FACTORS INFLUENCING ADOPTION OF WEARABLE CONTINUOUS GLUCOSE MONITORING SYSTEMS DEVICES IN INTERNET OF THINGS HEALTHCARE

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DEDICATION

This dissertation is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother Mrs Nargis Akter, who taught me that even the largest task can be accomplished if it is done one step at a time.

I also want to dedicate this thesis to my uncle Luthfar Rahman who lives in Germany, as he helped me a lot for collecting data and also gave me courage in my every step of the study.

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ABSTRACT

In smart healthcare system, Continuous Glucose Monitoring Systems (CGMs) devices are very developed system to measure blood glucose which is sensor-based. The number of users for this device is low in usage though this device provides some features for blood glucose monitoring. The adoption rate for this device is also lower than 20%, whereas other wearable smart devices are used more in developed countries and developing countries as well. The aspire of this assessment is to investigate the factors, that make user's intention to use wearable CGMs device in the Internet of Things (IoT) based healthcare to monitor blood glucose measuring. This study has set off research in IoT healthcare, focusing on CGMs based on previous studies about some wearable devices. The key aim of the study is to deliver an adoption model to find the current factors as a guideline for the user in adopting wearable devices in smart healthcare. From this adoption model, developers can be helped by taking the proper suggestion to make sure users' intention to adopt this device. The identified factors for adoption model of CGMs devices are Interpersonal Influence, Self- Efficiency, Personal Innovativeness, Attitude Toward Wearable Device, Health Interest, Perceived Value, Trustworthiness and Intention to Use. For factor identification, the weight of each factor was measured to get the most cited factor and more weight ratio valued factor. Based on the identified factors an adoption model is developed for measuring users' intention to use the CGMs device. Here, content validity index and content validity ratio methods were also used to measure the content validity of each construct after expert validation. In order to evaluate the model, a questionnaire has been developed and distributed to the respondents, who have the knowledge and experience of using wearable CGMs device for their own blood glucose monitoring. Based on the collected data from 97 respondents, Smart PLS software is used to analyse the data. The results show that interpersonal influence, attitude toward a wearable device, trustworthiness and health interest have significant impact whereas personal innovativeness, self-efficiency and perceived value have no significant influence on measuring intention to use wearable CGMs device.

ABSTRAK

Di dalam sistem penjagaan kesihatan pintar, Peranti Pemantauan Glukosa Berterusan (PPGB) adalah sistem yang sangat maju untuk mengukur glukosa dalam darah yang berasaskan sensor. Bilangan pengguna bagi peranti ini adalah rendah walaupun peranti ini menawarkan beberapa ciri untuk pemantauan glukosa dalam darah. Kadar pengambilan peranti ini juga rendah iaitu kurang daripada 20%, sedangkan peranti pintar boleh dipakai lain digunakan lebih banyak di negara maju dan negara yang membangun juga. Hasrat penilaian ini adalah untuk menyiasat faktor-faktor, yang menyuntik niat kepada pengguna untuk menggunakan peranti PPGB yang boleh dipakai dalam Internet Pelbagai Benda (IPB) berdasarkan penjagaan kesihatan yang boleh memantau pengukuran glukosa dalam darah. Kajian ini telah meneliti penyelidikan dalam penjagaan kesihatan IPB, yang memberi tumpuan kepada PPGB berdasarkan kajian terdahulu mengenai beberapa peranti yang boleh dipakai. Matlamat utama kajian ini adalah untuk menyampaikan model penggunaan bagi mencari faktor-faktor semasa sebagai garis panduan bagi pengguna dalam menggunakan peranti yang boleh dipakai dalam penjagaan kesihatan pintar. Daripada model penggunaan ini, pembangun dapat dibantu dengan mengambil cadangan yang betul bagi memastikan niat pengguna untuk menggunakan peranti ini. Faktor-faktor yang dikenal pasti bagi model penggunaan peranti PPGB adalah: Pengaruh Interpersonal, Keberkesanan Sendiri, Inovasi Peribadi, Sikap Terhadap Peranti yang Boleh Dipakai, Kepentingan Kesihatan, Nilai yang Dilihat, Kepercayaan dan Niat Penggunaan. Bagi tujuan untuk mengenal pasti faktor, nilai bagi setiap faktor diukur untuk mendapatkan faktor yang paling banyak disebut dan faktor yang mempunyai lebih banyak nilai nisbah. Berdasarkan faktor-faktor yang dikenal pasti, model penggunaan dibangunkan bagi mengukur niat pengguna untuk menggunakan peranti PPGB. Di sini, indeks kesahan kandungan dan kesahan kandungan bagi kaedah nisbah juga digunakan untuk mengukur kesahan kandungan bagi setiap konstruk selepas pengesahan pakar. Bagi tujuan untuk menilai model, soal selidik telah dibangunkan dan diedarkan kepada responden yang mempunyai pengetahuan dan pengalaman menggunakan peranti PPGB yang boleh dipakai untuk memantau glukosa dalam darah mereka sendiri. Berdasarkan data yang telah dikumpulkan daripada 97 responden, perisian Smart PLS digunakan untuk menganalisis data. Keputusan menunjukkan bahawa pengaruh interpersonal, sikap terhadap peranti yang boleh dipakai, kepercayaan dan kepentingan kesihatan mempunyai kesan ketara manakala inovasi peribadi, keberkesanan diri dan nilai yang dilihat tidak mempunyai pengaruh penting dalam mengukur niat untuk menggunakan peranti PPGB yang boleh dipakai.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

At	-	Attitude
ATW	-	Attitude toward Wearable Device
AVE	-	Average Variance Extracted
CAM	-	Conjoint Analysis Model
CFA	-	Confirmatory Factor Analysis
CGMs	-	Continuous Glucose Monitoring System
CVI	-	Content Validation Index
CVR	-	Content Validation Ratio
HBM	-	Health Belief Model
HI	-	Health Interest
INF	-	Interpersonal Influence
IoT	-	Internet of Things
IT	-	Information Technology
IU	-	Intention to Use
PI	-	Personal Innovativeness
PV	-	Perceived Value
S2S	-	Sensor to Sensor
SD	-	Self Determination
SE	-	Self-Efficacy
SEM	-	Structural Equation Modelling
TAM	-	Technology Acceptance Model
TBM	-	Trust-Based Model
TRA	-	Theory of Reasoned Action
TW	-	Trustworthiness
UTAUT	-	Unified Theory of Acceptance and Use of Technology
WFT	-	Wearable Fitness Technology
WR	-	Weighted Ratio

LIST OF SYMBOLS

$\sum$	-	Summation
N	-	Total Number
Ne	-	Number of Experts

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Nowadays, with the proliferation of technologies, people tend to have more relaxed for a smart life. Internet of Things (IoT) is a network of linked objects through the internet, which is capable of collecting and exchanging data. It is a buzz word which is changing our daily lives. IoT works by a sensor to sensor with a cloud-based application. Improvements of sensors and announcement technologies, have shaped it potential in support of users to incessantly examine a variety of physical circumstances by the use of healthcare wearable devices. Consistent with a study by Yup and Lee (2018), a healthcare wearable machine is identified like "a machine which is self-directed, non-aggressive and also carries out health tasks specifically for instance monitoring or supporting over an extended time".

From the 13th century, wearable technology was marked as a great invention The College of Optometrists (2015). After 100 years, the first hearing aids were invented by a French mathematician named Jean Leurechon, which is widely familiar because of ear trumpets uses (Van Etten, 1624). Again, the glass contact lens was firstly invented in 1887 that fits whole eyes Lunney, Nicole R Cunningham, *et al.* (2016). In twenty centuries, a big amount of healthcare wearable devices was produced rapidly through the improvement of electronic technology innovations. Following the hearing aids, soft contact lenses were also introduced in the same way in early 1971, said by Hochheiser (Casselman *et al.*, 2017).

By following the trends of smart technologies, the successful research by Worcester Polytechnic Institute, 2015 stated that insulin pumps were also invented at the same time of 1971 (Casselman *et al.*, 2017). Sensor market of wearable devices was expected to be $100.35 million near to 2018 (Business Wire, 2015). An independent_research company known as Ipsos studied that among five adults, one had plans to have a gadget which is wearable through a year in U.S.A (Lunney, Nicole R Cunningham, *et al.*, 2016). Wearable technology market was expected to rise up to $5.8 billion through 2018 from $750 million, 2012 (Lunney, Nicole R Cunningham, *et al.*, 2016). In IoT, wearable technology is one of the most promising areas, as a stand with quite some smart features. Range of the wearable devices in healthcare starts from different famous fitness trackers (Fitbit, Apple Watch, Samsung Gear) to more refined wearable healthcare devices (Marakhimov and Joo, 2017).

Previously, blood glucose measuring was done by finger prick devices but, now in after 20^{th-}century Continuous Glucose Monitors (CGM) has been introduced to measure blood glucose easily (Olczuk and Priefer, 2018). From 1999, new technology came up to measure the blood glucose level of diabetes patients for Type 1 and 2. The development of CGMs allowed patients to monitor their blood sugar by inserting a device subcutaneously (Olczuk and Priefer, 2018). IoT in healthcare domain will reach $2 trillion by 2025, stated by Mckinsey (Mahdavinejad *et al.*, 2018). The realisation of IoT healthcare systems can even do remote treatment for patient monitoring as well as disease detection, which is a very fashionable feature (Kim & Kim, 2018). Continual monitoring of health status by the use of wearable devices in healthcare is very much beneficial to chronic patients like as diabetes, heart patients and asthma as well (Yup and Lee, 2018).

However, IoT healthcare offers lot opportunities and benefits; the level of adoption of wearable devices for blood glucose monitoring is still low compared to other wearable devices like fitness tracker (Olczuk and Priefer, 2018). Here, researchers also stated that some factors measurement is needed to identify the user's intention to use wearable CGMs device in smart healthcare towards monitoring their blood glucose.

1.2 Problem Background

In a study by Olczuk and Prifer (2018), stated that CGMs was first introduced in earlier 1999 shortly. But now, it contains quite more smart features, although very less amount of people is using this device. People had some issues in terms of accuracy as it is based on the sensor, but now this device has come forward with special techniques. Now, it gives results in every five minutes with improvised accuracy (Olczuk and Priefer, 2018). In another study by Gia *et al.* (2017), mentioned about United Kingdom prospective diabetes group assumption which claimed that CGMs could reduce long term complications of diabetes patients from 40 to 75%.

According to Chang *et al.* (2016), wearable devices are having great highlights having smart features for global information technology companies. Since, the wearable device market is in the early phase, major factors have not been identified, which influence the adoption of wearable devices. Among different types of information technology devices, wearable devices, wearable devices have more attractions as the next generation smart devices. There, authors proposed a technology acceptance model, task-technology fit with associated external factors named as: privacy, security, trust, lifestyle, innovativeness for the usage intention of wearable devices.

Now in the market place, users are minimal in number, who are currently adopting this device, especially for type 1 and 2 diabetes patients. For type 1 diabetes patients, the adoption rate for CGMs device stands for only 8%, whereas for type 2 diabetes patients using proportion stands for 17%. This data was also collected form very few developed countries like Germany, Switzerland, U.S.A, UK, Sweden, Saudi Arabia (Engler *et al.*, 2018). So, this percentage of adopting CGMs device is very low compared to other wearable devices like as fitness tracker, activity tracker and it is not widely spread through the whole world including developing countries (Marakhimov and Joo, 2017).

On behalf of monitoring physiological parameters and examining consumer's health condition regularly, healthcare wearable devices are badly needed like as continuous glucose monitoring which is update feature for the closed-loop system (Marakhimov and Joo, 2017). Many IoT smart healthcare devices are focused on fitness activity tracker only whereas Yup and Lee mentioned some factors of wearable fitness tracker adoption such as interpersonal influence, perceived expensiveness, interest in health, personal innovativeness and also self-efficacy (Yup and Lee, 2018).

Some examined the user's impact through technology device uses like age, personality, self-efficacy, physical activity level, and also the uniqueness of that device such as usability, trust, motivational affordance on an intention to use a fitness wearable device (Rupp *et al.*, 2018). Another research mentioned some factors that are so serious and also will control consumers' approval of using disease management service (Kim & Kim, 2018). Disease management, through IoT, includes task scope, devices, expert support. The range of communal individual medicinal data was recommended the same vital attributes like accuracy, safety, privacy for cloud-based data (Kim & Kim, 2018). According to Yup and Lee (2018), the use of healthcare wearable devices provides significant benefits if it is about continuous health status monitoring. Such continuous monitoring goes through diabetes, a heart condition, and asthma.

According to Rodbard *et al.* (2018), CGMs device reveals the importance of patients burden for the acceptability of available CGMs devices in the market. It is also stated that, though CGMs devices are helping patients by measuring their continuous blood glucose, yet type 1 diabetes patients use this device 8 to 17% only. There, authors also identified the barriers of CGMs device adoption like expensiveness, uncomfortable to wear, satisfied with the analogue system, not familiar with CGMs, feel the pain to wear CGMs, infection possibility. They also stated some reasons for stopping uses of CGMs like how sensor look on the body, false alarms, data accuracy, complicated to use, skin irritation, pricing of the sensor. Some users also dis-trust if the device is now approved by the FDA (Food & Drug Association).

Following the same research by Rodbard *et al.* (2018), Diffusion of Innovation Theory (DIT) was also included, where CGMs is still now in the early adoption stage. And so, the process of adoption for CGMs depends on population attitude and also the experience of potential health benefits. Along with, that study indicates that such a study may be needed to more completely address these barriers like cost, benefits, accuracy for the adoption of CGMs devices. With the adherence for continuous use of this use, medical benefits are also required.

As it is seen that most of the study performed about activity monitoring devices adoption and also measures some factors which can influence user's intention to use wearable devices where maximum of the studies did not introduce factors for CGMs device adoption model. Consequently, there is a fundamental need for wearable CGMs device adoption model which can reveal the influencing factors for adoption of CGMs in smart healthcare.

1.3 Problem Statement and Research Questions

Though all devices in smart healthcare are a new trend, less amount of people aware of these smart devices (Marakhimov and Joo, 2017). As CGMs device was first introduced in 1999, but in this 20 years, the adoption rate of this device is still low though this device provides attractive, smart features, which is very helpful for diabetes patients. When new information and technology arrives, people take time to be useful with that system, if it is about health issues. People feel more conscious for the adoption of medical devices, as all IoT devices are based on sensor and also self-monitoring system (Marakhimov and Joo, 2017).

Despite the expected benefits of wearable healthcare devices, the market for them is still in the initial phase (Yup and Lee, 2018). By following Yup, a survey found that many people were interested in wearable health devices, but only a small number of them had adopted those. That study also mentioned about identifying the factors for adoption of wearable healthcare devices. To come up with newer technology of the health sector, the developers should identify and focus on some important factors, that make user intention to use wearable CGMs device. In recent works, researchers introduced about smart features of CGMs device and also its mechanism (Olczuk and Priefer, 2018), whereas CGMs device adoption factors were not formed to build up CGMs device adoption model.

As CGMs device is fully health-related and also provides smart features which are technology-related, so it is worthwhile to examine factors that influence the adoption intention of users for wearable CGMs device in smart healthcare (Yup and Lee, 2018). Therefore, this study attempts to propose a model for CGMs device adoption, which influence the users' intention to use wearable CGMs devices in blood glucose monitoring. The main research question for this study is in below:

"**How to develop user's adoption intention to use wearable CGMs devices to monitor their blood glucose?"**

The sub-research questions are as follows:

(a) What are the factors influencing adoption intention of wearable CGMs devices in smart healthcare?

(b) What is the model for the adoption of wearable CGMs devices in smart healthcare?

(c) What suggestions can be provided to the developer to ensure the user's adoption intention of healthcare wearable devices?

1.4 Research Objectives

(a) To identify factors influencing adoption intention of wearable CGMs devices.

(b) To develop and validate the model for adoption of wearable CGMs devices.

(c) To provide suggestion to the developer that ensures the user’s intention to adopt healthcare wearable devices.

1.5 Scope of The Study

The purpose of the research is to determine the factors that influence users’ intention to adopt wearable devices of blood glucose monitoring for diabetes patients in their daily life. This research is focusing on IoT healthcare which is closely related to health consciousness for patients of diabetes. In this context, this study chose blood glucose monitoring devices named CGMs which are now a newer trend of IoT.

Minimum numbers of people are using that kind of devices in terms of smartphones and other technologies. That’s why this study will identify the factors which can make user intention to use wearable devices of smart healthcare. This study will only focus on who is using this device or who have experience of using it. Then, this model will be validated using Smart PLS.

1.6 Significant of The Research

Significant of research is constructed with the importance of research, the main beneficiary of the research, secondary beneficiary of the research, importance to researchers and also the importance of the future researchers. In below, these all segments are described in different paragraphs.

The target of this study is to develop an adoption model for wearable CGMs device in smart healthcare, whether this device measures the blood glucose level of type 1 and type 2 diabetes patients. CGMs devices are included with several smart features like measuring blood glucose, giving an alarm, notifying patients 24/7 and also giving alarm 288 times daily (Maia and Araújo, 2007).

This study is motivated to identify and understand the factors which influence the user's intention to adopt wearable CGMs device in smart healthcare. This research will also investigate some acceptance model and theory of technology like the technology acceptance model, planned behaviour theory, self-efficacy theory, the theory of reasoned action.

The result of the study could assist developers who will develop smart healthcare wearable devices to take corrective actions in creating an intention for the users of using those devices. Developers can get ideas about the user's intention criteria for these devices, by how they can create their market policy and also can assure the user's satisfaction level fulfilling user's demand.

This study will be able to develop the user's intention to use the CGMs device in their daily blood glucose monitoring. Following the proposed model, users can identify the possible features and factors which other experienced people suggest and remarks. And from all of the possible features, including factors, users can consider the adoption of wearable CGMs device for their diabetes management.

As very few research performed in CGMs device, where all showed the use of CGMs devices, mechanism and history was performed. As a result, this study can help the developer by identifying the factors that influence the user's intention to adopt a CGMs device in smart healthcare. This study will also help possible users by the proposed adoption model of CGMs.

As for further research, others can take help to enrich the adoption factors for CGMs device as well as in other smart wearable devices. With this model, researchers can also identify the user's satisfaction level for post-adoption of CGMs. And from all of the possible features and factors, users can consider the adoption of wearable CGMs device for their diabetes management.

1.7 Structure of The Thesis

Chapter 1, introduces about problem background, research questions, research objectives, research scope, significant of research and also the structure of the thesis.

Chapter 2, explains about literature review that has been analyzed to find out the factors which influence user's intention to use wearable CGMs device, the existing model from different papers, justification of previously proposed model. This chapter also discusses factor formation.

Chapter 3, presents the research design, methodology, justifies the choice and used a particular methodological approach. The research framework is proposed with detailed steps and activities involved throughout the research, which are also described in detail.

Chapter 4, is about the development of the adoption model. Measurement items were extracted from the literature for instrument development. The questionnaire will be evaluated through the items measurement.

Chapter 5, describes the results of the main study. This chapter will show the final adoption model for wearable CGMs device with the measurement model and structural model assessment.

Chapter 6, describes the conclusion of the research with a discussion of the contribution and implications of the research results, the limitation of the study and also the future work for the research.

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