

# **ICT-based bracelet for early detection of depression**



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## Abstract

Information communication technology (ICT) has opened a door for different sectors to benefit from ICT by using its potential tools. Health industry is one sector benefiting from ICT solutions for improving service quality and productivity. By using ICT as a tool, this study raised one of the major social and health concern, depression also known as depressive disorder. The aim of this study was to find the potential ICT based solution for an early detection and monitoring of depression.

Individuals go through different phases of life for instance psychological trauma, sadness, sorrow, grief, unemployment and so on. The different life aspects lead individuals to depression and majority of us are not all fully aware of it. Time to time everyone feels down and gets the blues in reaction to frustration or a disturbing event which lasts a day or two. On the other hand, can last a lifetime and the illness is much more disabling. Blues has never been a cause for suicide but depression is.

The society we live in and the social norms we follow can have an impact to some sort of depression. It is not intentional but unnoticed small acts in our daily life routine can contribute to depression too. To treat depression many practice therapy and/or medical treatments. Depending on the stage of depression some get cured, some still suffer, and some commit suicide. In addition to that, depression is risk factor for coronary artery disease, cardiovascular disease and stroke. It has been proved and witnessed that depressed individuals respond better to treatment at early stage of depression.

By applying design science research (DSR) methodology as an approach, the ultimate goal of this study was to find optimal ICT based solution that can be used to monitor depression at early stage. Literature review was used to gather earlier knowledge on wearable technology and depression itself. While conducting the research, senior citizens are on focus as they are more prone to depression than younger generations.

Criteria-based self-assessment questionnaire and interview are the methods used by physicians to diagnose depression and its stage. This trend is susceptible to misinterpretation and inaccuracy as the diagnosis often depends on patient's subjective understanding of depression. Based on earlier knowledge, depression types and symptoms are listed on this study. From the major symptoms of depression; loss of interest in activity, stress and insomnia can be monitored using wrist worn device. As an artefact this thesis sets requirements for wearable device that can monitor heart rate, individual's activity and sleep patterns. The collected data from the wearable device are physical and physiological data set, which can further be used as an additional input by physicians to determine the existence of depression and its current stage. This data input also helps in reducing the risk of misinterpreting diagnosis.

### *Keywords*

Wearable technology, Wrist worn bracelet, Depression, Depressive disorder

### *Supervisor*

Adjunct Professor, University Lecturer Raija Halonen

## Foreword

I would like to express my appreciation to Adjunct Professor and University Lecturer Raija Halonen for introducing me to this research topic and for her uninterrupted guidance and support throughout the thesis work. I would also like to thank University Lecturer, Molin-Juustila Tonja for challenging me and for being a great opponent.

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## Abbreviations

BLE:	Bluetooth Low Energy
BPM:	Beats Per Minute
CVD:	Cardiovascular disease
CAD:	Coronary Artery Disease
DSR:	Design Science Research
EHR:	Electronic Health Records
EPR:	Electronic Patient Records
EU:	European Union
GPS:	Global Positioning System
ICT:	Information and Communications Technology
LCD:	Liquid Crystal Display
LED:	Light Emitting Diode
MEMS:	Micro-Electro Mechanical System
MIT:	Massachusetts Institute of Technology
NIMH:	National Institution of Health Care
NFC:	Near Field Communication
OLED:	Organic Light-Emitting Diode
PA:	Physical Activity
PHQ-9:	Patient Health Questionnaire
RTOS:	A real-time operating system
USB:	Universal Serial Bus
WHO:	World Health Organization
WWW:	World Wide Web

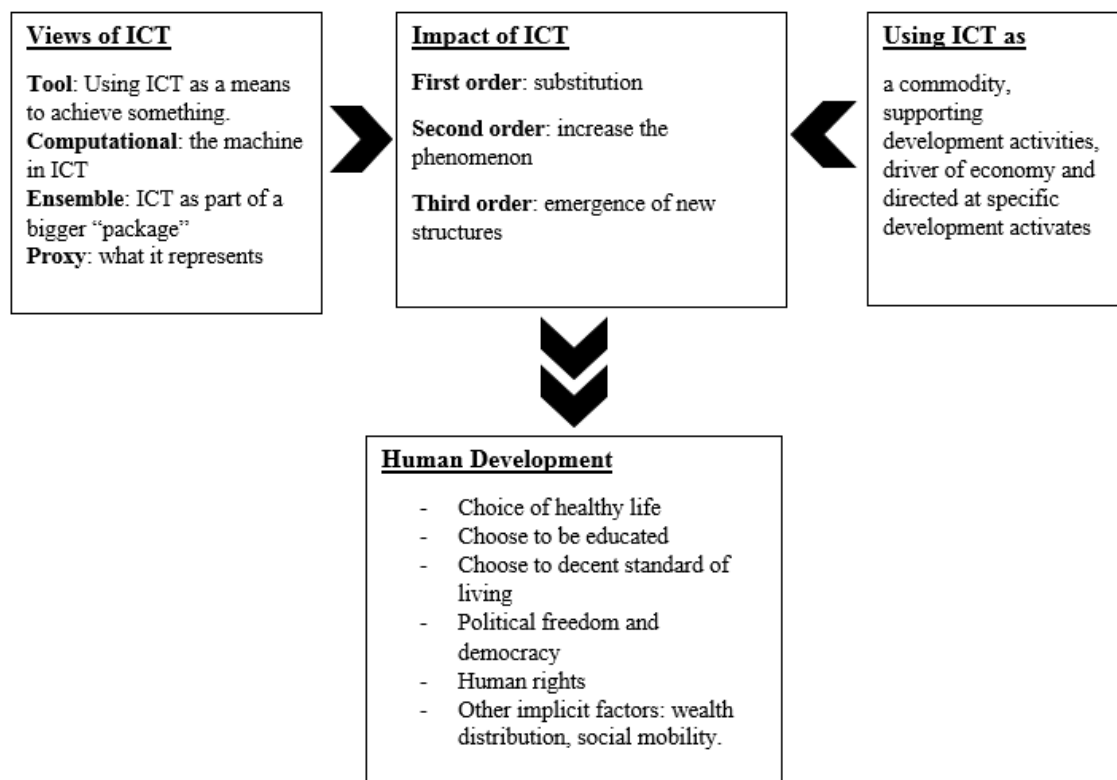
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# 1. Introduction

Information Communication Technology (ICT) is defined as set of tools designed for processing and transmitting data via electronic means. Its applications provide access to worldwide information and allow collaboration between people on different continents. (Qiang, Pitt, & Ayers, 2004, p. 23.) The goal of this study was to find out how ICT can be an answer to an early detection and monitoring major health concern depression also known as depressive disorder considering ICT's contribution in the health sector.

Sein and Harindranath (2004) summarized how ICT is viewed, used and conceptualized as a framework. Figure 1 shows the integrative framework for studying ICT and development.



**Figure 1.** Integrative framework of ICT in development (Sein & Harindranath, 2004).

Over the past decade the use of ICT in many different forms has rapidly accelerated and played significant role in improving access, easing our day to day activities and enhancing service quality. ICT has become handy for many sectors including health industry. (Sein & Harindranath, 2004.)

According to World Health Organization's finding 11% of EU citizens are victims of depression at some point in their life (Olesen, Gustavsson, Svensson, Wittchen, & Jönsson, 2012). The latter is the motivation to conduct this research.

The main question of this study was: How to detect and monitor depression with the help of wearable ICT device? This main question was answered with assisting questions:

- What is depression?
- How to monitor depression?
- What technologies can be used to detect depression?

In this study, design science research (DSR) was applied as a methodology. The main contribution of this thesis is setting set of requirements for the wearable device by creating awareness on the seriousness of depression. Based on earlier knowledge the study identified which symptoms of depression can be detected and monitored using an ICT based wearable device.

This thesis is structured in seven chapters. The introduction is followed by Chapter 2 prior research, focusing on the use of ICT in health sector, understanding depression and research on wearable devices. Chapter 3 describes the research method used to conduct this study. Chapter 4 elaborates the construct of the proposed solution; Chapter 5 describes the evaluation. Chapter 6 focuses on discussion and finally in Chapter 7 summarizes research findings, limitations and recommendations for further research are presented.

## 2. Prior research

This section emphasises on two main focus areas. On one hand it addresses ICT's use and its impact in the health sector (2.1). On the other hand, it defines one of the major concerns of public health, by giving a broad understanding of depression along with its impact in the society (2.2). The chapter ends with a research report on wearable devices (3.3).

### 2.1 Use of ICT in health sector

ICT solutions benefit number of sectors including health industry by enabling improvements in productivity and quality (Sein & Harindranath, 2004). ICT has enormous potential as tools in order to increase information flow and the dissemination of evidence-based knowledge, and to empower citizens (Chetley, Davies, Trude, McConnell & Ramirez, 2006).

As for health sector, eHealth has been used in many different forms. Mair et al. (2007) divided those forms into four broad categories; management systems, communication systems, computerized decision support systems and information systems. Rouleau, Gagnon and Côté (2015) explained the four categories in Table 1:

**Table 1.** ICT interventions (Mair et al., 2007).

<p><b>Management systems.</b> They are computer-based systems like electronic patient record designed for storing and displaying patient record and health information for different stakeholders in order to support administrative and/or clinical activities.</p>	<p><b>Communication systems.</b> This category includes e-mail and other telecommunication devices that are used for synchronous or asynchronous communication between patient and health professionals or within health professionals for sharing, support or consult.</p>
<p><b>Computerized decision support systems.</b> These systems refer to a real time computer-based system, which is programmed to support health professionals in decision making based on clinical guidelines and care pathways.</p>	<p><b>Information systems.</b> These are web-based systems rich with health and life style on general level designed to access information using Internet or intranet.</p>

Table 1 describes the core categories of ICT solutions.

The next subchapters describe potential use of ICT and its impact in health sector.

## 2.1.1 Potential uses of ICT in health sector

ICT in the health sector also known as eHealth is the use of information and communication technologies for health (Mair et al., 2007). Within health sector, ICT is used in various forms, for instance monitoring public health, educating health workers, tracking diseases, research and treating patients (WHO, 2005).

**Table 2.** Potential uses of ICTs in health sector (Pagliari et al., 2005).

<p><b>Professional Clinical Informatics</b></p> <ul style="list-style-type: none"> <li>- Decision aids for practitioners (prompts, reminders, care pathways, guidelines)</li> <li>- Clinical management tools (electronic health records, audit tools)</li> <li>- Educational aids (guidelines, medical teaching)</li> <li>- Electronic clinical communications tools (referral, booking, discharge; correspondence, clinical email/second opinion, laboratory test requesting/results reporting, e-shared care)</li> <li>- Electronic networks disease-specific clinical networking systems)</li> <li>-Discipline/disease-specific tools (diabetes informatics)</li> <li>- Telemedicine applications (for inter professional communication, patient communication and remote consultation)</li> <li>- Subfields (nursing &amp; primary care informatics)</li> </ul>	<p><b>Electronic Patient/Health Records (EPR, EHR)</b></p> <ul style="list-style-type: none"> <li>- Electronic medical records. Record linkage. The Universal Patient Indicator. Databases and population registers.</li> <li>- Achieving multi professional access. Technical and ethical issues.</li> <li>- Data protection/ security issues</li> <li>- Patient access and control</li> <li>- Integration with other services (social work, police)</li> <li>- Clinical coding issues (terminologies)</li> </ul> <p><b>Healthcare Business Management</b></p> <ul style="list-style-type: none"> <li>- Billing and tracking systems</li> <li>- Audit &amp; quality assessment systems</li> </ul>	<p><b>Consumer Health Informatics</b></p> <ul style="list-style-type: none"> <li>- decision support for patients e.g. genetic screening</li> <li>- Information on the Web and/or digital TV (public information and educational tools for specific clinical groups)</li> <li>- Clinician-patient communication tools:               <ol style="list-style-type: none"> <li>1. Remote: Clinical e-mail and Web-based messaging systems for monitoring disease, service-oriented tasks (booking appointment, recording prescriptions), consultation.</li> <li>2. Proximal: Shared decision making tools, informed consent aids</li> <li>3. Mixed: Screening tool that can be used online for depression and therapeutic interventions</li> </ol> </li> <li>- Access data protection issue</li> <li>- Quality issues for health information on the net - “virtual” health communities</li> </ul>
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Table 2 summarises potential use of ICT in health sector. It also highlights the technologies dominating eHealth which are clinical informatics, EPR/EHR and consumer health informatics. eHealth has helped to improve many areas in the health sector. Major benefits of eHealth are the following: enhancing quality of care by enabling access to more information to assist in decision making, EPR/EHR designed to make patient’s medical history accessible for practitioners to reduce the risk of poor delivery of care. ICT in health sector has also helped in enhancing communication and coordination among healthcare providers and improved administrative efficiency.

## 2.1.2 Impact of ICT in healthcare

In the early days, ICT contributed mainly to the timely and efficient communication of care data. These days the focus is shifting to improving quality and efficiency in health care by using on-line clinical data acquisition and processing. (Takeda et al., 2003.)

The complexity of choices of technologies, as well as the needs and demands of health systems suggests that the best way forward is to gradually introduce, test and refine new technologies. ICT is reasonably expected to be used efficiently and effectively in healthcare areas (Chetley et al., 2006).

**Table 3.** Emerging technologies in health sector (Pagliari et al., 2005).

What emerging technologies are likely to impact on health care?	How does research inform eHealth?	How do developments in eHealth inform research?
<ul style="list-style-type: none"> <li>- Satellite communications (for remote medicine)</li> <li>- Wireless networks (within hospitals, across geographical areas)</li> <li>- Palmtop technologies (for information, for records)</li> <li>- New mobile telephones</li> <li>- Digital TV (for disseminating health information &amp; communicating with patients)</li> <li>- The WWW and its applications for health (issues: quality control, confidentiality, access)</li> <li>- Virtual reality (remote/transcontinental surgery)</li> <li>- Nanotechnology</li> <li>- Intersection of bioinformatics and health informatics.</li> </ul>	<ul style="list-style-type: none"> <li>- Development - Need for user involvement in product conception, design and testing.</li> <li>- Iterative development.</li> <li>- Needs assessment, accessibility and usability research.</li> <li>- Multi-faceted expertise required.</li> <li>- Implementation               <ul style="list-style-type: none"> <li>- Understanding people and organizational factors, system acceptability, resistance to change. Use of tailored implementation strategies.</li> </ul> </li> <li>- Innovative methods for mapping functional and technology needs, place of systems in the organization</li> <li>- Knowledge management, systems approaches, communication networks models, organizational development to map pathways.</li> <li>- Outcome assessment as evaluation formative for clinical outcome.</li> </ul>	<ul style="list-style-type: none"> <li>- Potential of electronic databases such as population registers for epidemiological research.</li> <li>- Research into the impact or use of informatics tools suggests appropriate and cost-effective priorities for policy makers.</li> <li>- Areas of cross-over (bioinformatics)</li> </ul>

As it is shown in Table 3, using ICT in health sector opened a door to reach series of desired outcomes in health industry such as: assisting health experts in decision making by enabling remote consultation and robust communication, collaboration and cooperation among health workers. Health centres provide better quality service by improving dissemination; informing people about their medical choices; creating awareness for policy makers and governments about health risks and health needs. As well as outlining a health and administration system to be effective and efficient. (Mair et al., 2007; Pagliari et al., 2005.)

## 2.2 Understanding depression

This section focuses first on the notion and types of depression. Then it reports how depression is perceived by the society followed by depression and elderly. Finally, it explains depression's impact on the society and how it affects the economy.

### 2.2.1 Background on depression

The different phases of life that people go through such as unemployment, bereavement, psychological trauma tend to be possible victim of depression (WHO, 2015). According to World Health Organization (WHO) depression is a mental disorder. Some of its indications include poor concentration, low self-esteem, loss in appetite, tiredness, loss of interest, sadness and feeling guilty. This mental disorder is considered to be common among individuals. (WHO, n.d.)

Depression is something created by psychosocial factor like social isolation and socio-economic status (Hare, Toukhsati, Johansson, & Jaarsma, 2014). However depression is regularly seen, as a treatable and prevalent mental disorder (Kroenke, Spitzer, & Williams, 2001). By the year 2030 depression is predicted as one of the top three leading burden diseases along with HIV/AIDS and ischaemic heart disease. The latter causes early retirement and dependence on social support. (Mathers & Loncar, 2006.)

Beck and Alford (2009) clearly mention the identification points or behaviours of depression as follows:

1. A specific alteration in mood: sadness, loneliness, apathy
2. A negative self-concept associated with self-reproaches and self-blames
3. Regressive and self-punitive wishes: desire to escape, hide or die.
4. Vegetative changes: anorexia, insomnia, loss of libido
5. Change in activity level: retardation or agitation.

The characteristics defined by WHO can become long lasting and can lead to significant impairments in an individual's ability to take care of his or her everyday responsibilities (Marcus, Yasamy, van Ommeren, Chisholm, & Saxena, 2012). Depression is treatable unfortunately many depression victims do not get the needed care and support. From the many few of the obstacles preventing people from seeking help are lack of access to treatment and stigma related to depression. (WHO, 2012.)

### 2.2.2 Types of depression

Two people might suffer from depression but the symptoms might show they suffer from different types of depression. While the illness of depression has enough common features to be considered a diagnostic category, each person's version of depression is unique. (Greenblatt, 2011.)

Depression is not a mood swing or temporary emotional reaction to challenges in the daily life. Depending on how often one experiences depressive symptoms (see Table 4) and their severity, depression can be categorized as mild, moderate or severe. (WHO, 2015.)

**Figure 1. Table 4.** Types of depression (Greenblatt, 2011).

Type of Depression	Characteristics
Major Depression	<p>Loss of interest or pleasure in activities, trouble getting to sleep or feeling sleepy during the day, feelings of being "sped up" or "slowed down", being tired and without energy, feeling worthless or guilty, trouble concentrating or making decisions, thoughts of suicide.</p> <p>Experiencing five or more of the symptoms for two weeks or more is diagnosed as Major Depression.</p> <p>Death of loved one, divorce, disability, chronic physical illness, trauma, substance abuse, childbirth and job loss are possible reasons for major depression.</p>
Minor depression/Dysthymia/ Dysthymic Disorder	<p>Depressed mood, loss of interest or pleasure in things normally enjoyed. A chronic, mild depression that lasts for two years. Minor depression has less intense than Major depression.</p>
Bipolar Disorder	<p>Mood swings that range from high energy to low energy mood, also considered as depressive mood. When in the low phase, symptoms of major depression occur.</p> <p>Accompanied by at least three of the following symptoms: Inflated sense of self-importance, decreased need of sleep, extreme talkativeness, rapid flitting from one idea to the next, distractibility, overindulge in activities that result in negative consequence.</p>
Postpartum Depression	<p>Characterized by Major depressive episodes. Symptoms may last up to a year. 10-15% of women experience after giving birth within one month of delivery.</p>
Psychotic Disorder	<p>Symptoms of major depression along with hallucinations, delusions and paranoia. Psychotic depression appears when severe depressive illness coexist with some form of psychosis.</p>
Seasonal Affective Disorder	<p>A period of Major Depression, have cravings for sweets and starchy food, sleep more, lack of energy and withdraw from social situations. Most often happens during fall or the winter months, when sunlight gets less and less.</p>
Atypical Disorder	<p>Increased appetite, sleeping more than usual, feeling of heaviness in the arms and legs, oversensitive to criticism, positive event can temporarily improve mood. Atypical disorder is different than the persistent sadness of typical depression.</p>
Double Depression	<p>Occurs when a person with minor depression suffers an episode of Major depression.</p>
Secondary Depression	<p>Appears following a medical problem. Possible reasons for secondary depression are: After stroke, Parkinson's disease, Alzheimer's disease, acquired immunodeficiency syndrome (AIDS) or Psychiatric condition.</p>
Masked Depression	<p>Manifested as physical complaint with no organic cause. Masked depression can take a long time to diagnose.</p>

Greenblatt (2011) lists down the most common types of depression. Table 4 summarizes types of depression into ten broad categories. Most of the symptoms for depression are similar and include loss of interest, feeling hopeless, feeling helpless, change in weight, loss of appetite, self-loathing and thoughts of suicide. However, the symptoms have various levels. The same symptoms can be chronic for one or last few days for another individual. The severity of the symptoms creates the categories of depression shown on the Table 4.

The Patient Health Questionnaire (PHQ-9) is widely used to diagnose the level of depression as criteria-based self-assessment of depression scale (see Table 5). PHQ-9 consists of nine depression and depressive disorder symptom base questionnaire. American Heart Association Science Advisory uses PHQ-9 to assess patient's experience of anhedonia and mood. (Hare et al., 2014; Kroenke et al., 2001.)

**Table 5.** The Patient Health Questionnaire (PHQ-9) (Rumsfeld & Ho, 2005, p. 2).

<b>Over the last 2 weeks, how often have you been bothered by any of the following problems?</b>	<b>Not at all</b>	<b>Several Days</b>	<b>More than half the days</b>	<b>Nearly every day</b>
1. Little interest or pleasure in doing things	0	1	2	3
2. Feeling down, depressed, or hopeless	0	1	2	3
3. Trouble falling or staying asleep, or sleeping too much	0	1	2	3
4. Feeling tired or having little energy	0	1	2	3
5. Poor appetite or overeating	0	1	2	3
6. Feeling bad about yourself – or that you are a failure or have let yourself or your family down	0	1	2	3
7. Trouble concentrating on things, such as reading the newspaper or watching television	0	1	2	3
8. Moving or speaking so slowly that other people could have noticed. Or the opposite – being so fidgety or restless that you have been moving around a lot more than usual	0	1	2	3
9. Thoughts that you would be better off dead, or of hurting yourself in some way	0	1	2	3

The patient filled questionnaire (see Table 5) is read according to the following instruction to understand the level of depression. If total score is 1-4 it is categorised as Minimal depression; 5-9 is Mild depression; 10-14 is Moderate depression; 15-19 is Moderately severe depression and 20-27 is Severe depression (Rumsfeld & Ho, 2005). The diagnosis of depression is generally based on the filled scale based questionnaire, structured interview and clinical observation only. Such diagnoses are likely to be inconsistent as the latter often depend on subjective description given by patient and physician's interpretations of those descriptions. (Valenza et al., 2014.) Having patient's physiological and physical activity data collected from wearable device as additional variable can help to avoid biased interpretation.

### 2.2.3 Depression perceived by the society

The complex social interaction along with biological and psychological factors cause depression (WHO, 2015). It is important that depression needs to be understood as a very common mental health problem which can be treated with a variety of treatments available such as, psychological therapy and medicine (Fortune, Barrowclough, & Lobban, 2004).

Depression is perceived in two different ways by the society, known as Prozac notion story and stigma story. The group of society categorised as Prozac notion thinks depression is about medicine being a bad thing. It is important to understand that Prozac was initially developed to treat clinical depression. The Prozac Notion Story maintains that people take a lot of antidepressant for something that is not really an illness. (Lewis, 2006, p. 122.)

On the other hand stigma story focuses on people who think the society has negative attitude towards them and who feel embarrassed to seek professional help (Barney, Griffiths, Jorm, & Christensen, 2006). On a global context, about 70 % of mental illness victims do not get the required treatment due to the following reasons: lack of knowledge about mental illness and its treatment, ignorance about the treatment, stigmatization and expected discrimination against victims of mental illness (Thornicroft, 2008).

Stigmatizing attitudes toward people with mental illness are identified in the general public. Individuals with depressive disorders are perceived as dangerous, unpredictable, weak, no one but themselves to blame for their condition by the society. The stigmatization attitude is wide spread that victims choose not to seek professional help in fear of the social distance. (Cook & Wang, 2010 ; Barney et al., 2006.)

It is important to understand that there is public stigma, personal stigma and self-stigma. Public stigma is the general perception of an individual about what the general public feel or understands depression. Personal stigma is how the individual suffering from depressive symptoms understands the society's perception with regards to depression whereas self-stigma is how the individual suffering from depression believes the public or the society perceives depression. (Rüsch, Angermeyer, & Corrigan, 2005 ; Aromaa, Tolvanen, Tuulari, & Wahlbeck, 2011.)

A survey conducted by Aromaa et al. (2011) on randomly selected 10,000 individuals aged from 15 – 80 years old residing in western Finland, is a good example to show how stigmatization affects help seeking for depression victims. Sixteen statements were used for the survey to find out people's attitude towards public stigma. From the sixteen the following five statements are extracted to measure personal stigma (Aromaa et al., 2011, p. 4) :

1. Depression is a sign of failure
2. People with depression have caused their problems themselves
3. Depressed people should pull themselves together
4. Mental health problems are a sign of weakness and sensitivity
5. Depression is not a real disorder

The result of the study has shown that only 34% of individuals seek professional help when experiencing depression. The survey also confirmed the high level of stigma with regards to depression among the society proved by the high percentage of agreements to the statements mentioned above. (Aromaa et al., 2011.)

#### 2.2.4 Effects of depression in the society

Long lasting mild and severe depression can become a serious health condition when worsened can lead to suicide (WHO, 2015). According to WHO (2012), almost one million people commit suicide each year. For every person who commits suicide, there

are 20 or more who make an attempt. Statistics have shown that 11% of EU citizens suffer from depression at some point of their life (Olesen et al., 2012).

Depression is a common reoccurring disease. Its chronic effect has a major impact on economic cost. The economic cost of depression is high as it affects the general population including the active working force. (Wang, Simon, & Kessler, 2003.)

The early detection and treatment can save a significant amount of loss caused directly or indirectly by this disease such as:

- Early retirement – increases the number of society group above 60 years old.
- Sick leave which leads to loss of productivity - 50% is due to depression
- Suicide rates rise up – this act might get contagious in the society.
- In Europe annual cost of depression in total was estimated 118 billion Euro in 2004. This equals to 253 Euro per inhabitant (Sobocki, Jonsson, Angst, & Rehnberg, 2006).

In a cross-sectional survey conducted in 35 countries worldwide, 1082 participants diagnosed with major depression, 79% of the participants indicated to have experienced discrimination in their life (Lasalvia et al., 2013). Depression affects the entire activity of a person. Depressed individual functions poorly in activities at work, school and his or her social interaction with family and friends. (WHO, 2015.)

### 2.2.5 Depression as a medical illness

Even though depression has been recognized as a clinical syndrome for over 2,000 years, no satisfactory explanation was found for puzzling and paradoxical features of depression (Beck, 1967, p. 3). There are two views by physicians in considering depression as a medical illness. This study is done by considering depression as a medical illness.

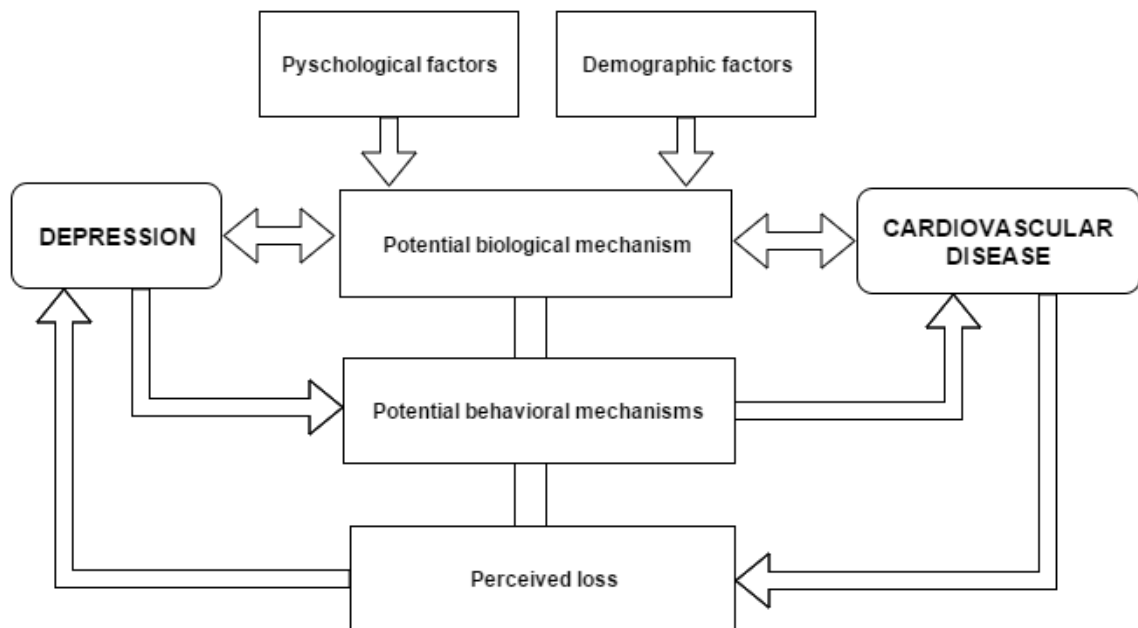
Every part of the human body including our brain is controlled by genes that are responsible for producing the enzymes for our body (Understanding Depression, 2009). However when there is an over production of these enzymes our body becomes imbalanced and this phenomena may be a cause for major depression (Bilici et al., 2001).

Depression may predispose an individual to atherosclerosis, arrhythmias, myocardial infarction, heart failure and sudden death (Grippe & Johnson, 2002). Depression is a medical condition that affects individuals emotionally and physically. It has genetic and biological causes because certain individuals are vulnerable to depression (Gotlib & Hammen, 2008, p. 87). Research finding carried out by Harvard Medical School supports that depression is biological because people who inherit two genes with a particular variant in a serotonin-transporter gene (5-HTT) were more likely to become depressed in response to stress (Understanding Depression, 2009).

Although women report being affected by depression twice as much as men, depression certainly affects men as well (Marcus et al., 2012). It is also important to understand that depression is not only related to laziness. Some of the well-known individuals who were victims of depressive disorder include Sir Isaac Newton, Ludwig von Beethoven, Napoleon Bonaparte, Winston Churchill, Michelangelo, Alexander the Great, Barbara

Bush, Abraham Lincoln, Stephen Hawking, Theodore Roosevelt and Charles Darwin (Marcus et al., 2012).

Depression and heart disease are common companions and each can lead to the other. Depression is a recognized risk factor for Coronary artery disease (CAD) (Grippe & Johnson, 2002). Depression and Cardiovascular disease (CVD) are common. Compared to the general population CVD patients have more depression. Individuals with depression are most likely in time to develop CVD and also have a higher mortality rate than the general population. (Hare et al., 2014.)



**Figure 2.** Potential factors explaining relationship between CVD and depression (Hare et al., 2014).

Figure 2 demonstrates the possible interrelation between depression and CVD. Psychosocial factors such as history of depression, anxiety, personality, social isolation, bereavement together with demographic factors like age, gender, socio-economic status and unemployment are potential contributors to biological mechanisms (see Figure 2). Potential biological mechanism includes autonomic nervous system, platelet receptors and function, coagulation factors, pro-inflammatory cytokines, endothelial function, neurohormonal and genetic. Potential biological mechanism can impact depression and CVD or the latter two can impact potential biological mechanisms.

Smoking, obesity, inactivity, poor diet and poor medication adherence are the potential behavioural mechanisms resulted from the impact of potential biological mechanisms. These behavioural mechanisms can lead to CVD or can also be the impact of depression. CVD can result in perceived loss and can lead to depression (see Figure 2). Perceived loss includes health, functional capacity, immortality/invincibility, independence, sexual relationship, employment and financial security (Hare et al., 2014).

Another major cause for depression and heart disease relation is the potential side effect of antidepressants (Hildebrandt, 2011). As interdependency and relation of depression and cardiovascular disease shown on Figure 2, this relation can also be further

explained by understanding the effects of antidepressants on patients. Adverse reactions are expected from antidepressants even though the new generation of antidepressants are better and have a lower rate of noncompliance compared to existing ones (Khawam, Laurencic, & Malone, 2006). Yet the number of patients encountering heart associated problems with the use of these new antidepressants has increased. The new generation of antidepressants are said to be better because they do not contain a substance known as cardiotoxicity like the previous antidepressants. (Pacher & Kecskemeti, 2004.)

However sudden and unexplained death among patients using antidepressant has raised the alarm to look into the source cause. Results of numerous recent basic research and clinical studies have identified electrophysiological effect in the new generation of antidepressant along with other drugs which proves that the antidepressants are toxic. Recent studies have also demonstrated that depression victims who are already a cardiac disease patient need great caution when using antidepressant drugs to avoid the unexpected, sometimes life-threatening cardiac arrhythmias. (Pacher & Kecskemeti, 2004 ; Wang, Parker, & Maxwell, 1981.)

### 2.2.6 Depression and senior citizens

As one can be predisposed genetically to diabetics or high blood pressure, in the same way individuals can be predisposed to depression genetically. If a family member has a history of depression, chances of having depression are higher than the ones who have no family history of depression. (Neumeister et al., 2002.) Senior citizens are more prone to depression than younger generation (Stordal, Mykletun, & Dahl, 2003). Senior citizens do generally experience more of the events that can trigger depression such as loss of family and friends, health impairment (Stordal, Mykletun, & Dahl, 2003), isolation, financial worries and less education in higher age group (Alexopoulos, 2005; Gray.n.d.).

However, the International Classification of Diseases (ICD-10) and American Psychiatric Association's Diagnostic and Statistical Manual (DSM-IV) define late life depression referring to depressive syndromes that arise in adults older than age 65 years old (Alexopoulos, 2005).

Among all age groups the highest rate of suicide occurs in the senior citizen group. This is due to the fact that 80% of depressive syndromes are present among people aged older than 74 years. Among people committing suicide men are more vulnerable than women. (Gray, n.d.) Female gender appears to be an important risk factors for depression among elderly community subjects (Cole & Dendukuri, 2003).

Although progress has been made in characterizing depression in the senior citizens and in improving its treatment, Major Depressive Disorder, Minor Depressive Disorder, Dysthymic Disorder, Bipolar Disorder and Adjustment Disorder with depressed mood are the common types of depression observed in the elderly people. They are caused due to the reasons listed in Table 4, plus dislocation and impairment (Alexopoulos, 2005).

## 2.3 Research on wearable device

The following subchapters highlight brief history of wearable technology followed by market focus of existing wearable ICT solutions and their features.

### 2.3.1 Background

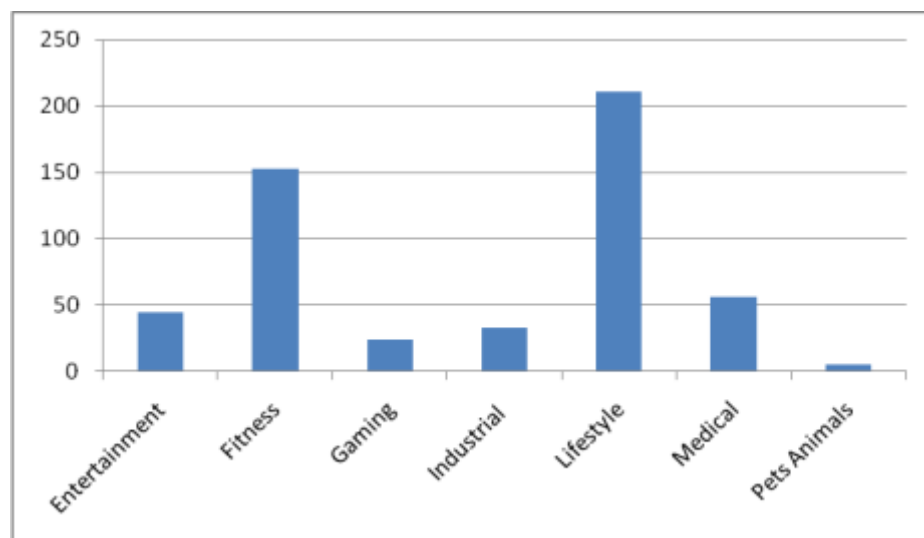
From room size, computers have shrunk in time to palm size. The transition in computing devices size make the devices shift from passive accessories to wearable appliances that can be integrated with our personal space and fit user's life style better. (Billingham & Starner, 1999.) A wearable device technology has opened a door for continuous healthcare monitoring to be more upbeat and affordable (Otto, Milenkovic, Sanders, & Jovanov, 2006).

Wearable computers by definition can be anything ranging from wrist-mounted systems to large backpack computers (Billingham & Starner, 1999). The first wearable computing device was designed by MIT students Thorp and Shannon in 1961 to win at blackjack table in Las Vegas. The device they designed to win the gambling card game latter called "The Gambling Shoe" (Thorp, 1998).

Wearable computer technology is opening up capabilities to record more details of "reality" from life and work experiences than have ever been possible (Strub, Johnson, Allen, Bellotti, & Starner, 1998). Having a system that can monitor human activity from wearable sensors is a stepping stone for applications and organizations working in healthcare and fitness monitoring (Choudhury et al., 2008).

### 2.3.2 Existing wearable devices

According to Wearable tech market (n.d.) database there are seven categories of wearable devices with amount to a total of 347 different types of wearable devices produced and on the market. These devices focus on different areas of market such as entertainment, fitness, gaming, industrial (wearable solutions designed to aid industrial workers accomplish tasks at hand, enhance work place safety), lifestyle, medical and pets (wearable technologies designed to aid companion pets and monitor & track their activity). Figure 3 shows the market categories.



**Figure 3.** Categories and market focus area of existing wearable devices (Wearable tech market, n.d.).

As it is shown in Figure 3, majority of the devices are categorized in health and healthy life style. These products range from headband to ankle bands developed in various styles to accommodate customer desires (Wearable tech market, n.d.). Over the last decade the interest in wearable technology has raised both in marketing and research. Wearable devices have introduced major benefits like wearability obviously, lightness, small in size and low power consumption. (Valenza et al., 2014.)

The market for wearable computing devices is booming over the years. Big name companies like Polar Electro, Apple, Samsung, Motorola and Microsoft's wearable devices are also included in the above list (Wearable tech market, n.d.). Using wearable devices for long term monitoring is challenging because of the issues related to comfort, artefact rejection and power consumption. To overcome those challenges, it is recommended to use multiple sensor for long term monitoring. (Valenza et al., 2014; Scilingo, Lanata, & Tognetti, 2011.)

### 2.3.3 Wearable devices hardware

It is important to understand the human body activity or physical activity (PA) in order to track any chronic disease. Obtaining accurate and detailed PA measurement is crucial to detect or see any disease or abnormality in the human body. In order to do so, accelerometer were chosen to measure the human body PA. (Chen & Bassett, 2005.)

Accelerometer is the most common component in wearable devices (Wearable tech market, n.d.). Accelerometers are devices that measure body movements in terms of acceleration. Accelerometer can also be used to evaluate PA's intensity. (Chen & Bassett, 2005.) As a device, accelerometer sends data wirelessly to a computing device by recognizing user activity using signals (Bao & Intille, 2004).

Accelerometer's miniature size makes it handy to embed them with wearable computing devices such as bracelets, wrist band and belts (Bao & Intille, 2004). A laboratory based trials have confirmed that triaxial accelerometers have shown more than 90% accurate results of various human body movement related to common daily activities such as walking, resting even detection of possible falls (Karantonis, Narayanan, Mathie, Lovell, & Celler, 2006).

There are various range of electromechanical devices used to measure acceleration but the most commonly used is piezoelectric sensors (John, 2011). Piezoelectric sensors can detect accelerations in one to three positions and record the data in internal memory (Chen & Bassett, 2005). However, since the latter are too large to use in all devices, technology findings have improved the accelerometer use and introduced Micro-Electro Mechanical System (MEMS) based accelerometer, a smaller and effective device. MEMS were first introduced about 25 years ago. (John, 2011.)

MEMS measure the physical acceleration that is measured by sensors. The sensors take into consideration the parameters of environment they are working in, such as temperature, pressure, force and light (Analog Devices, n.d.). MEMS technology has also numerous advantages compared to other devices. MEMS deliver accurate data; they are small in size which makes it cost effective. MEMS are capable of incorporating two or three devices thus, data reception, filtering, storing, transfer, interfacing, and all other processes can be carried out with a single chip. These devices also provide multi axis sensor. (John, 2011.)

Wrist worn devices that fall under the categories of medical or lifestyle have a built-in heart rate monitor also known as ECG sensors. ECG sensors are components designed to measure and record specifically made for medical human heart rate. Few of the wrist worn devices also include a feature known as skin impedance sensor which is designed to measure the amount of electrical resistance in the skin. (Wearable tech market, n.d.) It is also known as GSR sensors (EDA, n.d.).

Wrist worn devices possessing screen on the device itself use one of the three types of displays. Most of the devices use Liquid Crystal Display (LCD) which is flat visual panel designed to display images and videos by using properties of liquid crystals. Products like Polar Loop and ZITKO walk use Light Emitting Diode (LED) display. LED is a flat panel uses an array of LED as a video or dot matrix to display. (Wearable tech market, n.d.; ICT Dictionary, n.d.)

Limited products use Organic Light-Emitting Diode (OLED) Display, usually lighter and thinner than LCD. OLED's flat display panel have electroluminescent made out of organic compound designed to emit light in response to electric current. There are devices that have adopted touch interface as a feature to their wearable's regardless of the type of display they use; for example, Samsung Galaxy Gear 2, Moto 360 Sport uses OLED display, Sony SmartWatch 2, Moto 360 uses LCD display. (Wearable tech market, n.d.)

There are additional features included on the wrist worn bracelets that make wearable devices more useful on the daily routine of the user such as watch, vibrator to signal notifications by creating mechanical vibrations, microphone and audio speaker, button interface to control setting and functions of a device and most importantly Global Positioning System (GPS) to provide location and time information of the user based on satellite navigation technology. (Wearable tech market, n.d.; ICT Dictionary, n.d.)

Regarding power source wrist worn devices use rechargeable battery (batteries that can easily be recharged from a common power source) or wireless charging (recharging the device by placing it on its wireless charging dock) or disposable battery. Devices such as MOTO 360 use both wireless charging and rechargeable methods. To improve battery life devices like Microsoft Band, Samsung Gear S2 and Atlas fitness tracker use a technology called Ambient Light Sensor. This technology is designed to adjust the back light brightness of the screen according to the light level surrounding it. (Wearable tech market, n.d.; ALS, n.d.)

### 2.3.4 System and platform

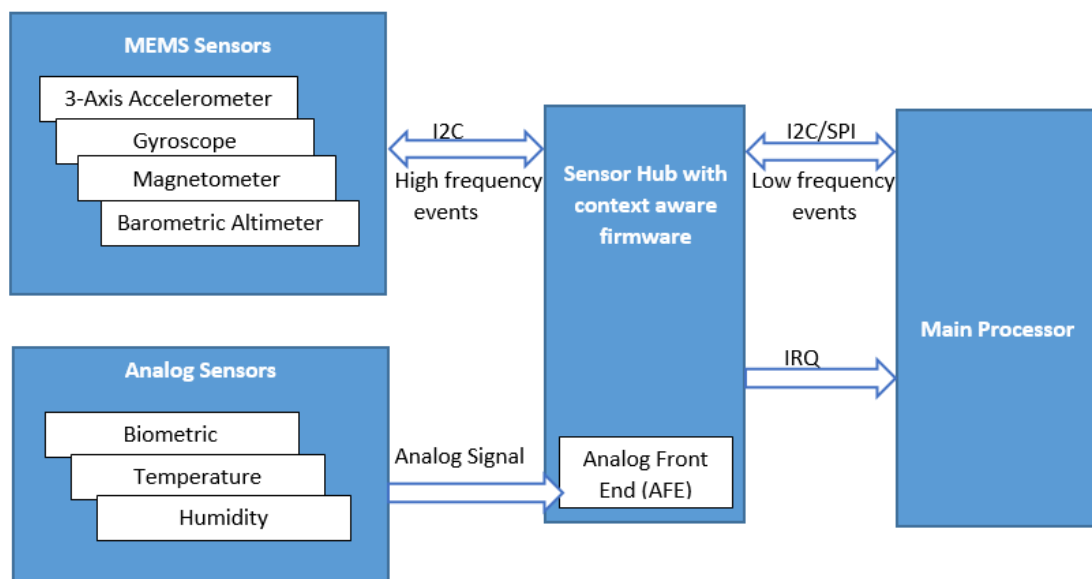
Connectivity is used as feature for wearable devices to exchange data between wearable devices and other mobile devices such as smart phones and laptops. The most common connectivity technology used in these wearables is Bluetooth. (Wearable tech market, n.d.) Bluetooth is a 2.45 gigahertz (GHz) frequency universal radio interface that enables electronic devices to connect and communicate wirelessly (Haartsen, 1998). Bluetooth Low Energy (BLE) and ANT+ are designed to enhance battery life for wearables by consuming low power (Ramasamy, Gowda, & Noopuran, 2014).

ICT dictionary defines connectivity as “ability of a software application or piece of equipment to connect to another application or piece of equipment” (ICT Dictionary, n.d.). From the many connectivity methods and protocols, the very few used by existing wearable technologies are: Universal Serial Bus (USB), Near Field Communication

(NFC), cellular network, WiFi and proprietary interface. Proprietary interface is communication within devices of same brand only. (Wearable tech market, n.d.)

As smaller size is one feature of wearables, microcontrollers play the biggest role in reducing overall size of wearables by integrating most of wearable's functionality on a single chip (Ramasamy, Gowda, & Noopuran, 2014). A microcontroller is a small computer (System on Chip) on a single chip also known as Integrated Circuit (IC) containing components of computer such as processor, programmable I/O peripherals and memory (Microcontroller, n.d.).

When a wearable device has multiple sensors, integrating data from different sensors that needs to be analysed in real time is going to demand the central processing unit. In order to alleviate this work load sensor hub is introduced on recent microcontrollers. (Ramasamy, Gowda, & Noopuran, 2014.) Figure 4 shows the role of sensor hub.



**Figure 4.** The role of sensor hub in a wearable system (Ramasamy, Gowda, & Noopuran, 2014).

As illustrated on Figure 4 collected data from sensors (MEMS and analog sensors) is sent to sensor hub instead of main processor. This technology takes the loads off from the processor, enhances performance and saves battery life. As for operating system, wearable devices with specific features can run on a real-time operating system (RTOS). An advance operating system is needed when features of wearable device includes extension to mobile phones. In such cases context aware algorithms are needed for sensor hubs. (Microcontroller, n.d.; Ramasamy, Gowda, & Noopuran, 2014.)

### 3. Research methods

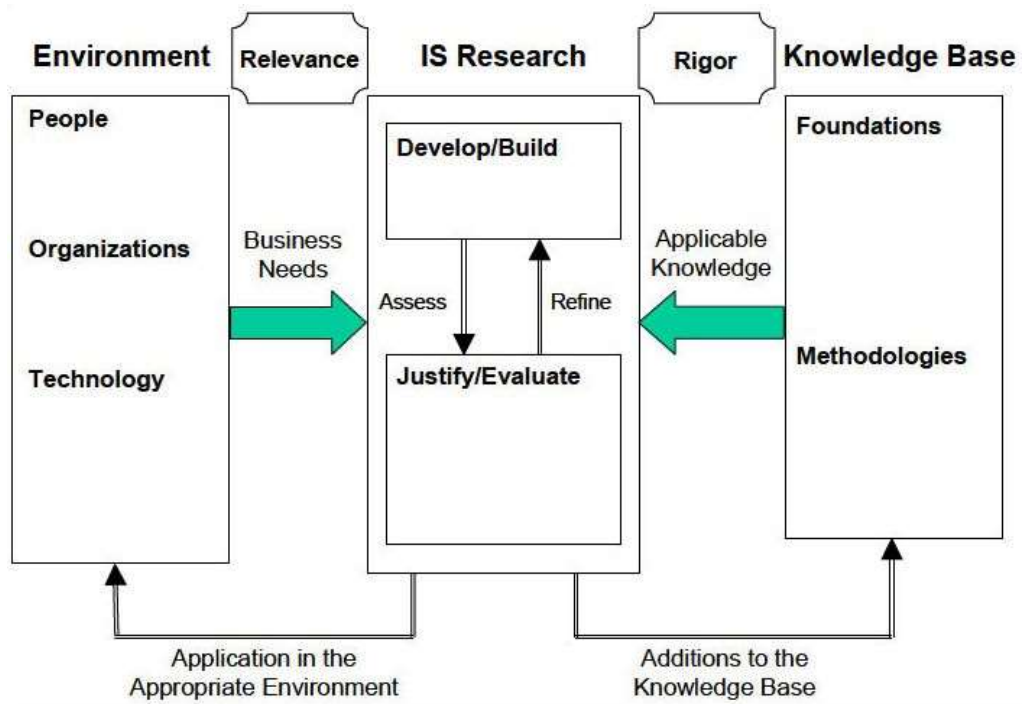
The ultimate goal of Design Science Research (DSR) is to create as well as evaluate IT artefact that solves known problems of an organization. The artefacts may include instantiations, constructs, models and methods. DSR involves a rigorous process to design artefacts to solve observed problems, to make research contributions, to evaluate the designs and to communicate the results to the appropriate audience. (Hevner, March, Park, & Ram, 2004.)

Hevner et al. (2004) asserted that DSR should address relevant problem by following six process iterations: identify the problem and motivation, define objectives of a solution, design and development, demonstration, evaluation and communication.

**Table 6.** Process model for DSR method (Hevner et al., 2004).

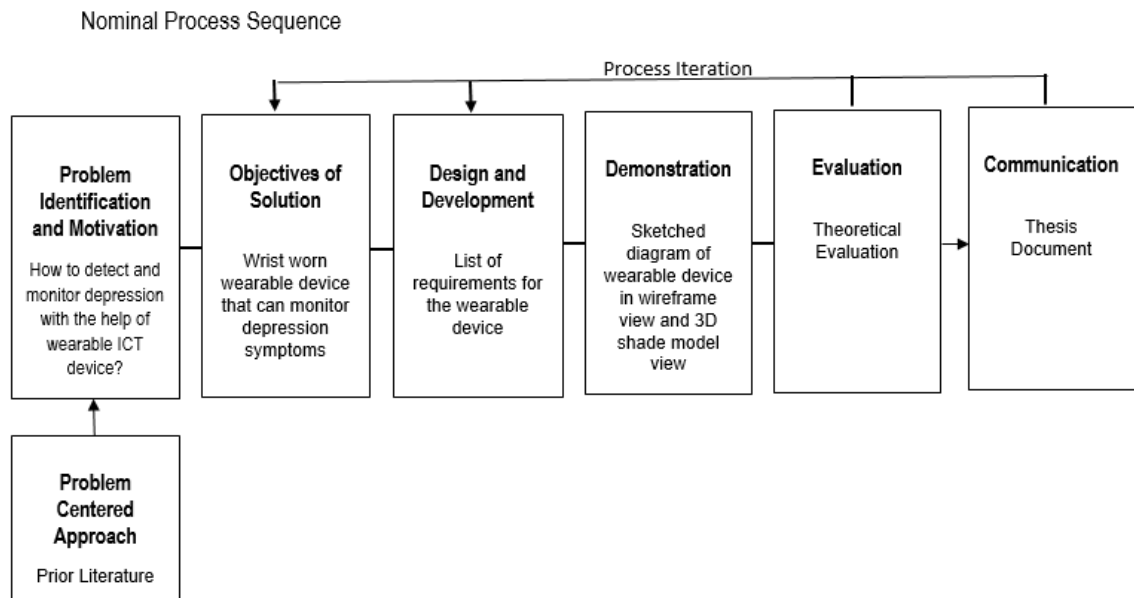
<b>Process</b>	<b>Description</b>
1: Identify problem and motivation	Process centred iteration by defining problem, show importance
2: Define objectives of a solution	Objective centred solution. Answers what would better artefact accomplish?
3: Design and development	Design and development centred iteration with the outcome of an artefact
4: Demonstration	Find suitable context, use the initiated context and artefact to solve problem
5: Evaluation	Observe how effective, efficient the artefact is by iterating back to design
6: Communication	Disciplinary knowledge professional publication

The process model on Table 6 was used on this study. The process model was applied with information system framework (see Figure 5) to identify the ideal solution for finding a possible solution for an early detection of depression with the help of ICT wearable device.



**Figure 5.** Information Systems Research Framework (Hevner et al., 2004).

The objective of DSR is to develop technology-based solutions to important and relevant problems (Hevner et al., 2004). The development of the artefact have to be a search process that draws solutions from existing knowledge and theories for the defined problem (Peppers, Tuunanen, Rothenberger, & Chatterjee, 2007). This study followed DSR process model with problem centric approach (see Figure 6).



**Figure 6.** Adopted research methodology in this study.

### *Activity 1: Problem identification and motivation*

The relevant questions on research are problem identifiers and motivation for DSR. The research questions can be answered using literature research (Offermann, Levina, Schönherr, & Bub, 2009). The study employed problem centric approach to answer the research question how to detect and monitor depression with the help of wearable ICT device? With assisting questions what depression is? How to monitor depression? And what technologies can be used to detect depression?

### *Activity 2: Objectives of the solution*

Second phase of DSR is designing solution; the phase is divided in to steps of artefact design and support literature research (Offermann, Levina, Schönherr, & Bub, 2009). On this study the objective was to find out optimal ways to monitor symptoms of depression with wrist worn wearable device. Based on earlier knowledge acquired from literature review the study identifies depression symptoms and the proposed solution will help in monitoring those symptoms.

### *Activity 3: Design and development*

Majority of existing wearable devices are designed to meet the specific market needs. Existing wearables can monitor activity, pulse rate and quality of sleep but they are designed as a lifestyle appliance or fitness tracker device. The wearable device proposed in this study consists of set of requirements that can monitor activity pattern, sleep quality, heart rate and other non-functional requirements. In addition, the wearable device featured panic button as a requirement that can alert user's doctor in case of extreme conditions especially when reaching at fatal stage of depression.

### *Activity 4: Demonstration*

On this study no actual construct was built for the artefact. To demonstrate the wearable device, sketched diagram of wearable device with wireframe view and 3D shade model view are designed and documented in Chapter 4 of this study.

### *Activity 5: Evaluation*

From the guidelines, evaluation in DSR focuses on valuation of design science outputs including theory and artefacts. Artefact evaluation includes theoretical arguments, laboratory experiments, mathematical proofs, criteria-based analysis, field experiments and simulations. (Pries-Heje, Baskerville, & Venable, 2008.) On this study theoretical evaluation was used to evaluate screen content and screen orientation of the wearable device.

### *Activity 6: Communication*

This thesis documents and presents, the entire research process starting from problem identification to proposed optimal solution along with artefact evaluation used to enhance the artefact's usability and readability taking in to consideration the context user, which in this case is the elderly.

## 4. The Construct

This section highlights the design aspect of the wearable device by presenting context (4.1), requirement for the wearable device (4.2), high-level conceptual framework (4.3), UML activity (4.3.1) and use case diagram (4.3.2). And later addresses the design (4.4) and system flow (4.5).

### 4.1 The context

The wrist worn device was specially designed to help both the physicians and mostly individuals suffering with depression. It was a device that can be used by all age groups but in this study it focuses on the elderly. Depression has been on the focus as it is affecting a large number of the society worldwide and has been proven to be fatal at its worst.

The wearable device was designed for monitoring depression and individual's activity and well-being at all time. In order to give the expected support, the device needs to collect real time data without interruption. The latter requires the user to wear the device at all time for 24/7. The device should be water resistant and water proof to make sure that it collects uninterrupted data.

Wearing this device on daily basis day and night is the number one requirement for the technology to deliver effective heart rate, activity and sleep pattern information. In the long run, the collected data will help alleviate depression crisis, which results in thoughts of suicide at higher stages. The device has a side button known as panic button, designed to be used in case of emergency. In this case, an emergency situation is when the user who is a depression victim, happens to reach the high level and starts having suicide thoughts. The panic button has a different colour to differentiate it from other buttons on the device.

The design considered its target group, which in this case was the senior citizens, and had appealing features with comfort. It is also important that the device is not considered as a "medical device" that monitors depression by the user due the existing self and public stigma (see Section 2.2.3). For the user comfortably wear the device, it is best to incorporate more functionality to the device beyond monitoring the wellbeing of the user.

In order to reinforce the daily use of the wearable device, incorporating a clock and calendar features makes it to be worn daily as a normal watch instead of a medical monitoring device. The wearable device is designed for emotional, physical and mental benefit of user, this is the main reason why the design is considering users comfort while using and wearing the device.

### 4.2 Requirements for the device

The wearable device needs to incorporate a decent set of functions and features in order to track and monitor depression symptoms and its level. The basic requirements for the wearable device are listed on the following tables.

**Table 7.** Functional requirement.

<b>Functional requirement</b>	
REQ 1	The device has to be worn on wrist by the user all the time.
REQ 2	The device must have two buttons on the right side.
REQ 3	The wearable device needs to be small and lightweight.
REQ 4	The device must be water and splash resistant for the user.
REQ 5	The device has to work under all weather conditions.
REQ 6	The device uses service application installed on a mobile phone as an app
REQ 7	The font size and display orientation of the text to be displayed on the screen should be readable for the user
REQ 8	The displayed information on the wearable device's screen must use minimum character units yet be informative and easily understood.

In order to have a complete data regarding the user's activity, heart rate and sleep pattern the device has to be worn on the wrist at all time and during any daily activity. Thus the device must be small and lightweight as well as water and splash resistant for the user to wear it in the shower or while swimming.

The two side buttons functionality is as follows: the first side button will be used for adjusting and controlling the wearable device's settings where as the second side button, will be used as panic button. The purpose of second button is to send an alert message when long pressed (Pressed for at least 3 seconds) by the user. The alert message indicates user's location, his/her current physical state including their pulse rate.

**Table 8.** MEMS sensors requirement.

<b>MEMS sensors</b>	
REQ 9	3-Axis accelerometer to monitor activity and sleep pattern.
REQ 10	Optical heart rate sensors.
REQ 11	GPS

**Table 9.** Connectivity requirement.

<b>Connectivity</b>	
REQ 12	Bluetooth Low Energy (Bluetooth 4.0)

**Table 10.** Compatibility requirement.

<b>Compatibility</b>	
REQ 13	The application software shall run on iOS, Android and Windows.
REQ 14	The device should support iPhone, Android and Windrows phone.

The collected data from wearable device are saved on cloud using service application installed on a mobile phone. The application software shall run on the mobile devices which uses an operating system iOS, Android and windows.

**Table 11.** Power source requirement.

Power source	
REQ 15	Rechargeable battery

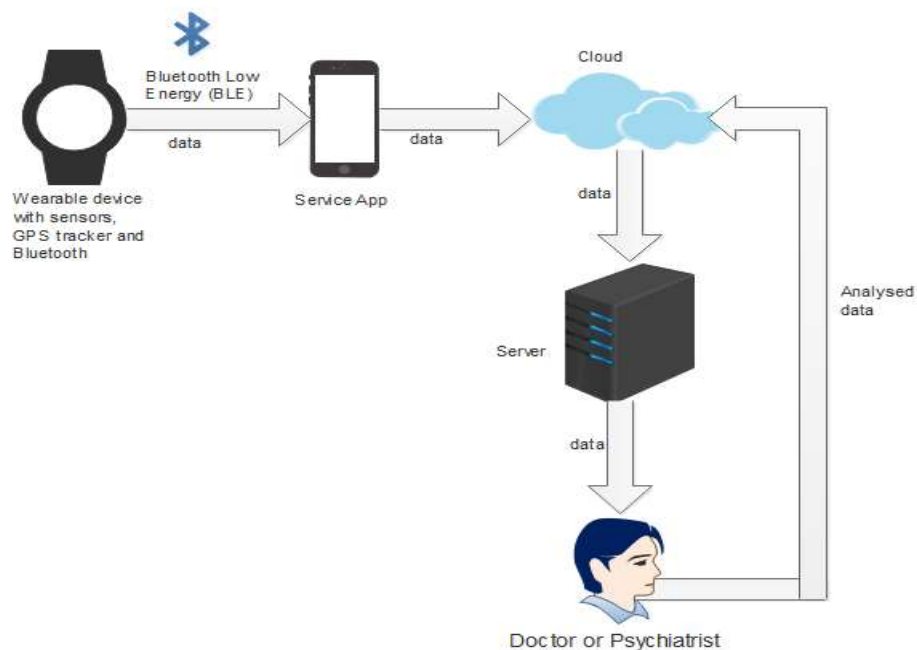
**Table 12.** Additional features requirement.

Additional features	
REQ 16	Digital watch
REQ 17	Calendar
REQ 18	Screen must display current time and date, battery usage indicator bar, connectivity status and BPM.

Adding extra features such a digital watch and calendar and displaying them on the screen helps the user consider the device as a digital watch instead of medical device. User can check current time, date including one's beats per minute.

### 4.3 Conceptual framework

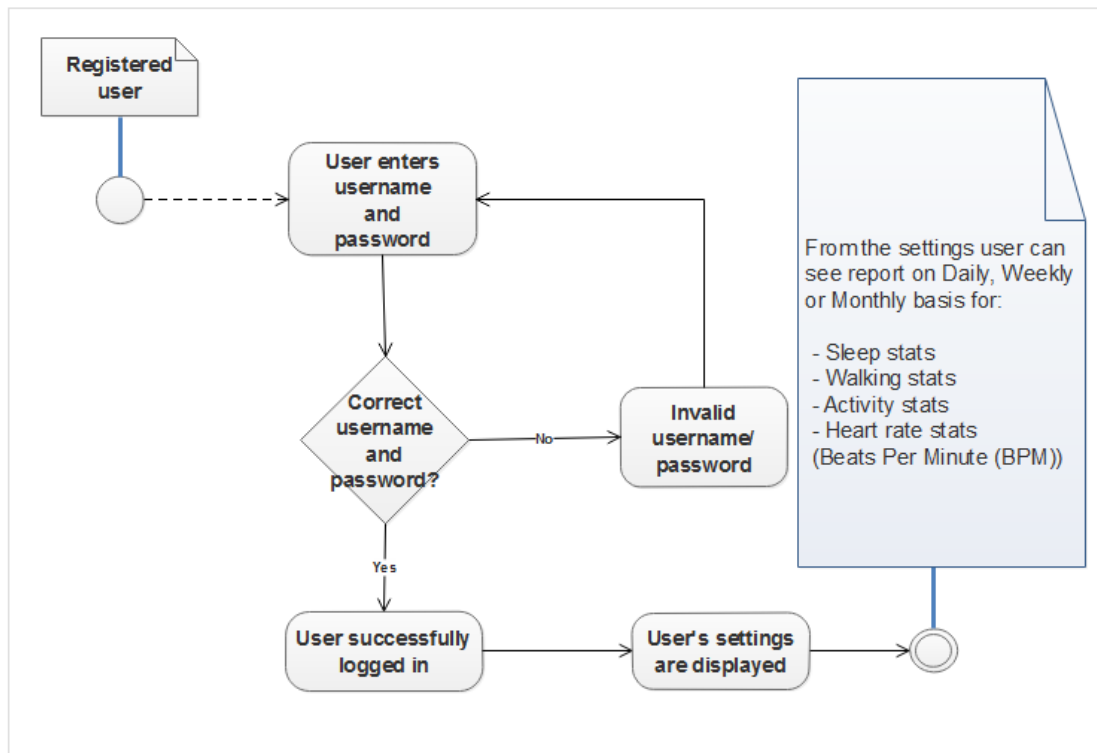
The wearable device is aimed to gather a reliable data about user physical activity using different sensors. The collected data from the wearable device are then send to cloud and be available for user and to doctor to be seen as report for user to track and monitor their activity and sleep pattern. Figure 7 shows high-level system diagram.

**Figure 7.** High-level system diagram.

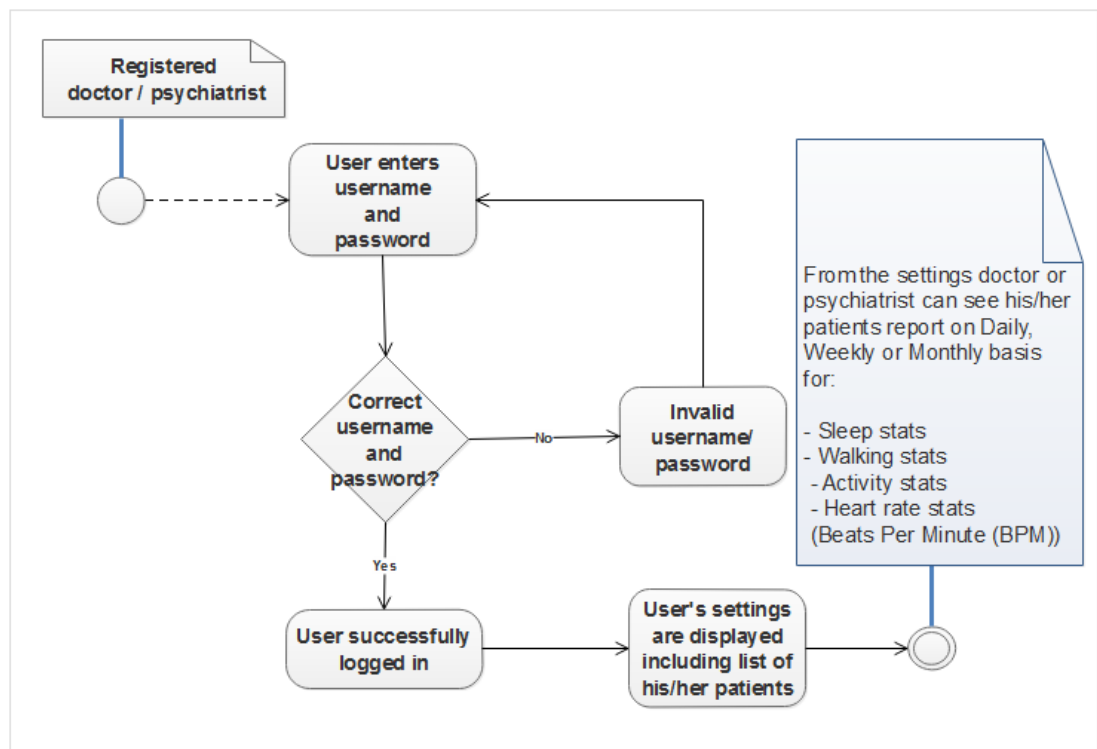
As shown on Figure 7, the wearable device incorporates technical requirements listed on section 4.2. The sensors collect user sleep, walking, activity pattern, and heart rate stats. The collected data are then stored on server. The primary goal is to use the collected user activity data as an input variable for authorized doctors and psychiatrics to access and analyse their patient's physical and emotional state.

### 4.3.1 UML activity diagram

The collected data from wearable device are personal. The reports are visible only for authorized users. Figure 8 and 9 show step by step user verification.



**Figure 8.** Activity diagram for the user.

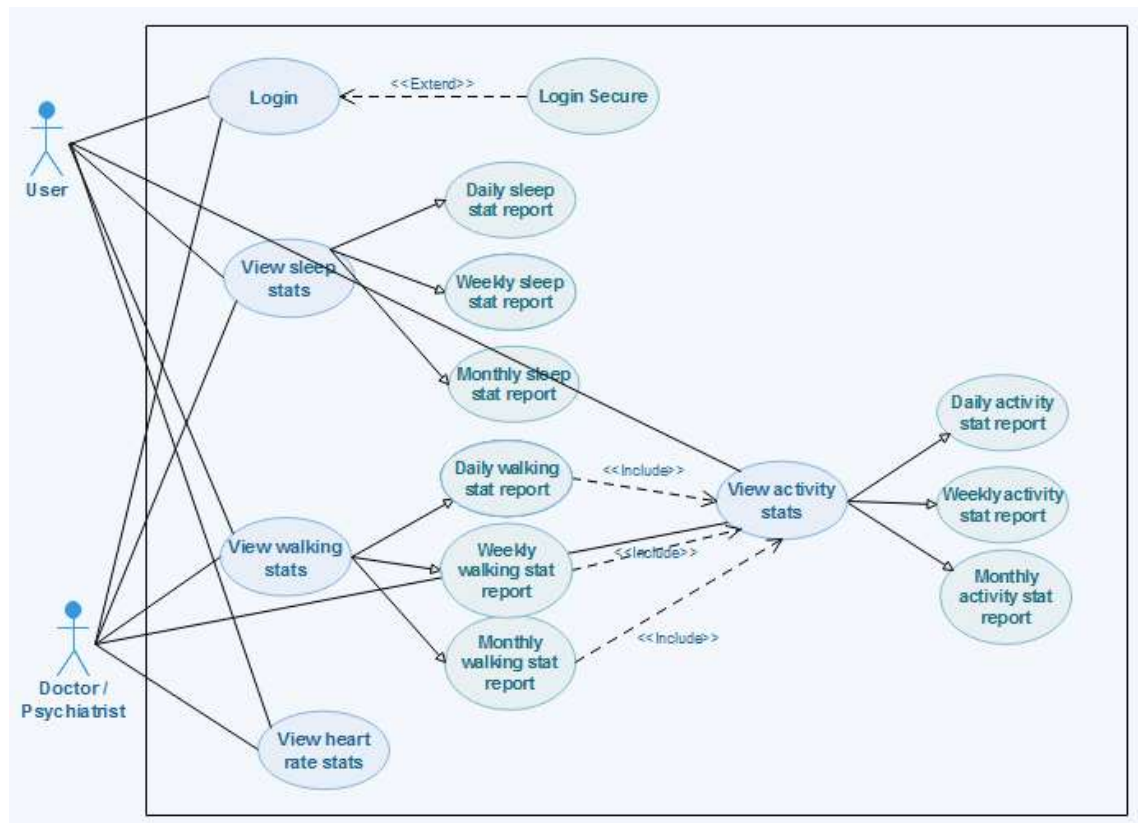


**Figure 9.** Activity diagram for the doctor/psychiatrist.

As shown on Figure 8 and Figure 9, user of system need to login first to view collected data stats. The user need to have the valid user name and password to view his/her own report only from user setting dashboard. As for doctor/psychiatrist they are permitted to see only his/her patients' data to analyse their physical, emotional and psychological state.

#### 4.3.2 UML use case diagram

The proposed system has two types of participating actors. User and authorized doctor/physician. The interactions among different elements of a system by user types are show on Figure 10.



**Figure 10.** Use case diagram for wearable device.

As illustrated on Figure 10, the collected data are seen by both participating actors as stat report. The collected data are personal and they need to be protected, thus user name and password is required for both user types to login in order to view the collected data.

As for the users, they can make the most out of the device by seeing their stats (recorded reports) for Sleep, Activity, Walking and Heart rate on daily, weekly and monthly basis. This gives a chance for the user to set a personal goal, monitor and access their routine, and life style. Report stats are the following.

- Sleep stats (Daily, Weekly and Monthly)
- Walking stats (Daily, Weekly and Monthly)
- Activity stats (Daily, Weekly and Monthly)
- Heart rate stats: Beat per minute.

**Sleep stats:** Daily report consisting of a detailed hour report of time spent in bed. These details enable the user to see the time spent in deep sleep, light sleep and number of wakeups in between. The registered hours also include the time the user went to bed and the wake up time. The weekly and monthly reports show an average for deep sleep, light sleep and average sleep daily.

**Walking stats:** Daily report for walking stats includes number of steps and total kilometre covered by the user. The weekly and monthly reports show an average number of steps and total kilometre.

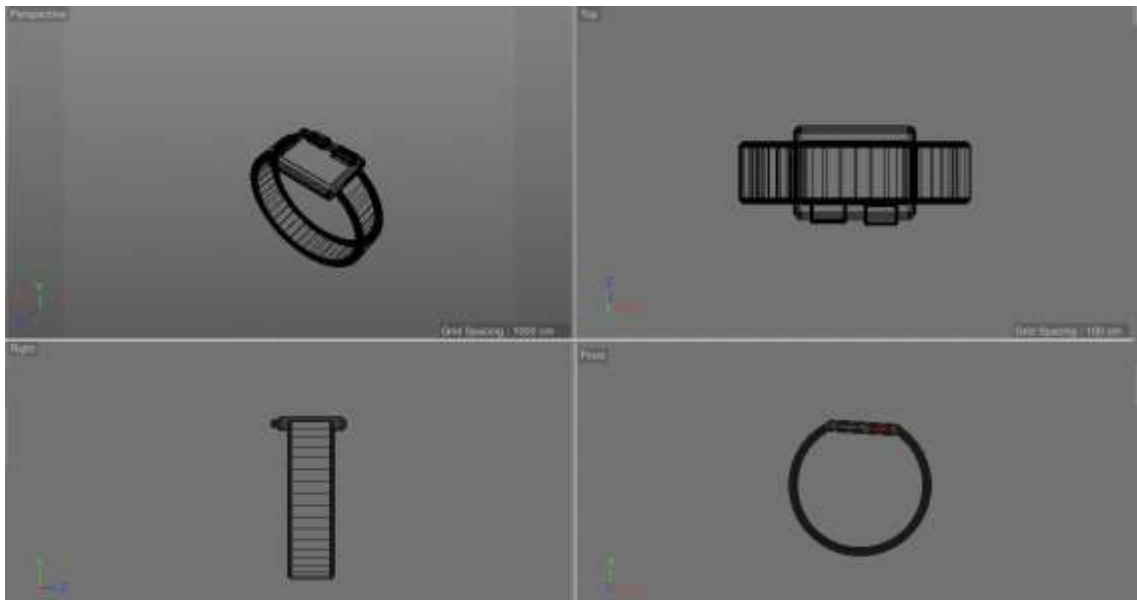
**Activity stats:** Daily report for activity stats is derived from walking stats. Based on number of steps and total kilometre covered the system calculates the duration for user activity and shows activity time. The weekly and monthly reports show an average steps and average activity.

**Heart rate stats:** Heart rate stats are reported as BPS.

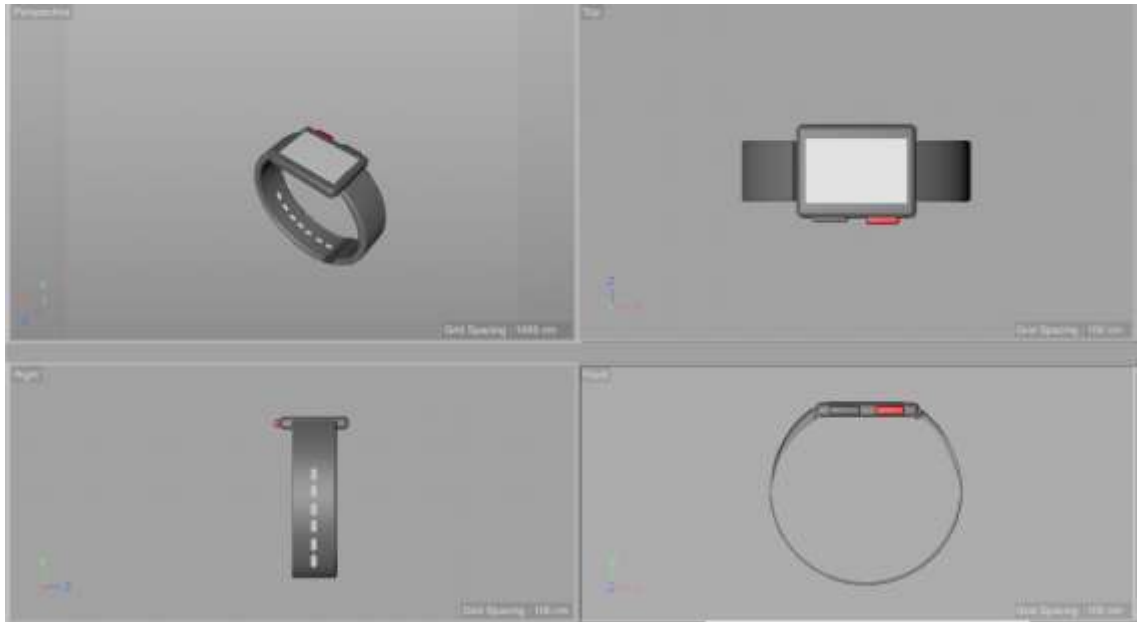
#### 4.4 The design

On this study, one of the very first requirement for the wearable device is to be worn day and night by the user to collect complete data. Most ideal and comfortable body location to meet the requirement is to wear it on the wrist as it also makes the collected information readily viewable and accessible to the user.

Below a sketched conceptual model view of wrist worn device was designed as an artefact. Figure 11 and Figure 12 show concept wireframe view and 3D shade model view respectively in perspective, top, right and front view.



**Figure 11.** Concept wireframe view for wrist worn device.



**Figure 12.** 3D shade model view for wrist worn device.

This section also evaluates the screen display of the wearable device based on the requirements set on prior sub-section. Actual artefact was not implemented. For this study, the scope was to design screen display content and screen view of wrist worn wearable device based on context user group which in this case was senior citizens. Figure 13 shows first version of screen display content.



**Figure 13.** Concept view of screen display artefact, version 1.

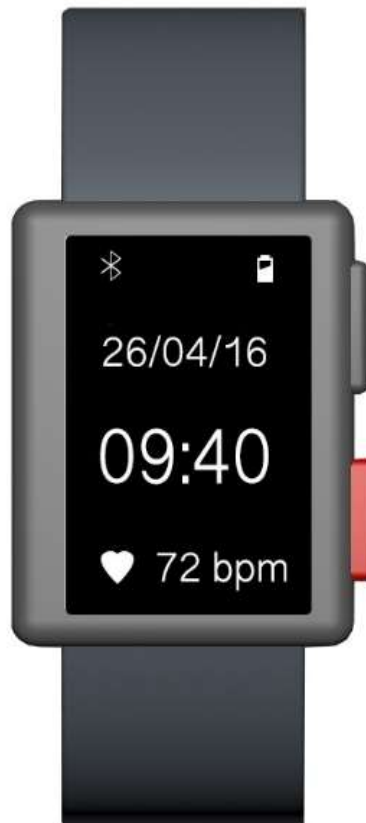
As shown above, the design on Figure 13 meets the requirements listed in Table 12 as additional features (REQ 16, REQ 17 and REQ 18). These features include displaying battery life indicator, Bluetooth, current time followed by the current date and a little heart icon with the heart rate value of the user constantly updated and displayed at the bottom right corner. The proposed screen view was adopted from different existing wrist worn devices used for various purposes.

However, the screen display suggested on version 1 (see Figure 13) has shown some limitation such as the orientation of the display. The vertical display of the screen makes it difficult to read the information on the screen. This unconventional sideways display takes a bit of wrist-twisting to read the information or to obtain a comfortable view. To overcome the limitation, the following version 2 screen view was designed.



**Figure 14.** Concept view of screen display artefact, version 2.

Version 2 has tackled the limitation encountered on version 1 (see Figure 13) by changing the display orientation from vertical to horizontal view. Information displayed on version 2's screen (see Figure 14) is now detailed and easy to read. The limitation of version 2, was that it failed to meet REQ 8 listed under functional requirements (see Table 7). Characters used to display information on version 2's screen seem to use most of the screen space, which resulted in a compact screen view.

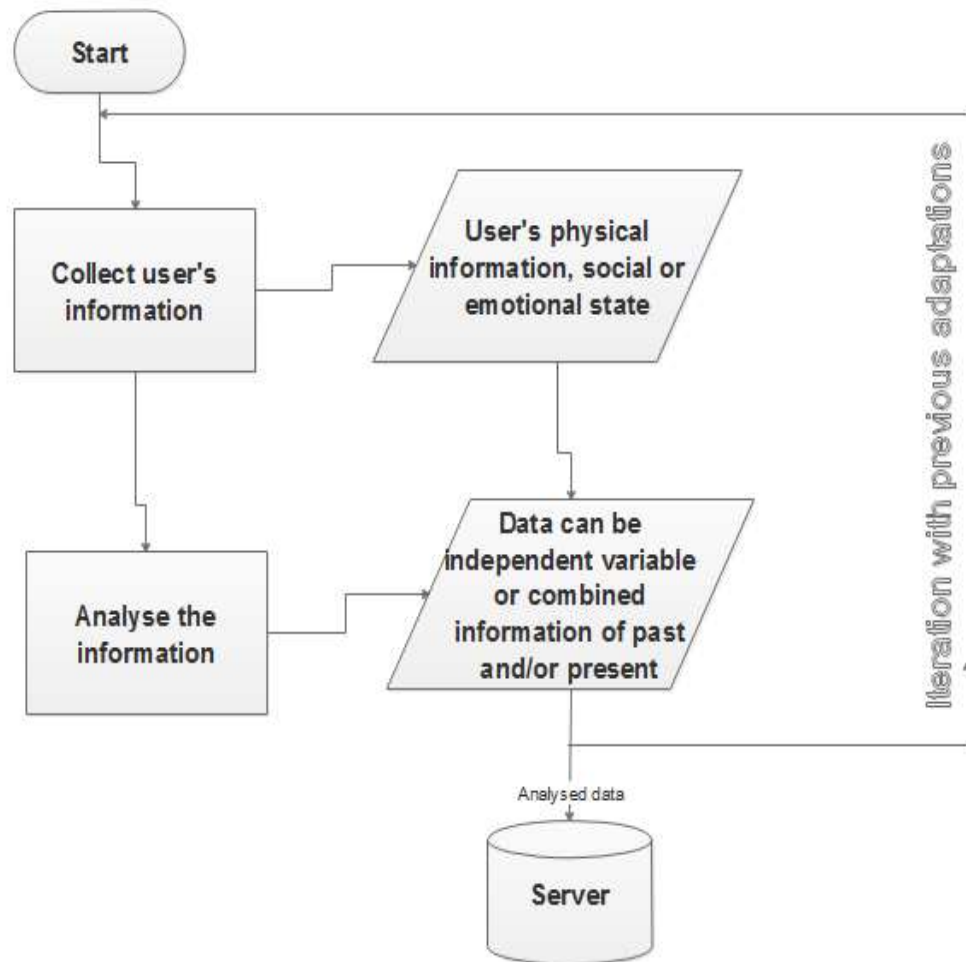


**Figure 15.** Concept view of screen display artefact, version 3.

Screen display is clearly one of the most important and key components in such devices. In order to have the desired quality, display of information and screen space usage version 3 has tried to overcome the limitations addressed on the two previous versions. Version 3's screen view (see Figure 15) is presented as a final design as it meets all the listed requirements related to screen content and display settings.

#### 4.5 System flow

The collected data from wearable device are physiological such as heart rate, sleep pattern and movement or exercise of the individual. These records are analysed and stored in a database. Figure 16 shows sample flow how on how the collected user data can be an input variable for physicians to analyse user physical and psychological state.



**Figure 16.** System's flowchart.

The collected user information from the wearable device includes users' activity, sleep and walking data (physical activity and physiological data). The collected stats can be used as a variable input along with other user's information such as interview, self-assessment questionnaire (PHQ-9). The analysed data shown on Figure 16 can be interpreted, evaluated and further categorized to minimal depression, mild depression, moderate depression, moderately severe depression and severe depression by physicians to access the wellbeing of their patients. Having the right set of individuals physical, social and emotional information helps to overcome inconsistency and misinterpretation of diagnosis.

## 5. Evaluation

As the artefact of this study was theoretical and as there was no construct built, all the requirements listed under section 4.2 could not be tested. However, few requirements related to screen display were evaluated using guidelines by Hevner et al. (2004). These requirements also took senior citizens into consideration.

In order to validate the wearable device's display design, screen view design artefacts were iteratively built and evaluated until a desired model met the requirements related to display setting and screen content. The screen views were designed and evaluated iteratively in three progressive versions. Table 13 shows the list of requirements used to validate and compare strength and weakness of screen display versions.

**Table 13.** Evaluation checklist.

No	Requirements	version 1	version 2	version 3
REQ 7	The font size and display orientation of the text to be displayed on the screen should be readable for the user.	✘	✓	✓
REQ 8	The displayed information on the wearable device's screen must use minimum character units yet be informative and easily understood.	✘	✘	✓
REQ 16	Digital watch	✓	✓	✓
REQ 17	Calendar	✓	✓	✓
REQ 18	Screen must display current time and date, battery usage indicator bar, connectivity status and BPM.	✓	✓	✓

✓ : Meet the requirement

✘ : Failed to meet the requirement

On this study, the design and evaluation of artefact has the elderly as a target user group. Even though the requirements were evaluated based on context user, the wearable device and its features are appealing to any age group users.

The requirements in Table 13 were set to make the wearable device's screen content simple and easy to read while displaying the basic information one can use on his/her day to day activity. The design was evaluated based on the requirement set which are related to screen and screen view only. Design version 3 seems to meet all the requirements listed in Table 13.

## 6. Discussion

The purpose of this study was to answer the research question how to detect and monitor depression with the help of wearable ICT device? Along with three assisting research questions; addressing the meaning of depression, how it is monitored and finding out any technologies that can be used to detect and monitor depression. In order to answer the research questions, literature review was used to find out existing knowledge. DSR was also used while designing and evaluating the artefact. The discussion is categorized in to three parts, the first part discusses about depression and the second part discusses about how depression can be monitored using wearable device. The final part discusses the artefact.

From the literature review, this study has identified society has biased perception and understanding towards depression. Depression is defined as a mental and common mood disorder (WHO, n.d.). Besides being a mood disorder, depression is rather a serious mental condition. The bias was noticed between health professionals with regards to considering depression as medical illness. Institutions like the University of Michigan Depression Centre, are one group who categorize depression as a real illness (Depression toolkit, n.d.). On the other hand, experts like John (2015) argue by saying depression is not a mental illness rather it is a mental disorder. Findings of this study imply depression is an illness, as depression is common companion with heart disease. Depression is severe than it sounds as it is risk factor for CVD, CAD and stroke.

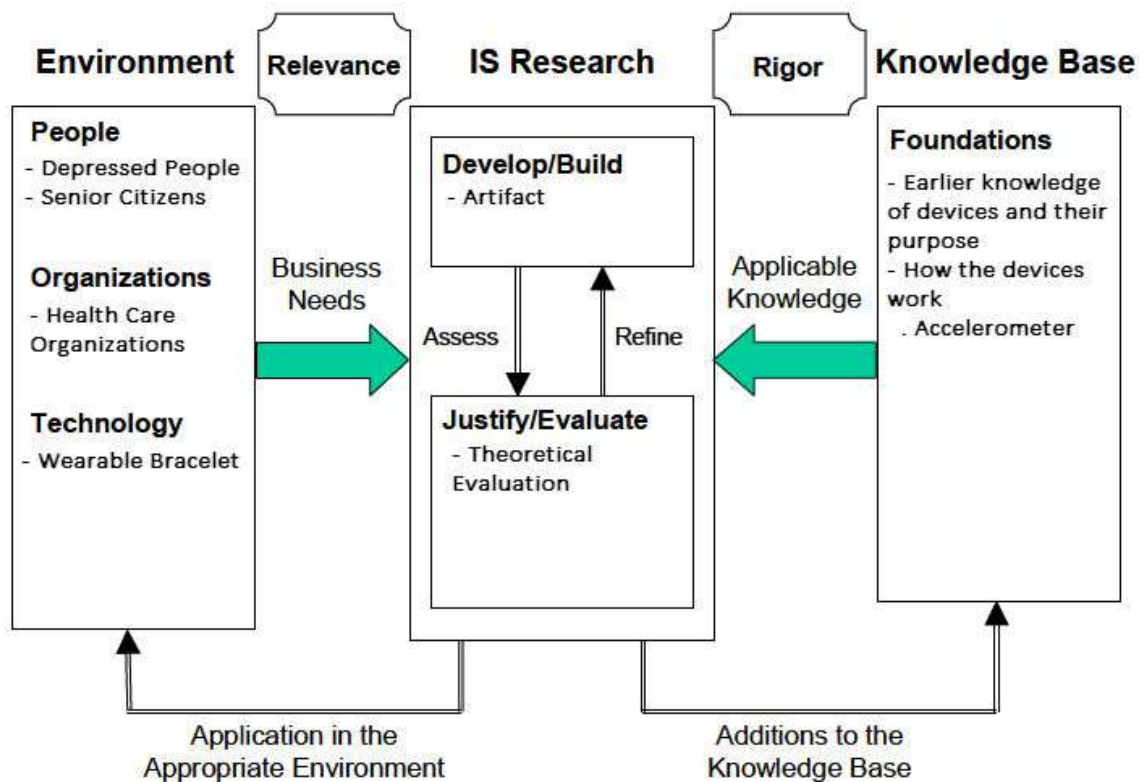
On this study depression types were categorised into ten broad categories. From the symptoms listed most common depression symptoms are stress, trouble getting to sleep or feeling sleepy during the day time, loss of interest in activities, insomnia, loss or gain of appetite, restlessness, feelings of being "sped up" or "slowed down" without energy and thoughts of suicide. From the latter stress, insomnia, feeling of being "sped up" or "slowed down" can be detected and monitored with the help of wearable device on the wrist. This is the reason why this wearable device is suggested as a solution to monitor depression as the early stage before it gets fatal stage.

Existing wearable technologies are designed to meet certain areas of market such as lifestyle, fitness tracker, entertainment, industrial work safety and medical. As the market is expanding, big name companies turned their face and start producing their version of wearable device. As existing wearable devices are not designed targeting depression, this study adopted few of existing knowledge from wearable devices and compiled them to extract a list of requirements that can be used for wrist worn wearable device that can monitor depression. From the requirements, the proposed solution on this study featured panic button. As thought of suicide is fatal stage of depression, panic button is designed to be used by the user to alert his/her doctor when in an extreme condition.

The intensity of physical activities can be detected by the high rate of heartbeat that results in augmenting the acceleration data (Bao & Intille, 2004). Accelerometer is the key sensor used to monitor activity in wearable devices. Limitation of accelerometer is that; it is mainly used for gathering a limited set of physical activities. Using multimodal sensors in other words using multiple sensor types, to collect signal from single body location is an alternative approach to overcome the limitation. (Choudhury

et al., 2008.) Having the right set of accelerometer will help to get the accurate data to be validated by professionals.

The longer depression goes untreated the more debilitating the condition becomes, which leads to an even greater price to pay. In order to prevent a society from facing these damages the artefact of this study is proposed as a mechanism that enables early detection of depression by monitoring user's activity. The solution artefact was designed using the following research framework (see Figure 17).



**Figure 17.** Research framework for wearable device.

Using research framework shown on Figure 17, wrist worn device is proposed as a solution to monitor user's heart rate, activity and sleep pattern. Requirements for wrist worn device are listed as an artefact of this study. The requirements are extracted considering connectivity, compatibility, user comfort, right set of sensors to collect all the relevant information that can be used to monitor user activity, sleep pattern, heart rate and easy user interface.

From the listed requirements for the wearable device, the only requirements which relate to device's screen content and screen settings are the ones which are theoretically evaluated. Evaluating the screen setting and contents was useful because the readability was main criteria for the device as target group on this study were the elderly. Having clear, readable and eye catching user interface for users of any group is a key to engage users with the proposed solution.

## 7. Conclusions

The motivation of the study was to find an ICT based wearable device that will assist in detecting and monitoring depression which is becoming a major social health concern. The study identified common symptoms of depression which can be monitored using combination of sensors. Most of the symptoms relate to activity, quality of sleep and stress. The study sets list of requirements for the wearable device that can monitor user's physiological and physical activity data, which is an important input for physicians to detect depression in a consistent and unbiased manner. As a theoretical background, literature review was used to answer research questions in this thesis. The major findings from literature review are addressed in the following three paragraphs.

In a research conducted by Mathers and Loncar (2006), depression is listed to be one of the major health concerns in 2030 next to HIV/AIDS and ischaemic heart disease. In fact, depression is identified as a risk factor for various heart and heart related diseases such as stroke, CVD, CAD (Hare et al., 2014; Greenblatt, 2011).

Depression is a concerning health issue not only by the increasing number of victims but also due to the known fact that its last stage leads to suicide (WHO, 2015). Any individual can be a victim of depression however women are more vulnerable to depression than men. This is due to the natural biological life cycle related to female gender such as menstruation cycle, giving birth which leads to depression also known as postpartum depression. (Marcus et al., 2012; Greenblatt, 2011.)

Although depression can be cured with proper treatment, research shows that 70% of mental illness victims worldwide did not benefit from the treatment. This is mainly due to the lack of knowledge among the society along with stigmatization, resulting to a biased understanding of mental illness and its treatment. (Fortune et al., 2004; Thornicroft, 2008.) Depression victims are among the 70% of mental illness victims which is an alarming number and greatly impacts the economy by creating a gap on the productive work force due to early retirement and extended sick leave (Wang et al., 2003).

The study focused on how ICT can be used in detecting depression at early stage based on literature. Finding out how data is transferred and how the device is implemented were left beyond the scope of this study. The major limitation of the study was that no construct was built for the artefact. All the listed requirements for the wearable device were not evaluated. The screen settings and screen content were the only requirements evaluated on this study. The evaluation was made based on theoretical background.

As further research recommendation, it is advised to add appealing and persuasive features to the wearable device to make it used by all age groups at all time. The device's design and feature can add value to make the device be considered as life style wearable or jewellery instead of medical device to avoid the stigma related to depression. One recommended persuasive feature can be calculating and displaying calories burned during activity or exercise for the user. Adding a feature which calculate and displays calories burned during day, makes the device be considered as fitness tracker instead of depression detecting and monitoring device.

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