance aggregates and processes this data and remove any existing overlapping or redundancy to record the aggregated activity information. This aggregated data is then synced back to the respective devices. The alerts about excessive sedentary behavior is issued on both smartphone and desktop.

4. **Triggered Sensing Mode:** In triggered-sensing mode, the user has both the StandUp desktop application and the StandUp Mobile application installed and running on her desktop and smartphone respectively. In this mode of operation the smartphone and the desktop with their own sensing capabilities work in an integrated, synchronized and effective manner to track the user's activity. In the Mobile only mode application drains the phone battery very quickly due to continuous sampling of activity sensors such as accelerometers and in the desktop mode no physical activity of the user can be accounted for. In the triggered sensing mode, system handles the limitations of the two other modes of operations, but requires Internet connectivity at all times to work in an ideal manner. In the triggered sensing mode desktop application based sensing is used to complement mobile based activity sensing and reduces energy consumption by dynamically switching on/off mobile sensors. At the same time the limitation of limited coverage is inhibited with the desktop application detecting user sitting while at work even if the mobile phone is placed on the desk.

   In a nutshell, StandUp employs a novel triggered sensing based technique to dynamically switch off or to reduce sampling frequency of mobile sensors whenever there is an opportunity to use infrastructure-based sensors i.e. the key/mouse events and webcam capture from desktop/laptop. The synchronization and the communication of the desktop application and mobile application running on the desktop and mobile application respectively is handled by the cloud instance. The user's activity related data is aggregated at the cloud and is available for disposal to both the mobile and the desktop application. The user can receive notifications on both the mobile as well as the desktop, as per the user's customized settings.

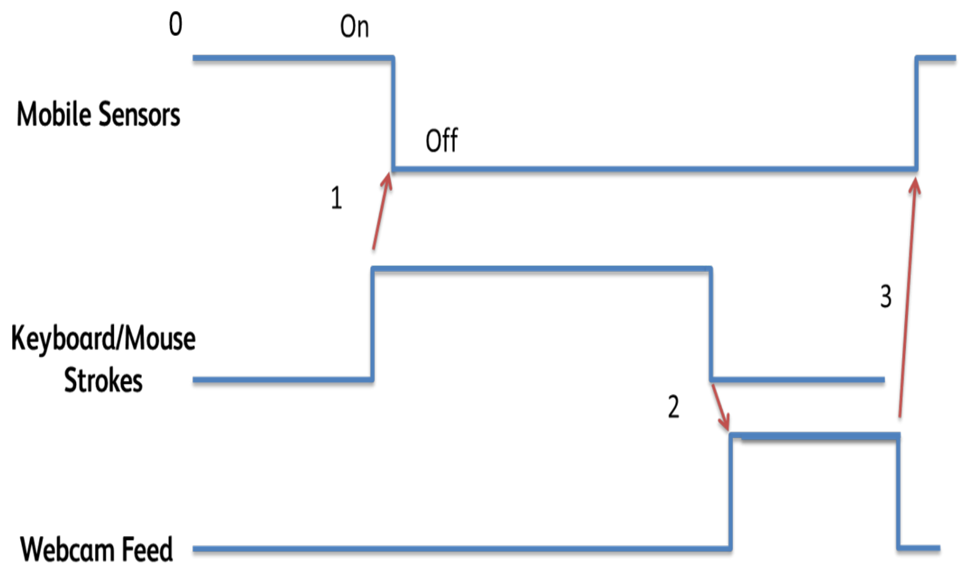

Figure 3.2: Triggered Sensing Mechanism

To demonstrate the working of StandUp system in the triggered sensing mode, let us take a look at the Figure 3.2. Red colored markers show different triggers to initiate different sensors. As an example, Alice is a user of the proposed system who walks to her office every day.

0- Initially while walking, StandUp mobile applications will keep mobile sensors ON to keep track of Alice's activities.

1- After, Alice reaches her workplace and starts typing on a keyboard or uses the mouse, a trigger is generated by desktop application to the cloud instance and it pushes a notification to switch off mobile sensors as shown by the first trigger.

2- Whenever there is an activity change detected using keyboard/mouse strokes i.e. when there is no activity for a certain time, the desktop application starts sampling the webcam feed and tries to detect user's face as represented by second trigger.

3- If the user's face is not detected by the desktop application, it tunnels a trigger to the mobile application via the cloud to switch on the sensors and again start tracking the user's activity.

The triggered-sensing approach ensures that there is minimum redundancy. It makes sure that when desktop is able to sense and track the user activity, the mobile should switch off its sensors and thus conserve battery. An average person sits for 6-8 hours in a day in his/her workplace environment, hence there is a significant interval of time which can be exploited to inhibit draining of battery. For the following sections, we will consider Triggered Sensing mode as the primary configuration in which StandUp system operates.

Chapter 4

Detailed Architecture

StandUp system comprises three main components namely StandUp Mobile Application, StandUp Desktop Application and Cloud Instance. Figure 4.1 shows the detailed architecture of StandUp system. We explain the main functionalities of each of the components briefly below.

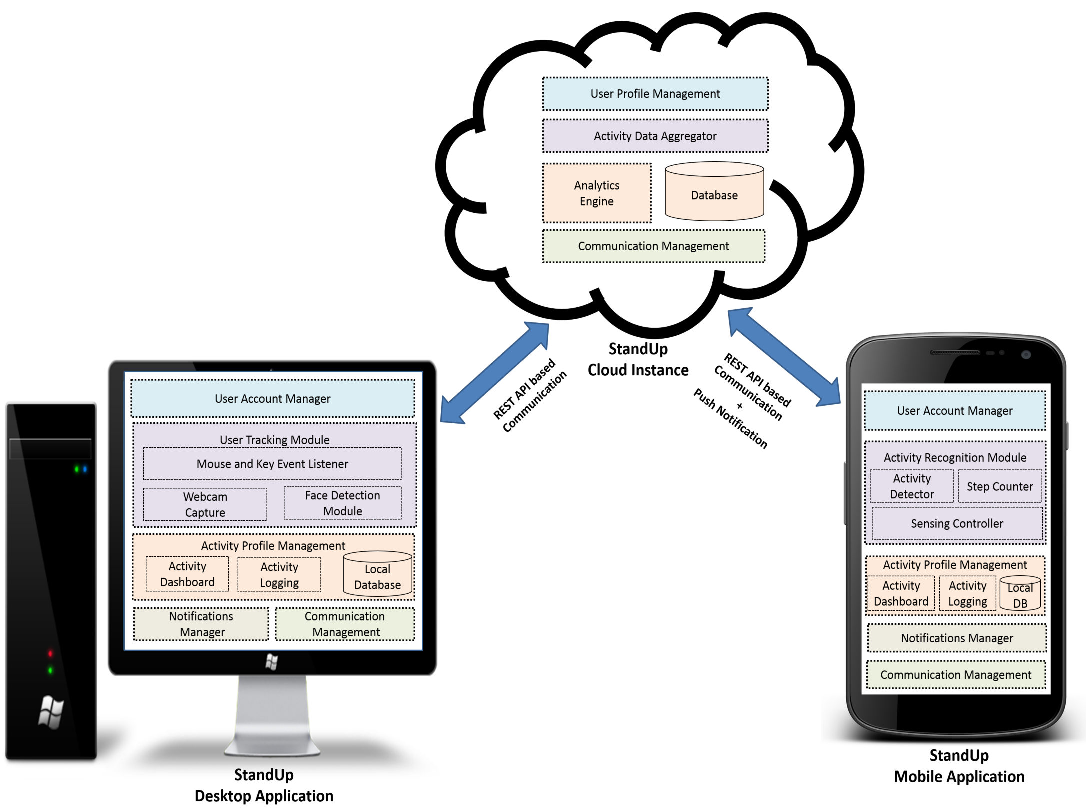

Figure 4.1: StandUp Architecture

4.1 StandUp Mobile Application

StandUp Mobile application is one of the key components of StandUp system which is solely responsible for tracking any physical activity of the user. Although desktop application can track if the user is sedentary or sitting, but without the mobile application system won't be able to keep a record of users other activities, especially when the user is not using a desktop/laptop. The main purpose of the mobile application is to track and report to the StandUp system about what the user is doing when he is not working on her workstation. The modern day smartphones are equipped by a multitude of sensors like accelerometer, gyroscope, proximity sensors etc. which can be used to detect the activity of the user. As discussed in Prior Art and Related Work, there has been a great amount of work in the literature as well as in the practical world which exploit the sensing capabilities of the smartphone to detect and track smartphone user's activity. Also, leading smartphone OS providers like Google, have released special APIs like Android Activity Recognition Module [16] which provides regular updates about the user activity using algorithms running on sensor's readings beneath. We build upon these techniques to track users activity on the smartphone.

Apart from tracking user's activity, the StandUp mobile application provides other important functionalities which include:

- User profile and User- customized configuration management,
- Activity Track record logging and visualization
- Synchronization and communication with cloud instance
- Dynamic Sensing (switch ON/OFF sensing triggered sensing)
- Alerts and Notifications in case of excessive sitting

We now take a look at the main modules of the StandUp Mobile application and how they facilitate the above mentioned functionalities.

- **User Account Manager:** User account manager module is responsible for user login and signup. The user can chose to sign up with an email-account or a social-networking site (eg. Facebook) account. The unique user-account details are registered at the cloud instance for future user-identification and synchronization with the desktop application. The user can also mention optional details like age, sex, height, weight, medical history which can be used for user-specific modeling at the cloud. Also this module enables the users to customize the system as per their choice, for instance users can specify timing interval during which sensing and tracking of activity is not to be done (eg. during night time), to enable/disable notifications, notification time period etc.

- **Activity Recognition Module:** This module is the heart of the mobile application and is responsible for detecting the activity of the user using sensors like accelerometer, gyroscope etc. Activity detector samples the sensors and processes the sensor data to detect user activity. Step counter uses the accelerometer data and is responsible for detecting and counting the number of steps whenever the user is detected walking or running. The activity recognition service runs in the background and can be probed for activity related data in real time. Sensing controller module facilitates the dynamic sensing, it can switch OFF/ON activity recognition service as per the user set configuration as well as in accordance to the trigger which the mobile application receives from the desktop application via the cloud instance to implement triggered sensing.

- **Activity Profile Management:** Activity Profile Management ensures that the activity related information from the activity recognition module is constantly probed for and logged locally into a local database for future use. The logging is equipped with proper time stamping, so that user's activities can be mapped to daily time-line. For instance, enough information is logged and stored to comprehend that the user walked 600 steps in 5 minutes from 5:00 PM to 5:05 PM on 26 February 2014. Also the user activity related data from the desktop which is synced and merged with the user activity related data from the mobile phone is handled by this module. This module also provides an Activity Dashboard which is used to display the current activity as well as historical activity track record to the user.

- **Notifications Manager:** This module facilitates the feature of alerting the user and suggesting them to stand up and move, whenever the user is detected to be sedentary or sitting for a long period of time. The threshold time can be customized as per the system configuration. The timestamps of the notifications are logged as well, in order to measure the user's compliance of the notification, to take an account of the fact that whether the user moved or not when she was suggested to. The notifications from the desktop tunneled via the cloud to the mobile application can also be displayed as per the user-defined settings and configuration.

- **Communication Management :** The mobile application is interfaced to the cloud instance via the Communication Management module. There are two modes of communication in which this module communicates with the cloud instance, firstly the mobile initiated REST API call to the cloud and secondly asynchronous push notifications from the cloud instance. The module uses the REST APIs exposed by the cloud instance to establish communication with it for purposes like registration, syncing data etc. Also this module enables the system to receive asynchronous messages from the desktop tunneled via the cloud. These messages can be excessive sitting alerts or the triggered-sensing requests, the module intercepts such messages and forward them to the Notification Manager or the Sensing Controller respectively.

4.2 StandUp Desktop Application

StandUp Desktop Application is the other building block of the StandUp system which tracks the users at their workplace. The basic assumption that we use for detecting the sitting time of a user is that the user is expected to be seated while working or present in front of the workstation. This assumption is based on the fact that standing desks are not very popular, especially in India and generally sitting type desks are present at workplaces. Although the desktop/laptop are not equipped with any specialized sensors, but the existing features like keyboard, mouse, webcam etc. can be used as sensing hints to detect that the user is working on the workstation and assumed to be sedentary or sitting. The desktop application monitors keyboard/mouse events to ensure that the user is working on her workstation. In case of absence of keyboard/mouse events for a small threshold (flexible) amount of time, the system opportunistically switches on the webcam (if available) to sample the webcam feed. The webcam feed is processed onto in real time to detect the user's face in front of the workstation. This secondary check using webcam handles cases like user reading a long document or watching a video and not using keyboard/mouse but still sitting in front of the workstation. If the user is not detected, the system can mark the user away and trigger sensing ON in the mobile application.

Similar to the StandUp Mobile Application, the desktop applications provides a set of functionalities apart from tracking the user sitting or sedentary in front of the workstation. These functionalities are mentioned below:

- User profile and User- customized configuration management
- Activity Track record logging and visualization
- Synchronization and communication with cloud instance
- Trigger sensing ON/OFF on mobile
- Alerts and Notifications in case of excessive sitting

Let us now take a look at the various modules of the desktop application which leads to enabling of the features listed above.

- **User Account Manager:**User Account Manager enables the user to login and sign up to the StandUp system. The user has the flexibility to login with an already created and configured account, created on mobile application previously, or the user can opt for creation of a new account. Similar to the mobile application account registration, in case of new account creation the unique user-account details are registered at the cloud instance for future user-identification and synchronization with the mobile application. Also other optional details like age, sex, height, weight, medical history etc. can also be fed into the system using desktop application as well. This module is also responsible for configuring user-specific settings for the desktop application like to enable/disable notifications, notification time period, working threshold period etc.

- **User Tracking Module:** User Tracking Module is the key component of the desktop application which is responsible to detect the presence of the user in front of the workstation. The Mouse and Key Event Listener service runs in background and is registered to listen and get informed about any mouse and key event. The User Tracking Module periodically monitors the mouse and key events, to detect user working. When the User Tracking Module detects that there has been no mouse or key events for some threshold period of time, the User Tracking Module initiates a secondary check to verify user's presence in front of workstation, by triggering the Webcam Capture module. This threshold parameter can be customized. The Webcam capture module switches on the webcam and forwards the webcam feed to the Face Detection Module. The Face Detection Module runs computer vision algorithms on the webcam feed in real time to detect the users face and report users presence to the User Tracking Module. The secondary check using webcam capture and face detection is optional and subject to availability of the webcam.

- **Activity Profile Management:** Similar to the mobile application, Activity Profile Management ensures that the activity related information from the User Tracking Module is constantly probed for and logged locally into a local database for future use. The logging is equipped with proper time stamping, so that user's activities can be mapped to daily time-line. For instance, enough information is logged to comprehend that the user was working/ detected in front of the workstation for 50 minutes from 4:00 PM to 4:50 PM on 26 February 2014. This module also handles the user activity related data from mobile application which is synced and merged with the user activity related data from desktop application. An Activity Dashboard is also included as UI component which is used to display the current activity as well as historical activity track record to the user.

- **Notifications Manager:** Whenever the user is detected to be working or sitting in front of the workstation for a long period of time, Notifications Manager issues alert to the user to stand up and move. The threshold time can be customized as per the system configuration. To monitor the compliance of user abiding to the notification, the timestamps of the notifications are logged. If the user wishes to, she can configure the desktop application to send notification to the mobile application via cloud, so that the notifications appear on both desktop and mobile.

- **Communication Management :** The desktop application communicates with the cloud instance via the Communication Management module. The Communication Management module uses the REST APIs exposed by the cloud instance to interface with it for communications like registration, data sync etc. It can also send triggering messages and notifications alert messages to the mobile application, which are tunneled through the cloud instance.

4.3 Cloud Instance

The Cloud Instance acts as an interface between StandUp Mobile Application and StandUp Desktop application. Mobile and desktop based applications report their observations to the cloud service periodically. StandUp Cloud instance aggregates these observations to build a day-based activity profile for a person and stores it into a database. The aggregated activity related user data is synced to desktop application and mobile application both. Further, it also uses the recorded personal information of the users i.e. age, weight, diseases, food habits, etc. when volunteered by the user; to do analysis and build risk models. This enables the system to provide personalized recommendations to the users. Further, the cloud instance helps in triggering different sensors at appropriate time.

Some of the important functionalities which are handled by cloud instance are listed below:

- User profile management and recording
- Activity data aggregation
- Synchronization of mobile and desktop applications
- Tunneling triggers and notifications from desktop to mobile
- Data analysis and building Health Risk Models

Some of the important modules of Cloud instance are briefly explained below.

- **User Profile Management:**User Profile Management Module is responsible for the user sign-up and registration for using the StandUp system. It handles registration and signup requests from both mobile application and desktop application. A user-profile identified by a unique email account ID or social networking ID, with the optional user provided details like age, sex, weight, medical history etc. are maintained by the module. The User Profile management ensures the link between the desktop and mobile application, by mapping the same user using the StandUp mobile application as well as the StandUp desktop application.
- **Activity Data Aggregator :** The StandUp system relies on two sources to obtain user activity related data, which are from the desktop application and from the mobile application. Both the application sends the collected activity data of user to the cloud. The data from these two sources is aggregated by Activity Data Aggregator to obtain an aggregated and more precise activity profile. Data Aggregator also removes redundancies, if any exist. The aggregated activity profile data is stored in a database. The mobile application and desktop application can sync their local databases with the cloud database.
- **Analytics Engine :** In cloud instance, where data of multiple users are available, Analytics Engine can build statistical models or long term study of the effects of sitting on

health. This system can thus be an invaluable source of information for building risk models for lifestyle diseases such as heart disease, hypertension and diabetes. The voluntary information from the user can include age, gender, sex, medical History, family medical history etc. coupled with activity pattern of the user available in the cloud, to build such models. Using these models personalized suggestions can be made to the user.

- **Communication Management :** Cloud Instance can be considered as the central node of the StandUp system. The StandUp mobile application as well as the StandUp desktop application needs to communicate with the cloud instance. The communication aspect of the Cloud instance is handled by the Communication management module. The module exposes REST apis which the mobile and desktop application can leverage on for sending data across. Also the Communication management handles the tunneling of asynchronous trigger request, or alert/notification message from desktop to mobile. It uses push notification mechanism to send such asynchronous messages to the mobile application.

Chapter 5

Implementation

We have developed a fully functional prototype for the proposed system. The prototype system is inclusive of a mobile application which runs on Android mobile devices, a desktop application which runs on Windows desktop/laptop platforms and a Cloud service based upon Django/Apache Web Framework running on Ubuntu based cloud server. In the following subsections we describe the implementation details of the three main components of the StandUp system.

5.1 Mobile Application

We have built a prototype mobile application for Android devices which is supported by all Android 3.0+ devices with accelerometer. The user has the option to signup using her Facebook account or she can alternatively choose to create a new account for the platform. The Activity Recognition Module is implemented as a constantly running background service. For Activity Recognition we use the inbuilt Activity Recognition Client API of the android. The Activity Recognition Client can distinguish the user's activity as Still, On Foot, On Bike or In Vehicle. When user is detected In Vehicle by the Android Activity Recognition Client our system considers and logs the user to be sedentary. The Android Activity Recognition Client is complemented by a pedometer service. Whenever the Android Activity Recognition Client detects the user to be On Foot our pedometer service is enabled which uses accelerometer or step detector sensor for counting and logging number of steps walked by the user. The pedometer service is switched off automatically whenever a transition from On Foot to some other user detected activity is encountered. For Android 4.4+ devices like Google Nexus 5 the pedometer service uses the inbuilt step detector sensor to detect steps. For other devices the pedometer service uses accelerometer readings to detect and log steps. For accelerometer based step detection we use a simple methodology to detect a step from accelerometer readings. Our pedometer service enables the accelerometer sensor and listens for any changes in the acceleration across X, Y and Z axes. To detect a step only the length of the vector (irrespective of device's orientation), L= sqrt(X2 +Y2 +Z2) is considered. The steps are counted when L moves up and down w.r.t the moving average. Continuous sampling of accelerometer/step detector information drains the phone's battery very quickly. Hence Activity Recognition Client complemented pedometer scheme saves on the battery consumption of the smartphone. For the visualization purposes we have a foreground activity which lets the user see her current detected activity as well as the detected user activity time line throughout the day. The Figure 5.1 shows a snapshot of the foreground visualization activity of our mobile application. Android sqllite is used for local database. For enabling desktop triggered asynchronous messages we use Google Cloud Messaging.

Please note that Android Activity Recognition API is used as a blackbox system and studying the algorithms running behind for activity recognition is beyond the scope of this work. There has been a lot of literature work pertaining to recognition of activity using smartphones as mentioned in Chapter 2.

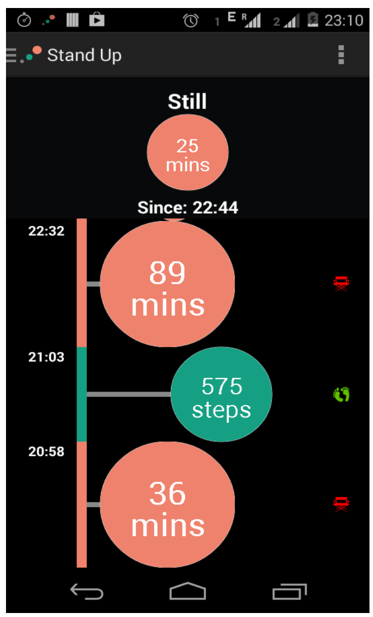

Figure 5.1: Snapshot of Mobile Application Visualization Activity

5.2 Desktop Application

We have implemented the desktop application as a Windows Form Application built upon Microsoft's .NET Framework 3.5 and supports desktops/laptops running Windows operating system with Microsoft .NET Framework 3.5+ installed. The user can login with the associated mobile application account or can create a new desktop-only account for the Standup System. Once installed and setup the desktop application is configured to run automatically whenever the system is rebooted or awakens after sleep. The key and mouse events are monitored by the application by registering lower- level Hooks which results in the execution of callback functions whenever a mouse or key event is encountered. The application tries to detect if webcamera is available or not. The desktop application webcam capture module and face detection module is built using Emgu which is an open source C-Sharp wrapper for OpenCV. For face detection the application uses HaarCascade Classifier which is scaled to detect a single and centered face. The local file system is used for storage purposes. The desktop application has two main windows forms which are used for visualization purposes. One is a small windows form which is positioned above the notification tray and shows the current status of user activity as shown in Figure 5.2. The other Windows form is popped up when the user double-clicks on the form located near the notifications tray. The user's current activity and her activity time-line for the day is displayed as shown in Figure 5.3.

Please note that the Face Detection module built using Emgu is vulnerable to conditions like low lighting, spectacles correction etc. The study and improvement of the underlying OpenCV algorithms is beyond the scope the of this work.

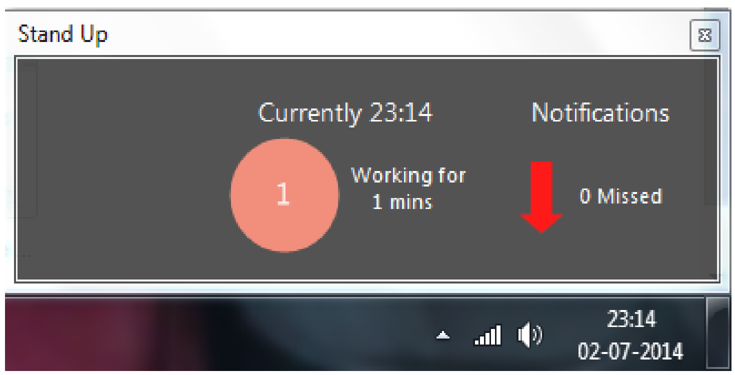

Figure 5.2: Snapshot of Desktop application's Windows Form Located near notifications tray

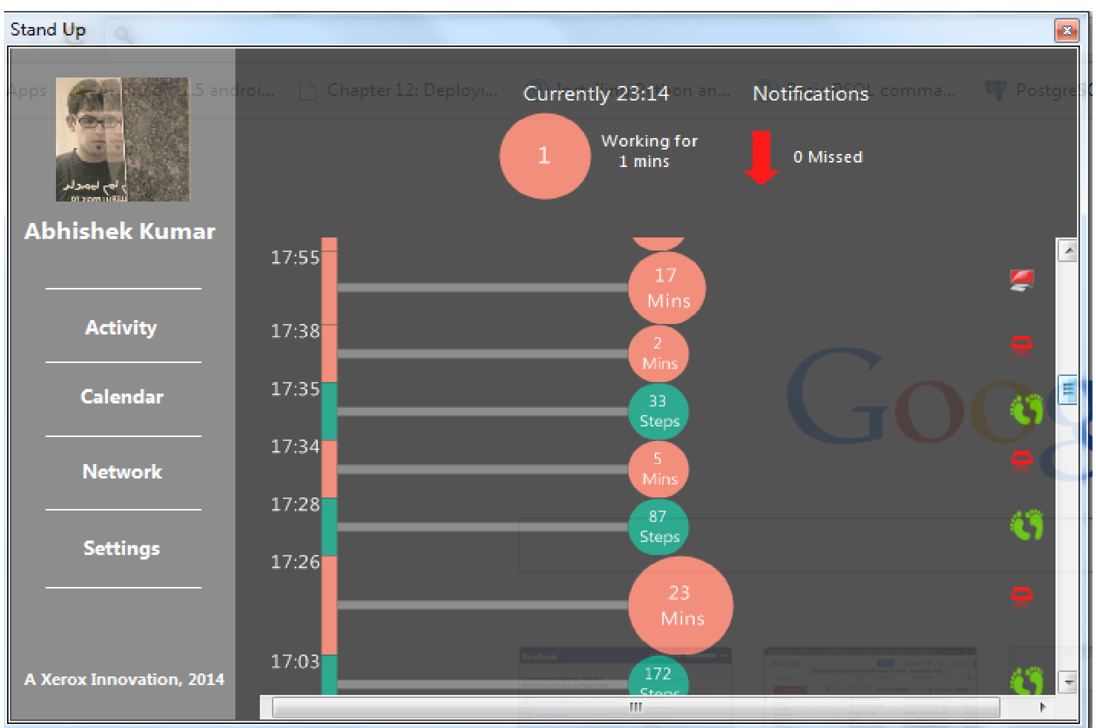

Figure 5.3: Snapshot of Desktop application's Windows Form with activity time-line

5.3 Cloud Instance

The Cloud Instance is implemented using Django Web Framework. The cloud instance exposes REST apis for communication. The Django service is mounted on an Apache server using mod-wsgi. The apache server runs on a ubuntu based cloud machine. MySql has been used for the database implementation which is modified and updated using the Django's model framework. The cloud application uses Google Cloud Messaging API for tunneling asynchronous messages to the mobile application.

5.4 Triggered Sensing Demonstration

In this section we will demonstrate the working of triggered sensing mechanism of our built prototype system. The following scenario describes how system behaves while in triggered sensing mode.

- **Step 1:** Initially the user has not switched on her workstation, Figure 5.4 shows the snapshot of the mobile application. The user is detected to be still.

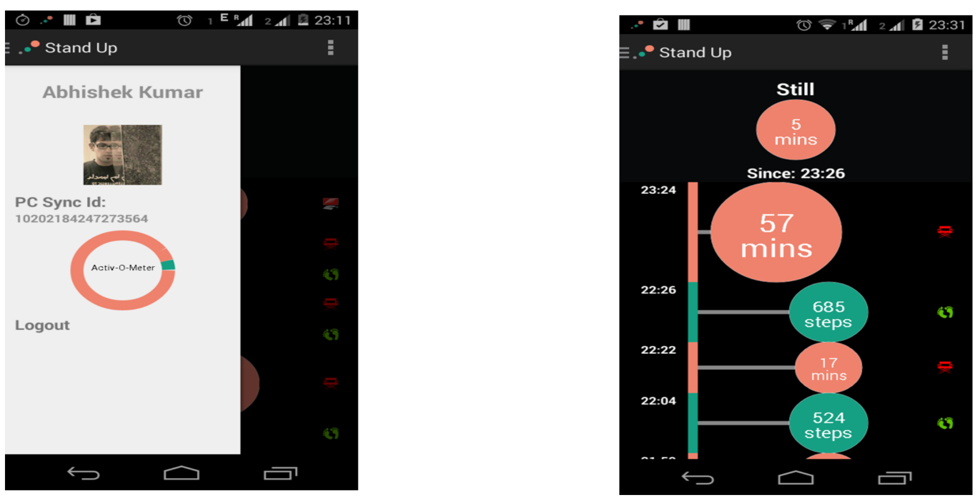

Figure 5.4: Step1: User is still, workstation switched off

- **Step 2:** The user switches on her workstation, the StandUp desktop is initiated and relays a message to mobile application triggering off the sensors on smartphone and marks the user as working . Figure 5.5 shows the snapshot of the mobile application and desktop application, both synced to display user working.

- **Step 3:** The user is active on mouse and keyboard on her workstation, the smartphone sensors are switched off . Figure 5.6 shows the snapshots of the mobile application and desktop application, both synced to display user working.

- **Step 4:** The user turns inactive on mouse and keyboard on her workstation, the webcam is switched on to detect user which detects the user face . Smartphone sensors remain

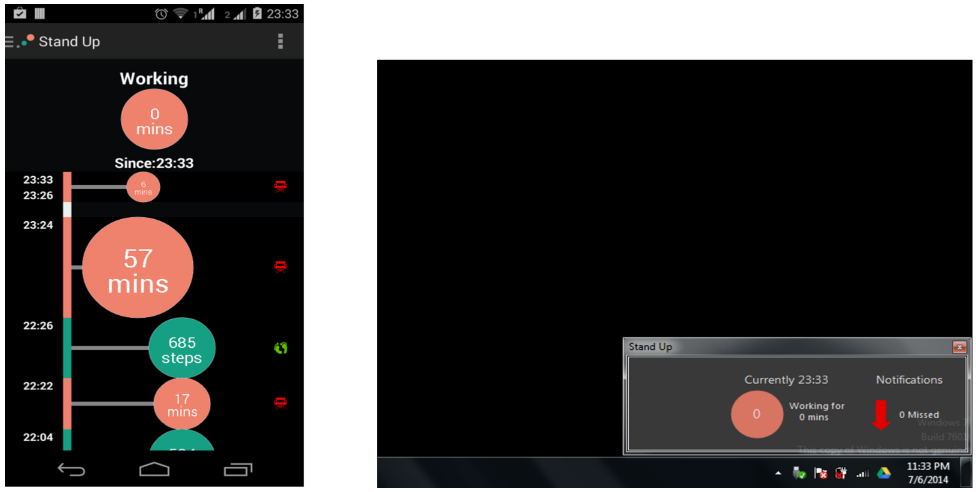

Figure 5.5: Step2: Workstation switched on

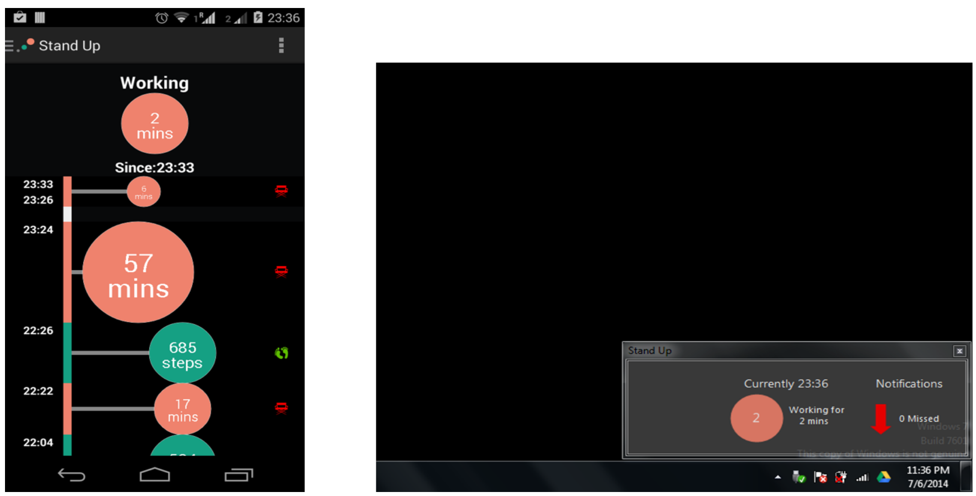

Figure 5.6: Step3: User active on mouse and keyboard, Mobile phone sensors off

switched off. Figure 5.7 shows the snapshot of the mobile application and desktop application (with webcam turned on and detecting user face), both synced to display user working.

- **Step 5:** The user is inactive on mouse and keyboard on her workstation, the webcam unable to detects the user. The desktop triggers a request to the mobile application to start sensing which detects the user walking. Figure 5.8 shows the snapshot of the mobile application detecting the user on foot and desktop application showing the user away.

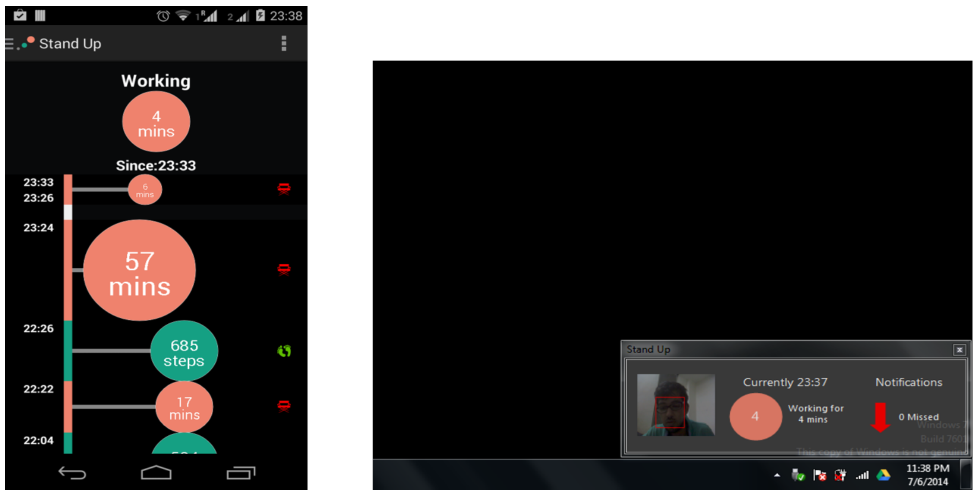

Figure 5.7: Step4: User inactive on mouse and keyboard,webcam turned on. Mobile phone sensors off

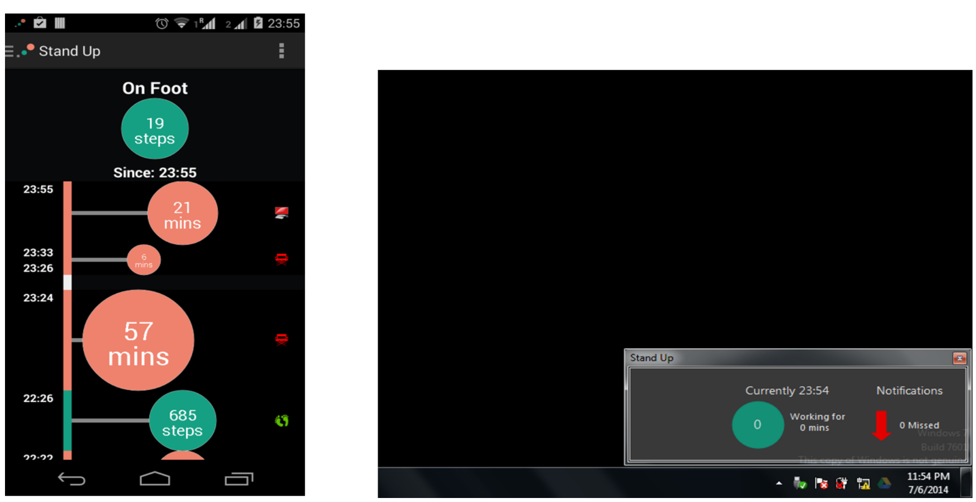

Figure 5.8: Step5: The user not detected on workstation, Smartphone sensors on

Chapter 6

Data Collection and Analysis

For the proof-of-concept and elementary evaluation of our proposed system, we carried out a pilot deployment of our prototype in dual sensing mode system for nearly four weeks among three workplace users. To evaluate the working and effectiveness of the triggered sensing approach in the real world scenario, we experimented the system in triggered sensing mode for nearly two weeks in real workplace environment and present the activity coverage-related statistics. We also monitored the battery drain statistics of the StandUp Mobile application when operating in triggered sensing mode and compare it with a popular activity tracking application available on Google Play. The details of the above mentioned deployment and experiment are given in the following subsections.

6.1 Dual Sensing Mode Deployment

We installed the StandUp mobile application and StandUp desktop application among a few users working in workplace environment. The system was configured to run in dual sensing mode. We collected the data for nearly four weeks and present the activity patterns of the three users who ran the applications continuously on their desktop and mobile over the period of deployment.We study the daily activity patterns of the users. The user daily activity is broadly categorized into three categories namely Still, Working (i.e. Sitting on Workstation) and On-Foot. The information about the daily Still and On-Foot time comes from the smartphone based sensing while the Working timelines come from the desktop application.

Figure 6.1, Figure 6.2, Figure 6.3 show the activity patterns of the three users during the deployment period. It can be seen that people are sedentary for majority of time and active only for very small duration of time everyday. Figure 6.4 display the number of steps walked by each of the user. The average number of steps waked by the first, second and third user are 6892, 5206 and 5223 respectively.

Table 6.1 and Table 6.2 summarize the activity patterns of the users across weekday and weekends. Different people have different behaviors, some are more active on weekends than weekdays

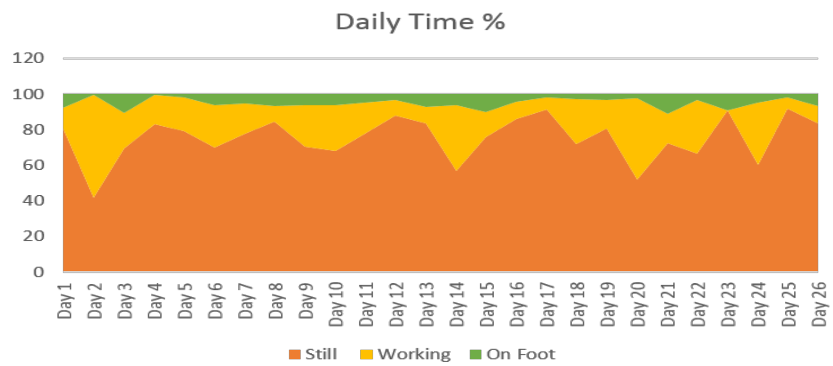

Figure 6.1: Day-wise Activity Distribution for User 1

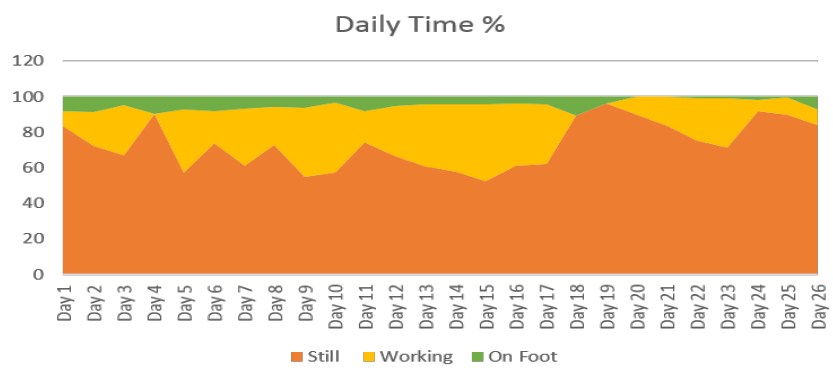

Figure 6.2: Day-wise Activity Distribution for User 2

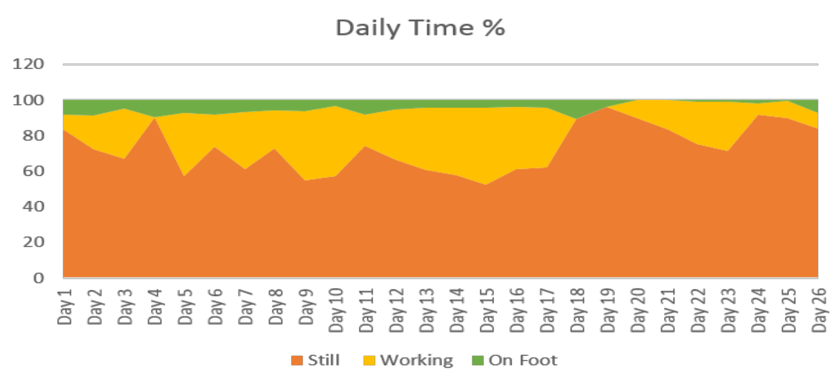

Figure 6.3: Day-wise Activity Distribution for User 3

User	Still (%)	Still (%) Weekday	Still (%) Weekend	Working (%)	Working (%) Weekday	Working (%) Weekend	On Foot (%)	On Foot (%) Weekday	On Foot (%) Weekend
User 1	75.11	72.09	81.91	19.57	21.68	14.81	5.31	6.21	3.27
User 2	72.98	69.41	81.01	21.96	26.2	12.42	5.05	4.38	6.56
User 3	76.29	73.91	81.63	19.91	22.43	14.24	3.79	3.64	4.12

Table 6.1: Average Daily Activity Distribution

and some more sedentary on weekends.

We also kept a record of the notifications which were issued to the users by the StandUp

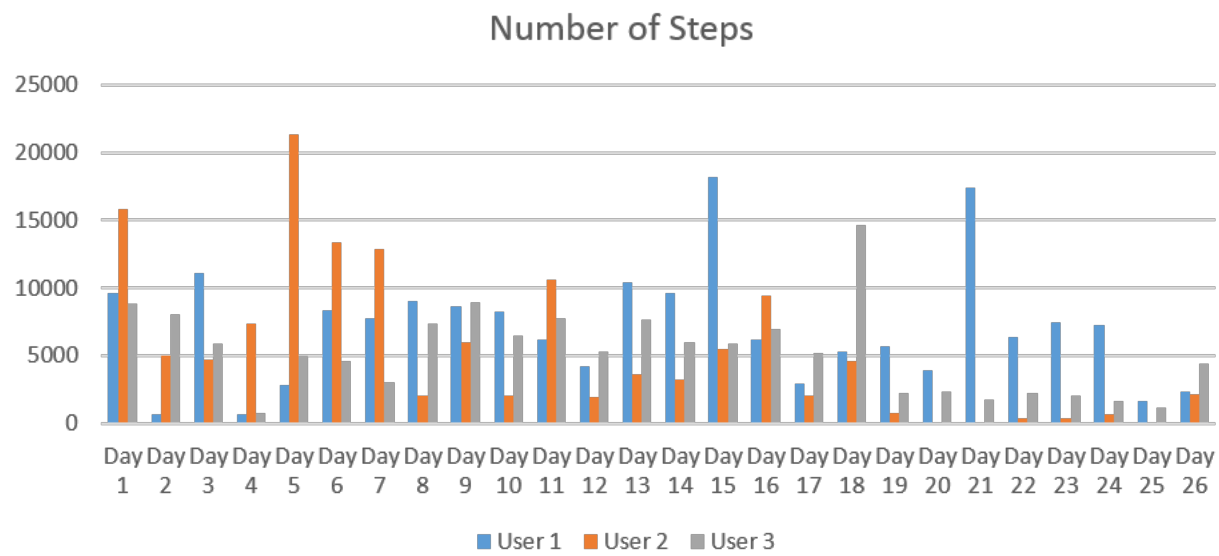

Figure 6.4: Day-wise Number of Steps

User	Average No Of Steps	Average No Of Steps Weekday	Average No Of Steps Weekend
User 1	6892	8493	3583
User 2	5206	6082	4816
User 3	5223	5144	5257

Table 6.2: Average Number of Steps walked

system and their respective compliance. Table 6.3 gives the details about the compliance of the notification by the users. The users were issued notifications based on a static threshold limit of being sedentary or working for 40 minutes. One of the users complied to atleast half of the notifications while others complied to nearly one-third of the notifications issued.

User	Number of Notifications Issued	Number of Notifications Missed	Compliance %
User 1	97	63	35.05154639
User 2	87	58	33.33333333
User 3	60	29	51.66666667

Table 6.3: Compliance to notifications

6.2 Triggered Sensing Mode Experiment

We did a preliminary evaluation of our proposed triggering approach by running the StandUp system configured to operate in triggered-sensing mode. We carried out the experiment in a workplace environment for nearly two weeks (10 working days). The workplace environment had continuous LAN and WLAN connectivity for the desktop/laptop but intermittent WiFi connectivity for smartphone and thus we relied on cellular network for smartphone's Internet connectivity. The issue with triggered-sensing mode is the dependency of Internet connectivity. Since the workplace environment had uninterrupted LAN connectivity for the desktop the triggers from the desktop were released on time , but the time they reached the smartphone was subject to the intermittent Internet connectivity due to average network conditions.

Figure 6.5 shows the coverage span of the StandUp each day. On an average StandUp system was able to track the activity for 97% of the daily time. Figure 6.6 display the day-wise time spent on workstation and the corresponding number of triggers from desktop to mobile made.It can be observed, that it is not necessary that more triggers will be raised if more time is spent on the workstation. Table 6.4 display the details about the delay which was encountered between the time desktop raised the trigger and the time at which smartphone received the trigger. In Table 6.4 $\mathcal{N}$ displays the number of triggers encountered on a particular day, while $\mathcal{T}_{max}(sec)$,$\mathcal{T}_{min}(sec)$ and $\mathcal{T}_{avg}(sec)$ give the maximum, minumum and average triggering delay period in seconds respectively. On an average the triggering delay was measured to be around 110 seconds. This is the delay encountered due to the intermittent WiFi connectivity and average cellular conditions prevalent at the workplace where the experiments were done. We can predict that the delay time with further reduce with better Internet connectivity and network conditions.

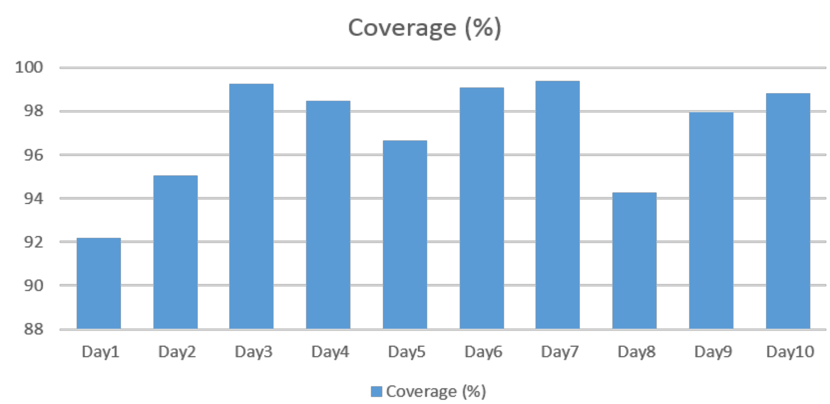

Figure 6.5: Activity Tracking Coverage % of StandUp in triggered sensing mode

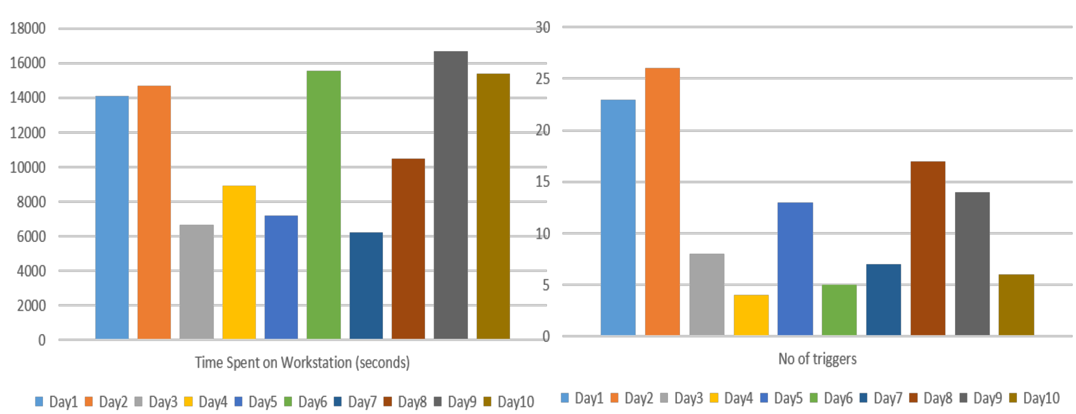

Figure 6.6: Time Spent on Workstation and Number of Triggers - Day-wise

Day	$\mathcal{N}$	$\mathcal{T}_{max}(sec)$	$\mathcal{T}_{min}(sec)$	$\mathcal{T}_{avg}(sec)$
Day1	23	1760	0	203.087
Day2	26	391	0	130.4615
Day3	8	235	1	62.75
Day4	4	594	27	245.5
Day5	13	500	43	126.3077
Day6	5	91	19	69.6
Day7	7	91	65	72.5714
Day8	17	203	0	38.7059
Day9	14	267	0	70.9286
Day10	6	171	0	89.6667

Table 6.4: Triggering Delay in StandUp triggered sensing mode

We also studied the battery drain statistics of the smartphone with StandUp mobile application running in triggered sensing mode. Figure 6.7 displays how the battery drains along with the activity detected by the StandUp system. As mentioned earlier , in triggered-sensing mode the mobile application switches off the sensing whenever the user is detected on the workstation. Hence the battery drain reduces while user is detected working. At the same time the mobile application switches on the accelerometer to count the number of steps whenever the user is detected to be on foot and hence it can be seen that the battery drain increases when user is detected on foot.

We also compared our StandUp mobile application with a popular activity tracking application available on Google Play store which uses accelerometer and GPS to track user's activity. Figure 6.8 display the Battery drain characteristics of the smartphone with the StandUp mobile app running compared to the Popular app running. It can be seen that the battery drains much faster in case of the popular application with respect to that of StandUp mobile application.

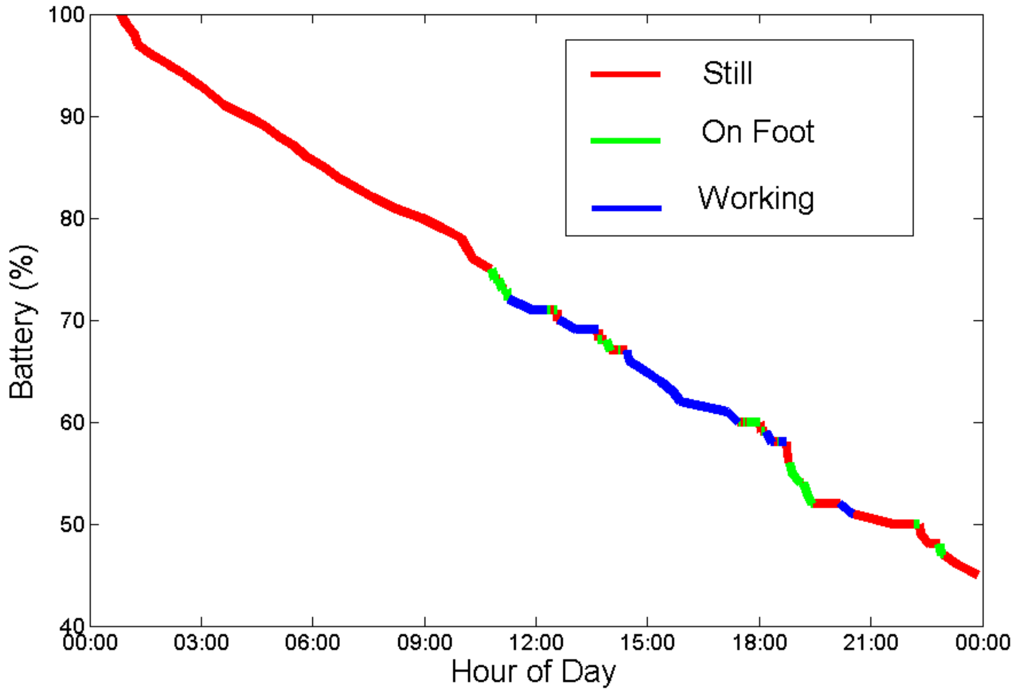

Figure 6.7: Battery Drain Characteristics: StandUp Mobile application in triggered sensing mode

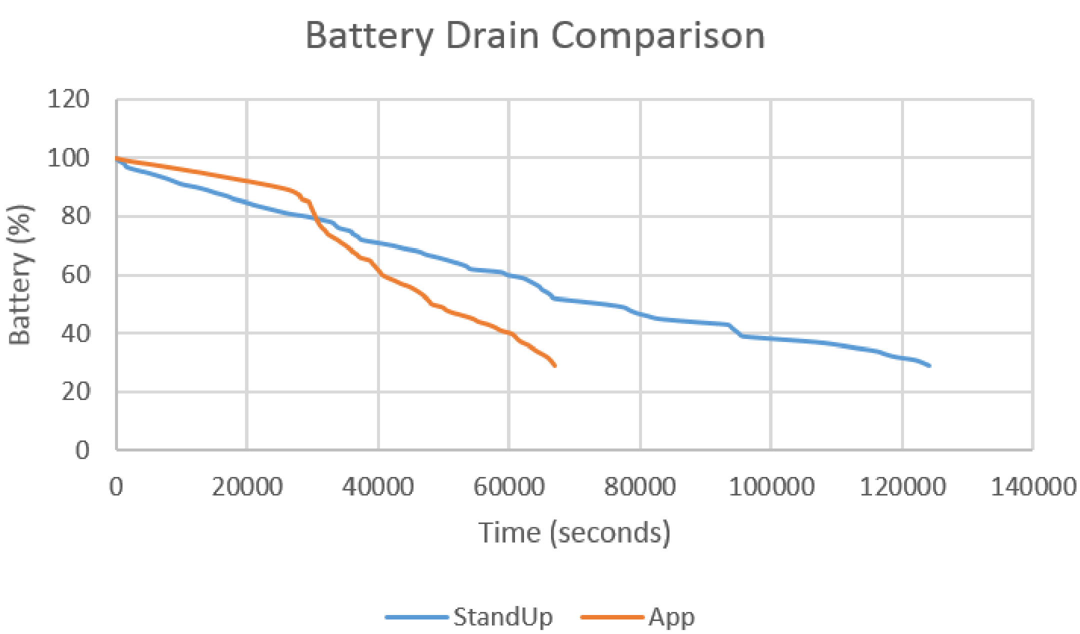

Figure 6.8: Battery Drain Comparison: StandUp Mobile application in triggered sensing mode vs Popular App using GPS and accelerometer

Chapter 7

Conclusion and Future Work

We design a system which can act as a useful remedy to curb down the harmful effects of excessive sitting especially in workplace environments in which people tend to have more desk jobs. We designed a multi-modal sensing system to track the user activity throughout the day. We leveraged the existing workplace infrastructure to track user's presence when at workplace. We used keyboard/mouse events to detect user working on workstation and therefore inferring user as seated. We also used webcam and face detection detect user seated in front of workstation and not using keyboard/mouse. The system also uses activity monitoring capabilities of accelerometer equipped smartphone to track user's activity.

The StandUp system is designed with three main components the desktop application, the mobile application and the cloud instance. The cloud instance is the heart of the system which stores and aggregates the activity related data coming from the desktop application and the mobile application. We described four major modes of operation of the system namely the desktop-only mode, the smartphone only mode ,the dual sensing mode and the triggered sensing mode. The triggered sensing mode is designed to make the system energy efficient as mobile phone sensors are switched off whenever the user is detected seated in front of the workstation. It also enhances the coverage span of tracking and tackles special cases like smartphone kept on tables while working etc. The system also issues alerts and notifications on both mobile and desktop suggesting users to take regular breaks.

We developed a fully functional prototype. On the desktop end we developed a Windows Form application on top of .NET frameworks which is compatible on majority of Windows OS. For smartphone we developed an android application which supports all Android 3.0+ devices equipped with accelerometer. The cloud instance runs on a Ubuntu cloud virtual machine which is running a Django-python based web service mounted on Apache server.

For the proof-of-concept we deployed the system configured in dual sensing mode in real workplace environment. We showed how a typical user is sedentary most of the time and active for a very short period of time. We were able to motivate the users to take a break and move in atleast one-third of the instances of excessive sedentary behavior. We also did experiment the

StandUp system in triggered sensing mode and were able to achieve nearly 97% of coverage even with average Internet connectivity conditions. Our mobile application is more battery friendly when compared to a popular activity tracking application.

StandUp is a novel framework which use the user's existing workplace environment and infrastructure to track their sitting and sedentary time especially during work hours and guide their physical activity. We built a prototype implementation of the system which can be enhanced and improved in many ways. We list down the areas on which our future work can be focused:

- A scalable deployment and evaluation of the system is required to study the effectiveness of the system in the real world.
- Integration of newly introduced and better performing activity recognition and step counting apis for smartphones like Google Fit.
- Include gamification to motivate the user
- Support to interact with wearable devices if users already possess one.
- Use if proximity and ligh sensors to detect if the user's smartphone is placed in the pocket or is on top of a table.
- Integration of medico-visual monitoring techniques to take an account of user's vitals like heart-rate, pulse etc. by capturing using webcam.
- Use of local communication interfaces like WiFi to support triggered sensing communication between desktop/laptop and smartphone. For instance, as long as the user is detected on the workstation (either by mouse/key strokes or webcam) the desktop/laptop can send regular heartbeat signals to the smartphone to indicate that the user is present on the workstation and the sensors should remain switched off. Such heartbeat signals can be send suing local communication interfaces like WiFi. As soon as the smartphone stop receiving these heartbeat signals it can be detected that the user is not detected on her workstation and sensors should be turned on to detect user activity on smartphone. This approach removes the dependency of internet availability for triggered sensing to work.

Bibliography

[1] FitBit
www.fitbit.com/

[2] Nike Fuel Band
www.nike.com/us/en_us/c/nikeplus-fuelband

[3] Jawbone
https://jawbone.com/

[4] The Runkeeper
http://runkeeper.com/

[5] Runtastic Pro
https://www.runtastic.com/

[6] EyeLeo
http://eyeleo.com/

[7] WorkBreak
http://www.trisunsoft.com/pc-work-break/

[8] StandApp
https://itunes.apple.com/us/app/standapp/id541403079?mt=8

[9] BreakTime
https://play.google.com/store/apps/details?id=uk.co.lufar.breaktime&hl=en

[10] Workrave
http://www.workrave.org/

[11] Breaker
http://davidevitelaru.com/software/breaker/

[12] Timeout
http://www.dejal.com/timeout/

[13] Motion 24X7
http://24-7.motionx.com/

[14] Moves
https://www.moves-app.com/

[15] Nike Fuel Band Price
http://store.nike.com/us/en_us/pd/fuelband-se/pid-924485/pgid-924484

[16] Android Activity Recognition Client
http://developer.android.com/training/location/activity-recognition.html

[17] http://ergo.human.cornell.edu/CUESitStand.html

[18] http://usatoday30.usatoday.com/news/health/medical/health/medical/cancer/story/2011-11-03/Prolonged-sitting-linked-to-breast-cancer-colon-cancer/51051928/1

[19] http://www.runnersworld.com/health/sitting-is-the-new-smoking-even-for-runners

[20] http://blogs.hbr.org/2013/01/sitting-is-the-smoking-of-our-generation/

[21] http://endeavourpartners.net/assets/Wearables-and-the-Science-\of-Human-Behavior-Change-EP4.pdf

[22] Breaks in Sedentary Time. Beneficial associations with metabolic risk http://care.diabetesjournals.org/content/31/4/661.abstract

[23] Ergotron JustStand Survey and Index Report - JustStand.org http://www.juststand.org/portals/3/literature/SurveyIndexReport.pdf

[24] Staiano AE1, Harrington DM, Barreira TV, Katzmarzyk PT., Sitting time and cardiometabolic risk in US adults: associations by sex, race, socioeconomic status and activity level, British Journal of Sports Medicine http://www.ncbi.nlm.nih.gov/pubmed/23981954

[25] Church, Timothy S., Diana M. Thomas, Catrine Tudor-Locke, Peter T. Katzmarzyk, Conrad P. Earnest, Ruben Q. Rodarte, Corby K. Martin, Steven N. Blair, and Claude Bouchard. "Trends over 5 decades in US occupation-related physical activity and their associations with obesity." PloS One 6, no. 5 (2011): e19657.

[26] Hedge A., Ray E.J. (2004) Effects of an electronic height-adjustable worksurface on self-assessed musculoskeletal discomfort and productivity among computer workers, Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting, New Orleans, Sept. 20-24, HFES, Santa Monica, 1091-1095.

[27] Kwapisz, J. R., Weiss, G. M., and Moore, S. A. Activity recognition using cell phone accelerometers. ACM SigKDD Explorations Newsletter 12, 2 (2011), 74-82.

[28] Yang, J. Toward physical activity diary: motion recognition using simple acceleration features with mobile phones. In Proceedings of the 1st international workshop on Interactive multimedia for consumer electronics (2009), ACM, pp. 1-10

[29] Brezmes, T., Gorricho, J.-L., and Cotrina, J. Activity recognition from accelerometer data on a mobile phone. In Distributed computing, articial intelligence, bioinformatics, soft computing, and ambient assisted living. Springer, 2009, pp. 796-799.

[30] Hache, G., Lemaire, E., and Baddour, N. Mobility change-of-state detection using a smartphone-based approach. In Medical Measurements and Applications Proceedings (MeMeA), 2010 IEEE International Workshop on (2010), IEEE, pp. 43-46.

[31] Khan, A. M., Lee, Y.-K., Lee, S., and Kim, T.-S. Human activity recognition via an accelerometer-enabled-smartphone using kernel discriminant analysis. In Future Information Technology (FutureTech), 2010 5th International Conference on (2010), IEEE, pp. 1-6.

[32] Zhang, S., McCullagh, P., Nugent, C., and Zheng, H. Activity monitoring using a smart phone's accelerometer with hierarchical classification. In Intelligent Environments (IE), 2010 Sixth International Conference on (2010), IEEE, pp. 158-163.