Seasonal Affective Disorder Monitoring System

Negar Makvandian
Abstract

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Wireless Sensor Networks (WSNs) are essential technologies for environmental monitoring. They are composed of small electronic devices, which can monitor, collect and report environmental data autonomously and continuously with respect to energy consumption and accuracy of data. Recently, mobile phones have become an integral part of our daily lives. They have been widely used as mobile sensors to monitor the human behaviour and emotion. Mental problem is becoming a global concern in modern society. Some of the psychological problems, such as Seasonal Affective Disorder (SAD), may cause depression and sickness due to the lack of sunlight in long and dark winters. In this master thesis, we design a system, named Seasonal Affective Disorder Monitoring (SADM), to measure human sociability and light exposure to study the SAD psychological problem among people. The goal of this work is to monitor and improve the mental and physical health of people in our society. The system utilizes both stationary sensors and mobile sensors for monitoring light intensity and human activities continuously, which can help us to learn more about their mental and physical health in different seasons. The results give us a history of the level of the people’s activity and also the percentage of light intensity in the environment and light intensity that individuals received in daily life. Using this information, we analyse the relation between human behaviour and seasonal changes.
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Chapter 1

Introduction

Seasonal Affective Disorder (SAD) is a type of depression that occurs among people who live in places with long winter and darkness. This problem is mostly obvious in late autumn and winter time, and can reduce the quality of life for individuals and their families. People have less energy and less interest to interact with others. Social withdrawal, less energy, lack of interest in activities, changing diet and sleep patterns are common symptoms of SAD [2]. The first three symptoms and the sleep pattern are possible to monitor by motion sensors automatically and quantitatively and location sensor in smart phones.

The idea of designing an automatic monitoring system comes from a lack of long-term monitoring to recognise and study this seasonal disorder scientifically to large population. It is only possible by analysing history of patients with serious symptoms manually by doctors.

Mobile phones have become an integral part of the daily lives of people. They are equipped with high performance processors, sensors and Internet capable connections. Built-in sensors such as motion sensor and location sensor have been used in several application because of their performance. They also are easy to use in different mobile applications with various goals. We take advantages of this technology to make an Android application to monitor people's sociability continuously. Another technology which is widely used during these days is Body Area Networks (BAN). This technology has been used in various areas such as healthcare and sport for both monitoring the human health and performance. In this work, we use this technology to have a wearable sensor for users to measure the light received by a user during their daily light, since among of received light is one of the major causes of seasonal disorder. There is a huge market of wireless and mobile healthcare applications. Their aim is to help people to achieve a better and healthier life. We would like to find the relation between environmental condition and human feelings. As we mentioned earlier, in particular, seasonal changes such as darkness and the intensity of light in everyday life, have strong impacts on human feelings and behaviour. Therefore, we also use Wireless Sensor Networks (WSNs) [3] in our work. By using both stationary sensors and wearable sensors, we can measure the intensity of light in the environment and the light intensity received by individuals.
1.1 Motivation

SAD seriously reduce the quality of life for individuals and it affects on their social life. They feel hopeless, depressed and having less energy. It sometimes causes some social problems like suicides. It is mostly hard for both patients to express how do they feel and for doctors to recognise this disease and distinguish it from depression since the reliability of patients answers are typically low. The aim of this project is to form a new sensing and communication system by integrating stationary sensors, wearable sensors and mobile smart phones to recognise SAD in terms of providing mental healthcare for people. SAD can be identified whilst still in it’s early stages by looking a patient histories. It also could help doctors to offer better treatment to patients. Our aim is to combine current technologies to implement a system in order to have a healthier society with lower rate of mental and social problems. In addition, we try to find out how computer science technologies could be engaged with psychology.

1.2 Problems

Every year, when days become short and dark, some people may recognise changes in their behaviour and different feeling. They have a hard time to wake up in the morning and they become slow down. They tend to eat more specially sweets and their energy level decrease. They lose their interest to do activities and they lose their concentration. They also withdraw from friends and family. Therefore, their personal relationships and their work are both affected, so they become less productive in the society. These changes are symptoms of the seasonal disorder disease. It would be possible to control these unwanted changes by combining current technologies in computer science to monitor people's daily sociability and environmental conditions which may cause these problems.

1.3 Objective

The only diagnostic tool nowadays for SAD is a good clinical interview with help of Seasonal Pattern Assessment Questionnaires (SPAQ), which is specialised for SAD. We would like to introduce a monitoring system which could capture long-term SAD symptoms. We expect the collected data can improve the life of people and quantitatively study mental disorder such as SAD. By observing their daily activities and the amount of light they are exposed to in everyday life, people are able to know more about their feelings and internal state such as depression. Also, this information can help psychologists to diagnose SAD and give patients more effective treatments.

1.4 Approach

In this thesis, we design and implement SADM system, which integrates both smart phones and wireless sensor networks, to monitor people sociability and environment condition in order to improve the quality of life for people. We measure social interaction of people using built-in mobile sensors, location and
motion sensors; however, this is not enough to infer people’s activities and their health condition. The accuracy and the analysis of collected data are major challenges of this work. We believe captured data in long-term, could give users and doctors good history of people’s sociability and behaviour which is affected by environmental changes such as light, since the lack of light is a major factor causing SAD. Therefore, SAD could be controller in earlier stage.

1.5 Report Structure

The report is organised as follows. In Sections II and III, we present the background and related work. We describe the system design in Section IV. Detailed implementation is illustrated in Section V. We evaluate the system in Section VI. We conclude the work and discuss about the future work in Section VII.
Chapter 2

Background

2.1 Seasonal Affective Disorder (SAD) disease

Seasonal Affective Disorder (SAD) [2] is a type of depression that occurs among people who live in places with long winter and darkness. This problem is mostly obvious in late autumn and winter time, which can reduce the quality of life for individuals and their families. SAD’s symptoms are same as with other types of depression:

- Hopelessness
- Weight gain
- Changing sleep pattern
- Less energy
- Loss of interest in work or other activities
- Less sociability
- Unhappy

There is no special test for recognising SAD. History of symptoms can help to recognise this disorder in the first stage. The cause of SAD is unknown. However, our environment have an effect on our body and our mental status. Reducing the level of sunlight in fall can influence our body’s internal clock. SAD even may occur in some people during the summer. This is because of our body’s natural chemical which is different from person to person. In addition, ”The change in season can disrupt the balance of the natural hormone melatonin, which plays a role in sleep patterns and mood.” [4]

2.2 Mobile Sensors

Android is one of the most popular mobile operating systems and it is based on Linux. Android has several built-in sensors such as Location sensor (GPS), motion sensor (Accelerometer) and light intensity sensor. Accelerometers are found in every Android device, and are hardware-based sensors that can be used
to detect user’s movement. It measures the acceleration force in \( m/s^2 \) that is applied to a device on all three physical axes (x, y and z), including the force of gravity. As we mentioned above, another mobile sensor which is common is a location sensor. It returns user’s location by using GPS provider or Networks provider. However, it is energy consuming and it does not return the location as fast as users want. Furthermore, GPS usually does not work indoors.

2.3 Wireless Sensor Networks

![Wireless Sensor Networks](image)

Figure 2.1: Wireless Sensor Networks.

Recently, Wireless Sensor Networks (WSNs) \[3\] has found an essential place for environmental monitoring, home automation, and industrial monitoring. They are small in size and can sense, monitor and collect environmental conditions such as light intensity, temperature, humidity, and pressure autonomously and continuously with respect to energy consumption, accuracy of data and cost. Afterwards, WSNs can communicate with each other in short distances and hop-by-hop through the entire network to transfer collected data to a base station. Figure 2.1 illustrates a typical WSNs and their communication until they reach the base station or other networks. Communication between embedded devices like WSNs should be low cost and low speed pervasive communication. IEEE 802.15.4 is a standard which provides low cost, low speed pervasive communication between embedded devices by specifying the physical layer and media access control to have suitable communication under these conditions.

2.3.1 Contiki

Contiki \[5\] is an open source, portable and multi-tasking operating system for the Internet of things like Wireless Sensor Networks. Because of Contiki’s features, it has been used for various projects, such as wildlife monitoring. It is designed for memory-efficient networked embedded systems. It is based on the C programming language, and can communicate with both IPv4 and IPv6.

2.3.2 Zolteria Z1 and Ambient Light Photo Sensor

Zolteria Z1 \[6\] is used in this work as a stationary light sensor. This sensor does not have a light intensity sensor, therefore; we use an attached Precision Light Sensor. Figure 2.2 represents Zolteria Z1 with the attached Precision
Light Sensor. This sensor can be used for area monitoring and collecting environmental information such as temperature and humidity. It is deployed in an environment for monitoring some phenomenon like light intensity in our work.

Figure 2.2: Zolteria with light sensor attached.

Table 2.1 represents Zolteria Z1 parameters.

<table>
<thead>
<tr>
<th>Zolteria Z1 parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro controller</td>
</tr>
<tr>
<td>RAM</td>
</tr>
<tr>
<td>Flash memory</td>
</tr>
<tr>
<td>Radio Chip</td>
</tr>
<tr>
<td>Sensors</td>
</tr>
</tbody>
</table>

Table 2.1: Zolteria Z1 parameters.

Ambient Light Photo Sensor (APDS-9007) is an analogue light photo sensor. It is small in size and measures the light intensity, in addition, it suits applications that performed under the high brightness. It has close to human eyes and it is Low sensitivity variation across various light sources.

In the Table 2.2, you can find the feature of this sensor.

<table>
<thead>
<tr>
<th>APDS-9007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
</tr>
<tr>
<td>Size</td>
</tr>
<tr>
<td>Vcc supply</td>
</tr>
</tbody>
</table>

Table 2.2: APDS-9007 features.

2.4 Body Area Network

Body Area Network (BAN) [7] [8], is a technology which introduces small, lightweight and low-power sensors to monitor and log humans’ physiological activities. They can be used on, in or around a human body for long time. They are used in various medical and non-medical applications to improve health care and the quality of life. Figure 2.3 shows a wearable sensor (Lilypad) in this
work, which measures light intensity received by individuals. It is small in size and light to carry.

![Figure 2.3: Lilypad-wearable sensor.](image)

The LilyPad Arduino is a micro-controller board with a light sensor which is designed for being wearable. It can be sewn to the cloth and be with a user for long time. Table 2.3 represents Lilypad’s hardware and their features.

<table>
<thead>
<tr>
<th>Lilypad’s features</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro controller</td>
<td>ATmega328V</td>
</tr>
<tr>
<td>SRAM</td>
<td>1 KB</td>
</tr>
<tr>
<td>EEPROM</td>
<td>512 bytes</td>
</tr>
<tr>
<td>Flash memory</td>
<td>16 KB (of which 2 KB used by bootloader)</td>
</tr>
<tr>
<td>Operating Voltage</td>
<td>2.7-5.5 V</td>
</tr>
<tr>
<td>Input Voltage</td>
<td>2.7-5.5 V</td>
</tr>
<tr>
<td>Digital I/O Pins</td>
<td>14 (of which 6 provide PWM output)</td>
</tr>
<tr>
<td>Analog Input Pins</td>
<td>6</td>
</tr>
<tr>
<td>DC Current per I/O Pi</td>
<td>40 mA</td>
</tr>
</tbody>
</table>

Table 2.3: Lilypad’s features

2.5 Web Services

A web services [9] provides a method of interoperating between two electronic devices over a network. In other words, it is a software system designed which support interoperable machine-to-machine interaction over Internet. In our work, we use web services to provide communication between our Android application on the smart phone and a web server. HTTP [10] is an application protocol for distributed, collaborative, hypermedia information systems. We use HTTP requests to send messages to the web server over the web. Apache is a web server software and we use Apache2 in our work to make a web server. In the server side, we use PHP to produce dynamic web pages and handle sensor data

2.6 Service Analysis

The aim of using service analysis is to clean, inspect, transform, and model our collected data. In this work MATLAB is used for data analysis. By analysing data, we try to highlight useful information and make a conclusion of our work.
Chapter 3

Related Work

A study of winter fatigue and winter depression [2] has been conducted in Sweden. It includes details about light effects humans. SAD disease is the result of a dichotomy between social time and the time of the body and nature. The study also discussed SADs’ symptoms and light room treatment.

The BikeNet Mobile Sensing System [11], shows the use of sensors in sport. It describes a system which is a combination of several sensors. It aims to sense and collect environmental data such as pollution monitoring, and also sense the cyclist condition. This paper demonstrate the values of mobile wireless networks in our life and how we can regulate our activity to improve the quality of our life. This work focus on different aspects such as, health, safety, and fitness that it can bring to its users. It provides a information which helps cyclist to find good routes, and also useful ride data to analyse in order to improve the cyclist skill.

DietSense [12], is a system which monitors a person’s dietary habits. This work is mostly related to image processing; however, it is the system that could be integrated with our monitoring system to monitor the dietary of users changes across the seasons.

SociableSense [13], represents a system that monitor the sociability of people at workplaces. It captures users behaviour in office environment and measures their sociability with their colleagues. The aim of this work is to have a deep understanding of social dynamics in the office environment to helps companies to better manage employees and increase their productivity. This system includes accelerometer and microphone sensors and bluetooth is used to provide a real-time communication.

Research on BANs [7], studies the use of wireless sensor networks around human body to support not only medical applications but also non-medical applications. Moreover, it introduces the new IEEE 802.15.6 standard. A survey on wireless body area networks [8] has discussed about eHealth and various usages of the BAN for monitoring healthcare and their benefits to patients.

Activity and emotion recognition [14] is another work that focuses more about mental disorders and its aim is to support early diagnosis of psychiatric diseases. Activities recognition [15] describes a method to recognise activities continuously, since the amount of daily activity is essential to both physical and mental health. With such a system, people are able to make a connection between their daily activities and their mental health [16]. Activity recognition
from accelerometer data [17], reports the work to recognise user activity by using a single wearable accelerometer. This system classifies collected data in eight activities:

- Standing
- Walking
- Running
- Climbing up stairs
- Climbing down stairs
- Sit-ups
- Vacuuming
- Brushing teeth.

Real-time motion classification for wearable computing applications[18], is a technical report which represents motion classification system. This system retrieve information about user’s status in real-time. In wearable computing, context awareness is an essential issue. Analysing Features for Activity Recognition [19], emphasize on activity feature to recognise the activity by its features.

MoodMiner [20], uses mobile phone to propose a framework for assessing individual’s daily mood. Various mobile sensors such as accelerometer, light sensor, sound sensor(microphone) and location sensor(GPS) work together with call log on smart phone, to monitor human behaviour and assess daily mood. EmotionSense [21], proposes a fully context-aware programmable mobile sensing system for social psychology research. It studies user emotion based on mobile phones and recognises both individual emotions and activities.

Small sensor and mobile devices have been studied for healthcare [22]. There are many applications related to healthcare in the market. However, few of the existing work is about monitoring one specific psychological problem. Healthwear [23] utilised mobile phones as wearable computers that can monitor the users’ vital sign continuously. Affective healthcare [24] is a recent mobile service that allows people to understand and recognise their emotion and their level of stress.

iCalm [25] is a well-defined system for continuous long-term monitoring of autonomous nervous system. It is designed as a reliable, low power, low cost, and comfortable to wear device.
Chapter 4

SAD Monitoring System Design

4.1 System Overview

In this section, we try to give an overview of our system. In order to measure peoples sociability and how they have been effected by environmental conditions, we design a system by using different hardwares such as, stationary sensors, mobile sensors, and wearable sensors (BAN). We aim to collect information and history of people sociability, to give people information about their mental status. Moreover, psychologists can have a good history of their patients who are in danger of SAD. Therefore, they can give patients better treatment. As shown in Figure 4.1, SAD monitoring system includes several components which are described in detail in the following section.

4.2 System Components

The system is based on four major components, built-in mobile sensors, WSNs, wearable sensor (BAN) and a web server. In our system we use HTC Android smart phone. Two built-in sensors in Android, motion sensor (accelerometer)
and location sensor (GPS), are responsible to monitor and log user’s movement and location respectively. In addition, the smartphone saves all data on the SD card and wait until it receives an upload request from the user to transfer data. The accelerometer records all movements of the user in three axes X, Y and Z. Accelerometer is very sensitive to each small movement. Therefore, it is very hard to limit its sensing to avoid unclear data. GPS gets a geographical position of the person who is carrying the smartphone. Geographical position is represented by a pair of latitude and longitude. By location sensor readings, it is possible to track users location. The location data is also stored on the SD card of the smartphone and transfer to the server upon a user upload request.

We use an Android application on the smartphone to use accelerometer and GPS to measure user activity and location and show all data on a phone screen. Figure 4.2, represent our Android application.

![Android Application Interface](image)

Figure 4.2: Android Application Interface.

In our work, Android smartphone also roles as a medium between light intensity sensors and server. We used a system provided by another master student. This system is an Android application that can connect a base station and communicate with other stationary light sensors. It receives all data from the light sensors and transfer them to the server or the mobile networks or wifi. We use the part of the Publish/Subscribe System [26] for the communication between stationary sensors and smartphone to transfer data from light stationary sensors to the server. The role of the stationary sensors in this project are measuring illumination. They are used as light intensity sensors to measure the intensity of light in the environment. The sensor nodes save all light data in built-in memory and transfer data to the base station which is another stationary sensor that connect to the smartphone over USB. They continue sampling until they receive a message from the base station to stop sampling. Then, they send all data to the smartphone through a base station.

Another component in this work is a wearable light sensor. This light sensor is small in size and measure the light intensity received by individuals both indoor and outdoor. This component includes one micro-board and one light sensor. The schematic of this sensor is very simple but it is not easy to program.
because of its limitations.

Web server is a Apache server with php pages and it is responsible for receiving all data from users that upload data. The server create a folder with a user’s name and save data which are uploaded by user in another folder by data and time.

### 4.3 Network Model

In a network perspective, each of our components are located in different networks. Therefore, in this section we represent the network model of our system. As showed in Figure 4.3 stationary sensors, measuring light intensity, communicate with the base station over the Zigbee protocol which is based on IEEE standard 802 [27] [28]. The base station is connected directly to the smart phone via USB.

The smart phone has access to the server platform through both wifi and cellular networks such as 3G. The server is an internet server. It means that users can access to the server over the Internet and their data which are saved on the server through the Internet. In extended work, we will make a website that users can see their result on the server as well as their data.

![Network Model Diagram](image)

**Figure 4.3: Network Model.**

### 4.4 System Design

We designed a SAD monitoring system, which includes stationary light sensors, mobile sensors on smart phones, wearable sensors, and a server on the Internet. In this platform, stationary sensors are used to measure the intensity of light in the environment. Wearable light sensors are attached to the clothes of users to measure the light intensity received both indoor and outdoor. The wearable sensors are small in size and can be with the users continuously and unobtrusive. Smart phones include different sensors such as location sensor (GPS) and motion sensor (accelerometer). These sensors are used for measuring activities and locations of people to understand their sociability. The server is responsible for saving all data from the various sensors.
Figure 4.1 shows the design of the system, how different components in various networks cooperate and how they communicate with each other. Stationary sensors have a short-range radio (IEEE 802.15.4). In our experimented set up, we use one stationary sensor as a base station to communicate with other sensors. The base station transfers all collected data from stationary sensors to the smart phone at the end of our experiment. The battery life of the base station is not a big issue, since we use base station at a specific time at the end of the experiment. We connected the base station to the smart phone by USB and run the Android application (publish/subscribe system). Figure 4.4 shows the base station and the smart phone communication. A lithium battery is used as an external power source since the USB standard dictates that the host device must provide power to the slave device. Then we should walk around the sensors. The base station sends a message to a sensor it detects in its range and receives all a set of readings from that sensor. The base station saves reading in its flash memory and over the request from the Android application it transfer all the data to the smart phones. After wards, the smart phone reports the sensing data to the server through cellular networks or wifi.

Figure 4.4: Base station and smart phone.

The wearable sensors can transfer data to the server directly by a cable or through a smart phone. The smart phone works as a medium for communicating with other components and networks. It can communicate with both the base station in the sensor network and the server on the Internet.
Chapter 5

SAD Implementation

Given the information about SAD disease and its symptoms, we implement our design in order to monitor SAD. We develop an application on smart phones by using current technologies including stationary sensors, wearable sensors and mobile sensors, as discussed below. In the following sections, we explain an implementation for all the components in our work, stationary sensors, wearable sensor, mobile sensors and a server.

We clarify why we choose above components and how we combine these components to work together in other to implement SAD monitoring system.

5.1 Sociability Measurement

We developed an Android application which uses mobile sensors, accelerometer and GPS, to measure people’s movement and geographical location.

Since we want to monitor the user activity and location for long time, we used an Android service. Android service is an application component in that used when the application should work for long time. It runs in the background even when users run other applications. Therefore, the application never stops and continues working until the user stops the application. However, there is a possibility that our service might be killed by the system. According to the Android developer website [29], the Android system will stop a service just when memory is low and it requires to recover system resources. We build the application by using Android service to handle restart. We use another Android component which is called activity to handle user interface. Service and activity interact with each other through a message handler. We use handlers in our implementation instead of threads to provide communication between service and activity. When the application is started, first activity starts working and make the interface to show the accelerometer and location values. The interface presents location data by latitude and longitude, and accelerometer data by X, Y and Z. The interface also includes a button, which is used by the user when data is going to be uploaded to the server. When the button is pressed, all data collected since the last transmission is sent to the server and a new file will be created to contain future sensor readings.

Activity also starts the service by startService(intent). An intent is an abstract description of an operation to be performed. In this work the intent is
used to communicate with a background Service. In the service, first we define SensorManager to access the phone’s sensors. Then, it set up built-in sensors and prepare them to use. For recognising user’s location, Location Manager checks GPS, if it is available. GPS will start sensing the geographical position of the user. It senses location changes (updates). LocationListener response to every single location update and the application save new location information, latitude and longitude, on the SD card of the smart phone and also shows the new location on the screen. We recognise users location when they are outdoor by the GPS. Since the GPS mostly does not work indoor, we do not receive more information about their location from the GPS. So, we assume that the users are indoor and the last reading from GPS is their position until we get a new reading.

Setupsensors function also prepares accelerometer to sense user’s movement. It defines accelerometerListener to catch each motion updates. Accelerometer recognises the motion update in 3 dimensions, X, Y and Z.

We measure users activity by accelerometer in order to monitor their activities and sleep pattern. We do not need to know what kind of activity users are doing in this study. Our aim is just to understand users are interested in doing activities and what is the level of their activities.

The combined data from the GPS and accelerometer help us to monitor and measure people sociability and their interaction with other people.

5.2 Light Intensity Measurement

We used two light intensity sensors in this work, wearable sensors and stationary light sensors. The users carry around the wearable light sensor to measure the intensity of the light that they receive.

Stationary light sensors are located outdoors to measure the light intensity in the environment.

In the following sections, we describe the implementation of these two light sensors.

5.2.1 Wearable Sensor

In our work we used Lilypad as a light intensity wearable sensor. It is attached to the users when they move around. Using this sensor we can measure the light exposure that each individual user receives both indoor and outdoor. The readings are important for evaluating the intensity of light received by individuals in their daily lives as well as those receiving light treatment. We can also combine the light intensity outdoor and indoor to measure the total light exposure.

Lilypad includes a micro-board with a light intensity sensor. It is hard to program due to the lack of resources. We wrote a code to measure the light data and transfer the data to the flash memory. In our implementation, Lilypad is sampling each 30 seconds and calculate the average of light in 5 minutes. Then it saves the average in the flash memory. Each sample is around 8 byte. Since the Lilypad’s memory is 1024 byte, it just able to save 128 samples. It means it can save data for around 10 hours, and after that it is out of memory. To avoid this, we decided to transfer data from Lilypad to the server each 8 hours. In this way, we are sure that we do not lose any data and we do not run out of the
memory. We can transfer light data from Lilypad to the server both through the smart phone and by serial port. We also wrote an application for downloading data from Lilypad. The format of a sample is ID, YYMMDD, HHMM, VALUE where ID is the ID of the sensor, YYMMDD is the date (year and month) and HHMM is the time (hour and minute) and VALUE shows the light sensor readings. The starting time for the first sample is hard coded, due to some hardware limitations such as lack of suitable time library. Therefore, we have to change the time in the code after transferring data to the server. Lilypad battery is 110mAh and it works around 12 hours without needs to charge. We decided to charge the battery each 8 hours when we transfer data to the server. In this way we solve the battery issue.

5.2.2 Stationary Sensors

Stationary sensors are widely used for monitoring environment conditions such as temperature, and light intensity continuously. As we mentioned earlier, lack of light exposure is considered as a main cause of SAD. Therefore, we decide to deploy stationary light sensors to measure the intensity of light outside our office building along seasonal changes. The light intensity sensors in our work can measure the intensity of light that we have in the environment. We deploy four sensors outside and inside our office building. Two sensors are located outdoor and two are placed in our office’s floor, one close to the window and one at the work desk. They measure light with high accuracy. They sample light data with a period of 5 minutes for 1 week. The format of the reading from light intensity sensors is ”ID, YYMMDD, HHMM, VALUE”. Since we use 4 stationary sensor in our experiment, for distinguishing their readings, we used ID in the format of each sample. All readings are stored in the flash memory of the Zolteria Z1 sensors. Zolteria sensors with light sensing component for measuring light intensity outdoor, works for around 4 days with two AA batteries. In our implementation, in case each stationary sensor runs out of battery, it just stops sampling and keep all data on its flash memory. So, we do not lose any data and we can retrieve the data from the flash memory later. The sensors save all light readings and they wait for a message from the base station. The base station is also a Zolteria Z1 sensor which is directly connected to the smart phone and we use an Android application that is provided by Publish/Subscribe System [26] for transferring data from each sensor to the base station and from the base station to the smart phone. When the base station sense any of our light sensor, it sends a message to it to get all the readings. It saves received data in its flash memory and then sends them to the smart phone. Afterwards, upon HTTP request, the phone transfers data from SD card to the server through the Internet. The system transfers data as a text file.

5.3 Server and Communication

In this work, we have a server over Internet which is responsible to store all reading from different sensors. As we mentioned in Section 2.5 our server is an Apache server running PHP. In our implementation for each user who uses our Android application we create a folder with the user’s name. In addition, when users press the upload button in the application, another folder with the
date, has been created inside the user’s folder. Since this system should work in long term experiment, in this way we can keep a track of user’s information and can have a users accelerometer and location reading in separate files for each day. We also follow this structure for light sensors data. In the server side, we create a file with date and save light readings. We decided to not use real-time communication due to the huge amount of data. Also, it is not necessary to have information in real-time. Therefore, we save all readings in the SD card and transfer data to the server. The smart phone works also as a relay in our system. It sends all collected data from mobile sensors and light sensors to the server over Internet. We decided to use a Publish/Subscribe System [20] for the communication between stationary sensors and the smart phone. In Publish/Subscribe system, stationary sensors send all their readings to the base station over the Zigbee protocol and the base station transfer them to the smart phone.
Chapter 6

Evaluation

In an experiment, we would like to collect readings from different sensors in our system and evaluate our system. We will explain readings from each sensor and methods for analysing data. In addition, the data analysis process helps us to highlight useful information, draw conclusions, and support decision making. We will show our results and analyse readings from different sensors we used in our work. We demonstrate that our system works and can be considered as a case study.

6.1 Experiment Setup

We chose a top floor of our building and our lab as the SAD system testbed. The reason for this decision is, we wanted to measure the light intensity both outdoor and indoor. We deployed 2 stationary light sensors in the fourth floor. As you can see in Figure 6.1(a) the stationary sensors are placed in the balcony on both left and right side of the balcony because we would like to measure the light intensity outdoor. In addition, Figure 6.1(b) and 6.1(c) show two more stationary sensors that we placed, one in our lab and on in the office close to the window. We would like to measure the intensity of light which enter from the window and intensity of the light that we have in the lab area from indoor lighting. To protect our two stationary sensors, which are located outdoors, from rain we put them in transparent plastic bags. In his way we keep them safe from rain and the bags do not effects on the sensors light readings. Moreover, we installed our SAD Android application on a HTC smart phone and two people have carried them during the experiment time. We decided to keep the smart phones in the pocket because we can measure most of the physical activities and also it is easier for our volunteers to carry the phone in their pocket. Our volunteers also carried wearable light sensors which were attached to their clothes. We decided to attach them on the shoulder. Because we would like to have them close enough to eyes, since the light intensity which is received by the eyes affects our mental status. Our experiment period was one week from Monday 2012-06-16 at 16:00 until Monday 2012-06-23 at 16:00. We gathered all readings from the various sensors and used them for analysing and to evaluate our system performance. Table 6.1 is a summary of the experiment parameters.
Figure 6.1: Experiment setup, stationary light sensors.
<table>
<thead>
<tr>
<th>Experiment Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment period</td>
</tr>
<tr>
<td>Experiment location</td>
</tr>
<tr>
<td>Number of volunteers</td>
</tr>
<tr>
<td>Number of smart pones</td>
</tr>
<tr>
<td>Number of stationary sensors</td>
</tr>
<tr>
<td>Number of wearable sensors</td>
</tr>
<tr>
<td>Sampling time for each light sensor</td>
</tr>
</tbody>
</table>

Table 6.1: Experiment Parameters.

6.2 Results

In this section we would like to show the result of the analysis of our collected data. Analysis of data is an important process in our project. We try to clean our data and highlight the useful information. Moreover, we try to find a smart way to analyse our data, find a relation between our data and suggest conclusions to show our system covers our system’s goals.

6.2.1 Accelerometer Data

The readings received from accelerometer are in three dimension $X, Y$ and $Z$. These three-vectors represent the movement of the smart phone. Accelerometer values are recorded in metres per second squared ($m/s^2$). For analysing the accelerometer data in our experiment, we performed three steps to make our accelerometer data more clear to analyse. In the first step, we combined all three values, $X, Y$ and $Z$, into one value. To perform three-dimensional input into one, all accelerometer values run through the following equation:

$$\sqrt{x^2 + y^2 + z^2} \quad (6.1)$$

In Figure 6.2(a), you can see our three-dimensional accelerometer reading for one day and also in Figure 6.2(b) one-dimension accelerometer data after we perform the above equation.

As you can see in Figure 6.2(a) and 6.2(b) the plots are not clear and they include noise. In the next step, we should reduce the noise from our accelerometer readings. We decided to filter the noise before analyse the accelerometer readings. We have huge amount of data with noise from accelerometer, since each phone devices has a different sampling rate and it is hard to control the accelerometer sampling rate by time because the accelerometer takes the sample for each small pressure on the phone. So, it is hard to control the sampling rate just by time. Some noise are irregular, because of the Android framework’s implementation. The accelerometer measures every pressure on the smart phone by onSensorChanged() function. Whenever this function determines that the accelerometer value changed, it takes a sample. So, for every small movement, we have reading from accelerometer. This feature of Android API limited us to define a time interval, such as light sensors, to manage sampling rate. Therefore, sometimes we have several readings for one second and sometimes we do not have any readings from accelerometer for few minutes. Moreover, orientation changes of the phone is quite common and it affects on the readings. According
to all above reasons, we received vast amount of data from accelerometer which makes our analysis hard. For reducing the noise from our accelerometer data, we use a moving-average filter. The main reason that we chose this method is, its simplicity. In addition, it is a common method of filtering the time series data to smooth fluctuations in cycles.

Classifying the accelerometer data in different levels is our focus in working with accelerometer data. First, we found different patterns for four common daily activities, sleeping, sitting, walking, and running. Afterwards, we applied the moving-average filtering method in each group of data.

In the next step, we found patterns of each activity and calculate the average of each activities individually. Figure 6.3 illustrates four patterns that we used in our work to classify accelerometer readings.

As a result, sleeping average is equal to 9.76 m/s$^2$, sitting is equal to 9.83 m/s$^2$, walking is equal to 9.86 m/s$^2$, and running is equal to 10.48 m/s$^2$. We defined the level of the activity between 1 to 4, Sleeping and sitting are defined as level 1, walking level 2, running level 3, and more in level 4. We classify accelerometer data in these four levels by calculating the differences between each peaks. We should note that, in this work we do not focus on recognising the people activity and these four activities are our solution to classify our data. They are examples of common physical activities that people have in their daily life.
life. So, in this way, we can find out how much activity users have in different levels. However, this classification did not give us a good result for classifying data. It sometimes classified data in the wrong level. Therefore, in future work we should find a better way to classify accelerometer data. We will talk more about it in Section 6.3.

6.2.2 Location Data

Readings from location sensor show how many hours users spend outdoor. People can control their social life by these information and spend as many daylight hours as possible outside specially during the winter. These data can also help doctors to track their patients to understand they have any interests to be outdoor with other people.

In addition, combination of location data and activity data give us more information about user’s social life. We measured people sociability by the combination of these two readings. Figure 6.4 is a user location track. The blue line is a GPS track and the red stars shows the data that we actually received from GPS. According to our assumption, since GPS mostly does not work indoor, parts of the blue line which do not cover by red starts shows that user is indoor.

In some specific conditions, for instance if the room had a huge window and user sat close to it, the GPS still worked. Vice versa, we did not have GPS readings if the user was in a car because of the speed of the car. By the GPS readings, we calculated the percentage that people spend outdoor per day.
Figure 6.4: GPS Data.

We also draw the GPS results over a map. Figure 6.5 presents the user location over a Google maps with date and time caption.

Figure 6.5: GPS Data on Google maps.
6.2.3 Light Data

We used four stationary light intensity sensors in our experiment in order to capture changes of light in our environment periodically. We used two sensors outside in the open area and two in our lab. The reason is to measure the intensity of light that we have around us both outdoor and indoor. We measure light that is visible to the human eye which has a wavelengths in range of about 380 nanometres to about 740 nm.

Plots of four light intensity sensors after one week experiment are shown in Figure 6.6. The light values are accurate and they affected by the location of the sensors. Node 1 and node 2 are the sensors which we located them in our lab. Although both nodes were indoor but the differences between their readings are obvious. The reason is, node 1 was close to the window but node 2 was in the lab far from the window and more shows the light value from lamps in our workspace.

Node 3 and node 4 were placed outdoor. The readings from these two nodes are almost same. Since node 1 was close to the window in our lab, there is more similarity between its readings and node 3 and 4. Our light values obviously show the daylight time and night time. The light changes are understandable by light readings. In Figure 6.6, the vector $X$ shows the date and vector $Y$ shows the light value in Lux which is the unit of the illuminant and it measures light intensity. Lux is used as a measure of the brightness of different light sources such as sun, star or a light bulb. Since, we ran the experiment during the summer in Sweden, we have a long daylight and short darkness. The light sensors measure the light intensity in millivolts (mV). We converted the light data from mV into the Lux by applying a function $lux = 10^{(x/560)}$.

Table 6.2 [1] presents an explanation of different Lux values.

<table>
<thead>
<tr>
<th>Lux Explanation examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-4}$ lux</td>
</tr>
<tr>
<td>0.002 lux</td>
</tr>
<tr>
<td>0.01 lux</td>
</tr>
<tr>
<td>0.27 lux</td>
</tr>
<tr>
<td>1 lux</td>
</tr>
<tr>
<td>3.4 lux</td>
</tr>
<tr>
<td>50 lux</td>
</tr>
<tr>
<td>80 lux</td>
</tr>
<tr>
<td>100 lux</td>
</tr>
<tr>
<td>320–500 lux</td>
</tr>
<tr>
<td>400 lux</td>
</tr>
<tr>
<td>1000 lux</td>
</tr>
<tr>
<td>10000–25000 lux</td>
</tr>
<tr>
<td>32000–130000 lux</td>
</tr>
</tbody>
</table>

Table 6.2: Lux values explanation. [1]

According to Table 6.2 we classify our light data in 8 groups as we describe in Table 6.3.

Afterwards, we calculated the percentage of each group of light we have in each days of our experiment period. Figure 6.9 presents the light classification
Figure 6.6: Light Intensity Stationary Sensors results.
## Ligh Data Classification

<table>
<thead>
<tr>
<th>Group</th>
<th>Light Value Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>More than 25000 lux</td>
</tr>
<tr>
<td>2</td>
<td>10000-25000 lux</td>
</tr>
<tr>
<td>3</td>
<td>1000-10000 lux</td>
</tr>
<tr>
<td>4</td>
<td>500-1000 lux</td>
</tr>
<tr>
<td>5</td>
<td>200-500 lux</td>
</tr>
<tr>
<td>6</td>
<td>50-200 lux</td>
</tr>
<tr>
<td>7</td>
<td>10-50 lux</td>
</tr>
<tr>
<td>8</td>
<td>1-10 lux</td>
</tr>
</tbody>
</table>

Table 6.3: Light Data Classification.

The aim to use wearable light sensor was to measure the light intensity that person is actually received. Results from wearable sensor are different day by day, due to the different places that user was. Figure 6.8 represents the intensity of data in each day. According to Table 6.2 and Figure 6.8 we classified our wearable light sensor readings in 4 groups as shown in Table 6.4.

As you can see, the classification between wearable light sensor data and
Figure 6.8: Wearable Light Data classification.

**Table 6.4: Wearable Sensor Light Data Classification.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Light Data Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 &lt; x ≤ 80</td>
</tr>
<tr>
<td>2</td>
<td>80 &lt; x ≤ 300</td>
</tr>
<tr>
<td>3</td>
<td>300 &lt; x ≤ 600</td>
</tr>
<tr>
<td>4</td>
<td>x &gt; 600</td>
</tr>
</tbody>
</table>
stationary light sensors are slightly different because of the user location during
the days of the experiment. For instance, during the day we mostly have light
data which exists in the workplace not the light that we have outside in the
environment.

6.2.5 Relation between light, accelerometer and GPS data

We believe that there is a relation between amount of light that people received
individually and their activity, according to SAD symptoms. In these work,
we tried to capture light data, accelerometer, and GPS data to have a good
history of people sociability and light data in long time, to investigate a relation
between them. Our experiment was run in one week during summer, to show
that the system works and it is doable to look for a relation between light
data and accelerometer data. Therefore, we are able to investigate that the
environmental conditions like light affects our lifestyle or not. By having this
history we can control our internal status and if we found differences in our social
manner because of lack of light, change our life style and try to use daylight
lamps in our home and workspace.

6.3 Discussions

People are usually not willing to talk about their mental problems. They feel
that a system such as the SAD monitoring system, intrude on their privacy.
People do not feel safe with such a system and think other people are spying on them. It is a matter of time to convince them that the aims of the SAD monitoring system is for providing information a person’s mental health to medical staff. An ethical issue with such a system is how to handle the data. How the data is handled has to be explained to the monitored patient to remove any worries about how the data is used.

The result of light sensors from both stationary light sensors and wearable sensors were accurate. Results form accelerometer data were quite different from the expected result. We had huge amount of data from accelerometer with noises which make the data analysis very hard. We classified accelerometer data in 4 different groups but in this way we did not get a very good result and data might be classified in the wrong group. Therefore, in future work we should find smarter way to analyse accelerometer data. One suggestion is using the pattern for various activity and train the pattern to the system for each activity. For illustration, users first train the system various activity such as sleeping, walking, sitting, biking, running, etc. and save them. Therefore, system has patterns for different activities and could classify accelerometer data in a right group by analysing the pattern. Our assumption for location data was, if we got data from GPS user is outdoor otherwise user is indoor. However, the received data from GPS showed it would be possible that user was outdoor but we did not get any reading from GPS and vice versa. We could improve our system to have more information about people sociability by integrating more sensors to the system.
Chapter 7

Conclusions and future work

Our feeling and mental health truly affect our individual and social life. Disorder disease such as Seasonal Affective Disorder (SAD) can reduce the quality of life for individuals and their families. People who suffer from SAD, have less energy and less interest to interact with others. This disorder problem can happen in different seasons of a year but it mostly happens during the winter specially in countries with long winter and darkness like Scandinavian countries. In this work, we implemented a system to keep track of human social behaviour and environmental conditions across season. Therefore, doctors have a history of patient’s sociability. They also have history of the environmental changes, so they can give the patients good treatment and suggestion to cope with seasonal disorder problem. Moreover, people who are interested to check their internal state changes cross seasons can use this monitoring system. Recently, there is a growing number of applications developed to monitor human behaviour and emotion. In this thesis, to demonstrate that the design is feasible, we implemented a system that monitors human social behaviour in different seasons of a year and study its relation with environmental conditions like darkness. The goal of this work is to keep our society healthy by using current technologies. We implemented an application for the Android platform which can help those who wish to understand and monitor their internal state changes across seasons. We used a combination of mobile phones, stationary sensors and wearable sensors to make a comfortable monitoring system for users. In this implementation, motion and location sensors which are built-in mobile sensors have been used to measure people sociability. In addition, stationary sensors have been used to measure light intensity as a environmental condition. Moreover, wearable sensors measured light intensity received by individuals in every day life. We believe that this system provides useful information which can help both doctors and patients in monitoring SAD. SAD monitoring system, provides history of people sociability and environmental circumstances. By these information, people can prevent disorder diseases in early stage and change their lives style in order to avoid this psychological problem. Results demonstrate how we are impacted by our environment and how we can regulate our activity patterns to improve our quality of life by avoiding SAD. Therefore, we would have a more
healthy society with a lower rate of suicide because of depression and less number of people who are suffered by disorder problems caused by seasonal changes.

7.1 Future Work

Current information from SAD monitoring system is useful and can be used as a history of mental status of individuals; however, it is not enough to recognize the SAD disease. In the future, we plan to extend our work by integrating more sensors to the system to collect more information about human activity and sociability. For instance, we can improve our system by adding speech recognition system. Since changing diet patterns is another symptom of SAD, monitoring diet patterns can help to recognize seasonal disorder. It would be useful to add this component in our future work. In addition, we would like to improve the accuracy of both the location and motion sensing data of our system to have more clear data without noise, especially for motion sensor. We also plan to improve our system by turn to real-time communication between smart phone and web server instead of polling sensors readings and transferring them to the server over user request. In this way, we would have a system with less users interaction which make it easier for the users to use the system. In this work, we tried to use services in Android platform to make it possible to run our application in background even when the users run another application. We partly cover this goal but still there are some bugs in our system for using the services in Android platform which should be covered in future work.

In this project we use a form, included in Appendix A.1, to get more information about the subject’s location, activity and their mental status. In future work, we would like to add another component to the Android application where users can directly send their mental status, such as happy, normal, sad, etc. In this manner, using the Android application the subject will be more likely to give the medical staff information about how they feel in everyday life. Results from the wearable light sensors are accurate; however, there is limitation for programming them. Therefore, we are thinking to find another wearable light sensor that be more flexible to program. The idea of using mobile sensors is absolutely a good idea because smart phone are integral part of our daily life; nevertheless, carrying the smart phone all the time even at home and during the night is one of the issues in this system. It also might be a good idea to try other wearable sensor which are easier to carry for long time for measuring motion and location.
Bibliography

[1] Luxvalue lux values explanation. 
   http://en.wikipedia.org/wiki/Lux
   Date visited: 2012-04-20.


   http://www.mayoclinic.com/health/seasonal-affective-disorder/DS00195/DSECTION=causes
   Date visited: 2012-08-05.


   Date visited: 2012-04-05.


Appendix A

A.1 SAD Form
Seasonal Affective Disorder Mood Test

Mood Level:  
- Bad
- Not very bad
- Normal
- Good
- Very good

Energy Level:  
- Do not feel any energy
- Tired
- Normal
- Energetic
- Full of energy

Depression level:  
- Depressed
- Little bit depressed
- Normal
- Happy
- Very happy

Activity Level:  
- Lower that 30%
- Between 30% and 50%
- Between 50% and 70%
- More that 70%

Lower that 30%: Do not have any activity or very low activity  
Between 30% and 50%: Have little activity like walking  
Between 50% and 70%: Doing your daily life and have a normal activity such as biking, walking, and etc.  
More that 70%: Doing your daily life and do some exercise like jagging, going to the gym, and etc.

Please write your activity and your location between specified time:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:00 – 10:00:</td>
<td>_______________, ________________</td>
</tr>
<tr>
<td>10:00 – 12:00:</td>
<td>_______________, ________________</td>
</tr>
<tr>
<td>12:00 – 14:00:</td>
<td>_______________, ________________</td>
</tr>
<tr>
<td>14:00 – 16:00:</td>
<td>_______________, ________________</td>
</tr>
<tr>
<td>16:00 – 18:00:</td>
<td>_______________, ________________</td>
</tr>
<tr>
<td>18:00 – 20:00:</td>
<td>_______________, ________________</td>
</tr>
<tr>
<td>20:00 – 22:00:</td>
<td>_______________, ________________</td>
</tr>
<tr>
<td>22:00 – 00:00:</td>
<td>_______________, ________________</td>
</tr>
<tr>
<td>00:00 – 02:00:</td>
<td>_______________, ________________</td>
</tr>
<tr>
<td>02:00 _ 04:00:</td>
<td>_______________, ________________</td>
</tr>
<tr>
<td>04:00 _ 06:00:</td>
<td>_______________, ________________</td>
</tr>
<tr>
<td>06:00 _ 08:00:</td>
<td>_______________, ________________</td>
</tr>
</tbody>
</table>

Sleep Date and Time: Date: __________, Time: __________

Wake up Date and Time: Date: __________, Time: __________