Mother-Baby Smart Watch M.B.S.W

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Owner:

Dania Ezeddin Masoud

Supervisor:

Mrs. Abir Obeid

Institution:

International School of Creative Science - Sharjah

Table of contents

1. Abstract

It is estimated that 1 in 20 pregnancies (5%) end in loss during pregnancy or birth in the UK alone. The loss of a baby inside the mother's womb is a tragic, emotionally-devastating experience for parents who are anxiously awaiting the arrival of a child. While 30% of the causes behind the loss of a baby during pregnancy seem to be unknown, another 70% of this "tragic" is mainly a result of poor medical care and health of both the mother and the baby. This had inspired and urged us to think of a very beneficial and easily-operated device that can save thousands of babies who had not open their eyes yet!

Our idea is based on a smart watch, which has the potential to support health in everyday living; however, this smart watch is fully dedicated to take care and keep in track of the health of both the mother and the unborn baby. This watch will act just like an 'always available' doctor that can assist the mother during every day of pregnancy by tracking her and her baby's health including heart rate, blood pressure, breathing rate as well as assigning what medicine and food the mother is allowed or NOT allowed to eat during pregnancy. Furthermore, the watch will have direct contact with the hospital for any emergency. This would really help mothers; especially mothers with no previous experience, which is the main aim behind our invention. The idea of strapping a wearable computer on someone's wrist is not new in which the daily use of smart watches had amazingly increased by 78% in 2018 since 2012 (during 6 years only). However, most of these watches track your basic health only, while our invention can be a reason of saving lives of mothers and unborn, innocent babies.

2. INTRODUCTION

Researchers and Gynecologists studying the medical practice dealing with the health of the female reproductive system found in a study held in 2016 that an estimated number of 211 million pregnancies occur yearly worldwide while a huge number of these pregnancies (10550000) end up with a tragic loss of the unborn fetus. Additionally, it is found that every day, 830 women die from pregnancy or childbirth which is about 298800 deaths yearly and according to the United Nations Population Fund (UNFPA) 2017 report, this is equivalent to "about one woman every two minutes." Although many countries halved their maternal death (the death of a mother while pregnancy or while birth) rates in the last 20 years, in which the rate had declined by 44% since 1990, the rate of maternal and fetuses' deaths are still high compared to the development of technology the world had gone through.

Nevertheless, depending on United Nations Population Fund's (UNFPA) report, "Most of these deaths are entirely preventable." In other words, it is confirmed and validated that over 79% of mothers and fetuses' loss can be obstructed by simply providing better health care.

2.1 HYPOTHESIS

The Mother-Baby Smart Watch is capable of tracking the pregnant mother and her fetus' health therefore it can be the reason of saving many lives that lack genuine and proper medical care.

2.2 Objectives

- ✓ To design and construct a smart watch that focuses on tracking the medical conditions of a pregnant mother and the fetus.
- ✓ To provide satisfactory and a fulfilling health care for both patients (mother and baby)
- ✓ To reduce the number of maternal and fetuses' death worldwide

2.3 Background and Supported Researches

Objectively, In this report we would refer to the following studies and researches we stand on in this project.

2.3.1 Health of Fetal and a Pregnant Mother

According to the UNICEF's 2009 study conducted by researcher JOHANNES BURG, "pregnancy is 300 times deadlier in the least developed world." In other words, pregnancy in undeveloped countries mostly leads to maternal death or stillbirth of the fetal in which it was found that over 85% of these deaths are observed in impoverished societies in Africa and Asia. This supports the fact that deficient medical care is mostly the dominant reason behind these high quietus rates of mothers and fetuses. Moving on, it was scientifically proven that more developed health care before, during and after childbirth can save the lives of women and unborn babies. These studies and researches are further reinforced by the fact that the high number of maternal deaths in some areas of the world (poor rural areas) reflects inequalities in access to health services, and highlights how medical care is the key of reaching 'The Sustainable Development Goals and The Global Strategy for Women's and Children's Health' which aims to reduce the global maternal death and stillbirth's ratio to "less than 70 per 100 000 births." This sheds a light on the idea that pregnancy loss is a global consequential problem that had urged many huge organizations such as the UNICEF, Centers for Disease Control and Prevention, and the World Health Organization to search for a utilitarian solution.

Given the above, people mostly wonder what type of medical care is essential for ensuring that a pregnant woman and her unborn fetal are healthy. Well, according to Gynecologists, it is very important to make sure that a fetus' heart rate, breathing rate and last but not least the fetus' movement are within the normal range. To begin with, Dr Daniel J Bell and Dr Yuranga Weerakkody et al. stated that a healthy fetus' heart rate (FHR) is:

- 140 bpm (average) by 5-6 weeks
- 170 bpm by 9-10 weeks

This is followed by a decline in the FHR to become:

- 180 bpm by 20 weeks
- 130 bpm by a term

However, if the fetal is facing Fetal tachycardia, which is an abnormal increase in the fetal heart rate (above 180 beats per minute) in the mainstream of cases, it is a result of abnormal electrical impulses originate from the atria, doctors will have some concerns towards the fetus' health thus will suggest some treatments immediately before any development of other medical problems. If no immediate response was taken (which mostly occur when a pregnant woman is not getting the medical care needed), doctors say that it may "cause trouble" for both the fetal and the mother.

Moreover, the breathing rate of a fetal is equally important to the tracking of the heart rate. Therefore, doctors' second step of ensuring the fetus' health is making sure that the breathing rate is within normal range. Depending on the study conducted by the Department of Obstetrics and Gynecology, University of Western Ontario, it was found that fetuses breathed at a rate of 44 breaths per minute, and the longest period of apnea noted was 14 minutes. Nevertheless, it was also confirmed that a fetus' breathing rate varies from the last 10 weeks of pregnancy. Any apnea occurring more than 14 minutes is considered an emergency and must be treated as quickly as possible. However, women getting less health care than needed or no health care at all can suffer from pregnancy loss due to no immediate medical response to apnea.

Last but not least, doctors had stated that if "no fetal movement" was "felt," it could be a bad indication. In other words, a decrease or cessation in sensations of fetal activity may be an indication of fetal distress or death. This reinforces the importance of continues tracking of the fetal movement. Therefore, all gynecologists focus on the fetal movement and consider it a very essential information to track the fetus' health. As a result, Nasello-Paterson, Natale, and Connors, researchers in Department of Obstetrics and Gynecology, University of Western Ontario, had made many studies that shed a light on the valuation of fetal body movements over twenty-four hours. They had conducted Continuous "24-hours" observations of "fetal gross body movements" which was performed on 20 women. The study had found that "fetuses at 24 to 28 weeks' gestation exhibit a diurnal pattern of fetal movement and move more frequently than do older fetuses. However, these movements are of a sporadic nature and relatively short duration." The study had also demonstrated that young fetuses "at 24 to 26 weeks' gestation" move "13.1%" of the time a day. This had suggested that fetal with similar ages moved on the average "53.4 +/- 1.6 times/hr". However, any fetal moving more or less can be an indication of pain and is considered "not good news," as described by Dr Nasello-Paterson. Again, if this had happened with any pregnant woman, doctors would take instant reactions and prepare treatments to prevent upcoming medical problems. However, women with no previous pregnancy experience and who lack continues tracking of medical care can become a victim of pregnancy loss.
Finally, all these points mentioned above delineate how dangerous it is for pregnant women and their unborn babies and illustrates the role of medical care tracking in preventing the death of millions of souls worldwide.

2.3.2 Links Between Technology and Medical Care

Over the last 100 years, humans had developed many inventions and had made many discoveries that led to the continues development of technology. Therefore, technology had transcended what used to be ‘impossible’ into reality. According to The Department of Research and Development Technology Innovation 2017’s report on Science & Technology Indicators, it was found that in the period between“1981–2015”, a total estimated number of “30 million scientific journal articles” were published globally. Additionally, the “world production” of new technological discoveries articles had increased “from almost 500,000 articles in 1981 to over 1,500,000 in 2015.” These statistics manifest and prove that the world had gone through a rapid development of technology which is still ceaseless till now.

Moreover, technology had varied in types thus became a very huge part of the world evolution and development; for instance: Assistive technology, Educational technology, Biotechnology, etc. Nevertheless, since the MBSW is an invention in bioinformatics and health, we will shed a light on Health Care Technology. According to The World Health Organization (WHO), health technology is all the “applications of organized knowledge and skills in the form of devices, medicines, vaccines, procedures and systems developed to solve a health problem and improve quality of lives.” To begin with, ‘medtech’ or medical technology was always a very important part of early and present humans’ lives. During the Stone Age, 3300 BC, early humans used very primitive forms of herbal medicine (the use of plants for medical purposes) to treat some diseases that could be treated using this type of medical care. The use of herbal medicine was still used although new forms of medical care and systems were discovered around the world such as Ayurveda in India. Subsequently, the development of health care was rapidly expanding thus new types were discovered and in 1800 BC, the oldest known medical text in Egypt as well as the oldest and most ancient medical system dealing with women's health and gynecological diseases such as “fertility, pregnancy, contraception, etc.” was discovered. This medical text is known as ‘Kahun Gynecological Papyrus.’ As a result, the science of gynecology was practiced by many leading to an immense evolution in discoveries within this science therefore gynecology had gone through many advancements and development.
Today, in the 21th Century, Medical technology is one of the most essential type of technology ever discovered wherein medical technology had become the reason behind the possibility of eradicating numerous infectious diseases such as Smallpox, Rinderpest and, the very well-known disease, Plague. These are very hazardous infections that had killed millions of people in a short period of time. However, thanks to medical technology, these treacherous infections are no more a threat to humanity. Additionally, technology dealing with health and medicine played a huge role in the discoveries of surgical procedures including surgeries of all different parts of humans’ and animals’ body. These facts highlight the importance of technology in health care in which many ‘impossible’ medical treatments became possible because of technology. This is an explicit proof which suggests that the presence of technology had led to this global medical care evolution and indicates that if technology was not developed in the first place, humans would still depend on primitive herbal medicine to cure simple diseases.

Furthermore, although medical technology had enhanced hastily, doctors and global health organizations are still seeking for more. A good example is the UAE's healthcare continues development. According to Khaleej Times, "UAE's healthcare industry has continued to evolve over the past few years, and today offers a range of new specialized services and treatments for residents." In other words, health care is one of the fastest growing sectors in the UAE. Indeed, UAE's leaders were one of the main reasons behind this mind-blowing development in only few years in which Sheikh Hamdan bin Rashid Al Maktoum, Deputy Ruler of Dubai and UAE Minister of Finance inaugurated the 43rd edition of the event that "witnessed the participation of more than 4,000 companies from over 150 countries" which had been running until February 1, 2018. The participants of this medical event displayed new inventions in medical technology such as "surgical robots, augmented reality systems, and artificial intelligence enabled scanners." This event further supports the idea that the development of medical health is still continues and outlines experts' interests regarding medical technology in the UAE and the whole world.

Moving on, technology had become a basic part of all individuals' lives including pregnant women where it was found in a study, conducted by the Australian Communications Consumer Action Network 2012, that 80% of all men and women in Australia have access to smartphones in the 18–34-year-old category. These findings are in line with the results of the Australian Journal of Primary Health report that had studied the number of pregnant women who use information and communications technologies to access pregnancy-related health information in South Australia. The study stated that 88% 0f the pregnant women, who took a part in this study, had 'smart phones.' Additionally, 91% of them had full access to the internet. These findings validate and prove the presence of technology as a part of most people's lives. However, it is important to note that not all participants used technology in the same way. Furthermore, "it is critical to make distinctions between access to ICTs and the corresponding use of these technologies to seek pregnancy-related health information." It was found that "11% of participants used the Internet to access pregnancy-related information." Yet the majority of them and with a percentage of 89% did not trust the information on the internet and had described them to "unreliable." In other words, they did use the internet to read about pregnancy yet they did not trust all what was mentioned. The participants had also clarified that information on the internet did not always fulfill their questions therefore they do not appreciate internet as a useful technology during their pregnancy period.

Notwithstanding, it is a proven fact that technology do play an important part within pregnancy where health technological devices are used to preform many functions. For instance: ultrasound which is a "type of imaging" that uses "high-frequency sound waves to look at organs and structures inside the body. Health care professionals use it to view the heart, blood vessels, kidneys, liver, and other organs. During pregnancy, doctors use ultrasound to view the fetus therefore it became possible to track the fetus' health. Ultrasound is a technological device that proves the importance of technology in the health care of pregnant women.

2.3.3 Smart-Watches

The smart watch device has been predicted to be the next huge hit in the ecosystem of wearable and mobile devices. Samsung, Apple, Huawei, Motorola and many other global companies had spent a lot of time and money in smart watch technology in the past years. In a study, it was found that “the global smart watch market valued $10,223.9 million in 2017.” Additionally, in 2013, “around 2.1 million units of smart watches were sold in the market.” This was the beginning of a new “era in the mobile technology space.” Today, smart watches are imaginably the most recognizable piece of the wearable technology. This is foreseeable since smart watches’ advantages overpower their drawbacks.

Moving on, smart watches have been recently used as fitness and health trackers thus it became very helpful which had led to their popularity within all people. Their ability of fitness tracking is mainly a result of the sensors and technologies used in making them.

Most smart watches these days contain 7 main sensors. To begin with, all fitness trackers smart watches commonly include an accelerometer which measures the “orientation and acceleration force” allowing them to determine whether the device is moving or not. Therefore, it is used to count the daily steps taken by the user. Additionally, most smart watches contain Optical heart-rate monitors which uses a very strong light that shines through the skin, and an optical sensor examines the light that bounces back to calculate the user’s heart rate. Moreover, Galvanic skin response sensor is indeed a very essential sensor in smart watches that measure electrical connectivity of the skin. These sensors come along with Thermometers, Ambient light sensors, UV sensors and Bio-impedance sensors which certainly have specific functions and play different roles in fitness tracking.

Most commonly, smart watches that deals with health and fitness Integrates HealthKit into your health and fitness apps so that the smart watch becomes a valuable data source in which it can deliver deeply informed health and fitness solutions. As described by Apple Company, HealthKit focuses on “creating a complete, personalized health and fitness experience” including:

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- Collecting and storing health and fitness data
- Analyzing and visualizing the data
- Enabling social interactions

Example of current fitness tracker smart watch

Apple Smart Watches are a good example of devices using HealthKits to perform the tasks mentioned above in which it many Parameters can be read by Apple Watch using Healthkit like the following:

Parameters than can read by Apple Watch using Healthkit

Permission	Healthkit Identifier Type	Read	Write
ActiveEnergyBurned	HKQuantityTypeIdentifierActiveEnergyBurned	✓	
BasalEnergyBurned	HKQuantityTypeIdentifierBasalEnergyBurned	✓	
BiologicalSex	HKCharacteristicTypeIdentifierBiologicalSex	✓	
BloodGlucose	HKQuantityTypeIdentifierBloodGlucose	✓	
BloodPressureDiastolic	HKQuantityTypeIdentifierBloodPressureDiastolic	✓	✓
BloodPressureSystolic	HKQuantityTypeIdentifierBloodPressureSystolic	✓	✓
BodyMassIndex	HKQuantityTypeIdentifierBodyMassIndex	✓	✓
BodyTemperature	HKQuantityTypeIdentifierBodyTemperature	✓	
DateOfBirth	HKCharacteristicTypeIdentifierDateOfBirth	✓	
DistanceCycling	HKQuantityTypeIdentifierDistanceCycling	✓	✓
DistanceWalkingRunning	HKQuantityTypeIdentifierDistanceWalkingRunning	✓	✓
FlightsClimbed	HKQuantityTypeIdentifierFlightsClimbed	✓	✓
HeartRate	HKQuantityTypeIdentifierHeartRate	✓	
Height	HKQuantityTypeIdentifierHeight	✓	✓
LeanBodyMass	HKQuantityTypeIdentifierLeanBodyMass	✓	✓
MindfulSession	HKCategoryTypeIdentifierMindfulSession		✓
RespiratoryRate	HKQuantityTypeIdentifierRespiratoryRate	✓	
SleepAnalysis	HKCategoryTypeIdentifierSleepAnalysis	✓	

Given the above, it is explicitly understood that the development of smart watches had led to their mind-blowing abilities in health and fitness tracking.
Moving on, to create a completely useful smart watch it indeed requires coding using programming languages.

To begin with, one of the most powerful programming languages is SWIFT. This programming language is an “intuitive programming language for macOS, iOS, watchOS and tvOS” which was designed by Chris Lattner, Doug Gregor, John McCall, Ted Kremenek, Joe Groff, and Apple Inc. Swift became one of the most popular programming languages in the world in less than 2 years from its release. This programming language is capable of creating a full operating system of a device hence it is used to design the way a smart watch would work. Additional, SWIFT can be less complicated and design or create an App on any Apple device. SWIFT is alternative to a more familiar language which is the primary programming language used when creating or writing software for OS X and iOS.

To explain more, when someone is building a program or software, he/she will deal with objects. Those objects are instances of Objective-C classes. It adds “Smalltalk-style messaging to the C programming language” to create a language that has the potential and that is capable of building a whole system for a device such as a smart watch.

Moreover, the mounting practice of JavaScript has created whole new methodological models of program construction and deployment. JavaScript is a “high-level, interpreted programming language” which is one of the “three core technologies of the World Wide Web.” According to Simon Holm Jensen, Anders Moller, and Peter Thiemann research analysis on JavaScript programming language, “JavaScript is an object-based language that uses prototype objects to model inheritance.” It is capable of developing JS based sites and apps. In other words, it is a developer’s assistance in programming websites and applications on any device such as a smart watch. Now days, JavaScript is used by more than 94 percent of all the websites and applications.

In the development of an application dealing with health, the programmer would use a programming language such as languages mentioned above to build a collection of useful programs thus creates different frameworks. If the MBSW (Mother Baby Smart Watch) was programmed on an apple watch for example, it will be using 5 different frameworks:

- HealthKit framework
- ResearchKit framework
- CareKit framework
- React Native framework
- WatchKit framework

All these frameworks will enable the MBSW to function and execute its’ job of tracking the health of a pregnant woman as well as the fetus.

Furthermore, in any device or application, data must be stored and organized in way that allows a computer system to access them electronically. In other words, a database is required in an organized collection of data. A very commonly used example of database is SQL. Structured Query Language, or SQL, is a computer language specialized to a particular application domain “used in programming and designed for managing data held in a relational database management system.” Many devices currently use SQL database to organize all the data. The MBSW is one of these devices in which the database that will be used is going to be SQL. A real time data base is also used in order to keep in track of all the new data collected every 3000 milliseconds

All these programing languages, frameworks and databases are the main reason behind the continues development of programming systems and applications. Without their invention, watches would have never become smart and devices would have never developed.

3. Solution Description

3.1 Devices:

- A Programmable Smart Watch with the following sensors :
  - Blood Pressure monitor
  - Optical heart rate monitor -pulse sensor- (OHRM)
  - Bio-impedance sensor
  - Motion sensors (accelerometers / wrist movement sensors)
- Smart phone to Take and analyze readings from optical sensors

Smart watch with the mentioned sensor

3.2 Method and Procedures (MoP)

3.2.1 Collecting the mother's Health data

Most fitness trackers are capable of tracking the health and fitness of any person using sensors and monitors. In the MBSW, a blood pressure monitor is used to read the systolic (the pressure when the heart contracts –beats-) and diastolic (the pressure when heart relaxes) blood pressure. It must be noted that Monitoring Blood Pressure is very important as the "variation in blood Pressure can affect the baby's supply of oxygen and nutrients." The monitor uses a very strong light that shines on your skin. It then calculates the amount of reflected light each time the heart beats and relaxes. This provides the data needed regarding the mother's blood pressure.

The systolic and diastolic blood pressures are then used to calculate the pulse pressure using the following simple formula:

Pulse Pressure = Systolic blood pressure – Diastolic blood pressure

For example, if a mother's blood pressure is 120/80 mm Hg, the pulse pressure will be 40 mm Hg. After calculating the pulse pressure, the results are compared to the normal pulse pressure range of a pregnant woman which is:

$$30 \leq X \leq 40$$

OHRM displays collected data regarding heart rate

Additionally, the MBSW can read a mother's heart beat -heart rate- using an Optical Heart Rate Monitor (OHRM).

This monitor calculates the blood pressure change in your skin capillaries by shining a strong light as well.

This is known as the Photoplethysmography technique (PPG) which is used to find the heart rate. PPG is a simple and low-cost optical technique that can be used to "detect the blood volume changes in the micro vascular bed of tissues." Using these calculations, (change of blood pressure), the watch reads the heart rate of the mother thus this health data could be tracked and displayed on the app. The normal range of a pregnant woman's heart rate is about 70 beats per minute to 80 or 90 beats per minute.

It must be noted that during exercise, the cardiac output and heart rate increase more when a woman is pregnant than when she is not. In other words, her heart rate could increase rapidly during exercise, thus a pregnant woman must not exercise as hard as a normal woman for during pregnancy, the woman's heart must work harder as the 'fetus grows.' Current fitness trackers support harder practice of sports because they deal with normal people.

Nevertheless, the MBSW function oppositely in which using motion sensors such as accelerometer that can determine your daily steps and exercise, do not support too much exercise for its' user.

Equally important, the breathing rate (oxygen flow in blood) and the respiratory rate are measured by most fitness trackers as well as the MBSW. In current smart watches, a Bio-impedance sensor is used to measure the breathing rate of the user. This is also applied in the MBSW, however using ratios linking heart rate and breathing rate.


'Photoplethismography technique' Present Optical Heart Rate Monitor

According to a comparative study about the relation between respiratory rate and heart rate done by Farah Bahmed, Farisa Khatoon and B. Ram Reddy, it was found that it is possible to calculate someone's respiratory rate using the heart rate. The researchers had investigated "simultaneous wave recordings of cardiovascular and respiratory systems in the 40 healthy individuals including males and females" for 15 minutes.

Their results were the following:

Table 1: Heart Rate (HR) per minute of 15 minutes duration Mean HR Values (for 40 cases)

Maximum (HR)	106.33
Minimum (HR)	65.40

Table Reference:

Table 2: Respiratory Rate (RR) per minute of 15 minutes duration Mean RR values (for 40 cases)

Maximum (RR)	28.73
Minimum (RR)	14.73

https://pdfs.semanticscholar.org/33f3/528a3485137656342abf02af5983210e6df6.pdf

This had led to the discovery of the ratio of the cardiovascular rate to respiratory rate which makes calculating the respiratory rate from the heart rate (cardiovascular rate) possible. It was found that “ratios of cardiovascular and respiratory rate may vary in the range of 3:1 to 6:1.” Using this formula, it is possible for any smart watch to calculate the respiratory rate. The MBSW therefore is capable of using the formula as well as the data collected from the Bio-impedance sensor to display an analysis of the breathing rate of the mother.

Moving on, throughout the process of tracking wrist movement, any smart watch with such motion sensors is capable of predicting sleeping patterns thus gives recommendations on how to improve the user’s sleeping patterns. According to the National Sleep Foundation's 1998 *Women and Sleep* poll, “78% of women report more disturbed sleep during pregnancy than at other times.” Additionally, in the same study, most women had reported “feeling extremely fatigued during pregnancy.” Pregnancy-related fatigue had been explained to be hormonal therefore normal.

However, the “wide-ranging effects of pregnancy on sleep” are still mysterious in which changes “occur in quality, quantity, and the very nature of sleep.”

Figure 1; the average daily hours of sleep of pregnant women

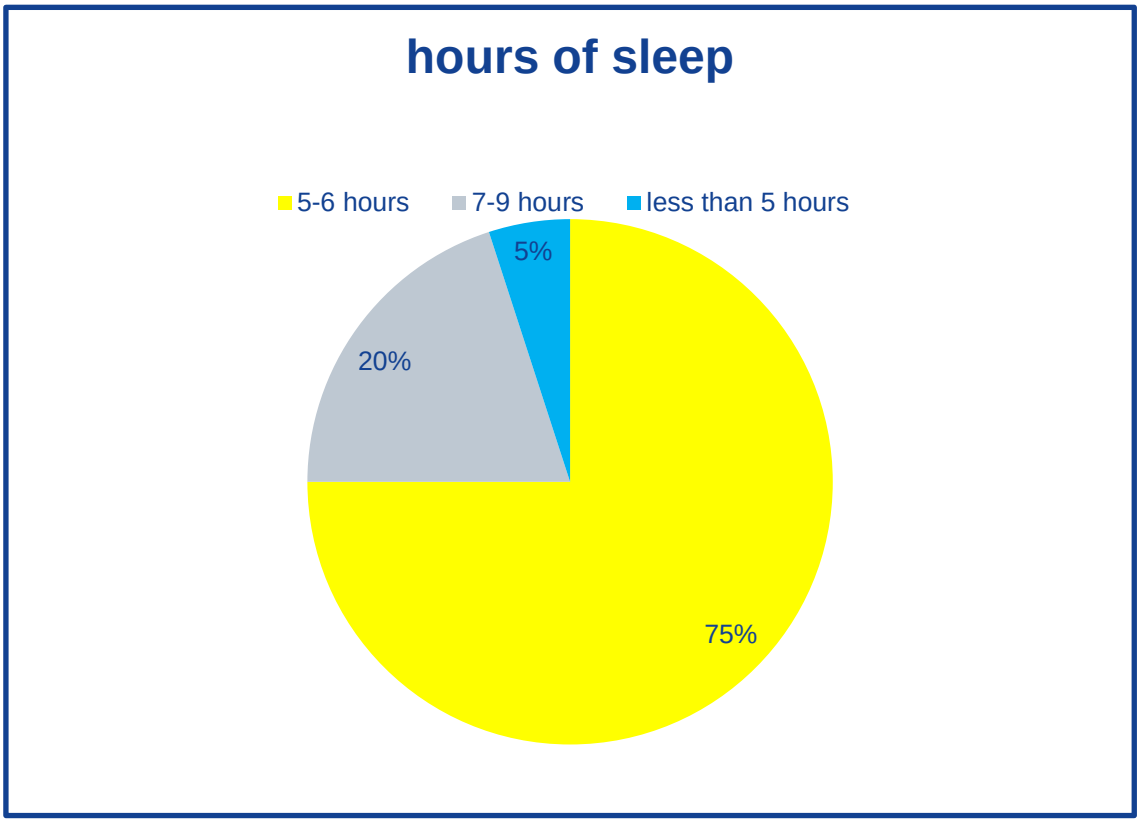


Figure 1 represents the average result of a study held in the UK that had observed the daily sleeping hours of 600 pregnant women. As shown above, the majority of them and with a number of 450 women sleep from 5 to 6 hours only while a pregnant woman should sleep at least 8 hours. Kathy Lee, a professor of nursing at the University of California San Francisco, who had studied how the effect of pregnancy on sleep, had clearly stated that a mother should “sleep for two:” for the fetus and herself. Given the above, it is understood that a pregnant mother should rest more than a non-pregnant mother however most of them do not get the sleep their body needs because of many factors thus they need constant sleep pattern tracking and constant recommendations.

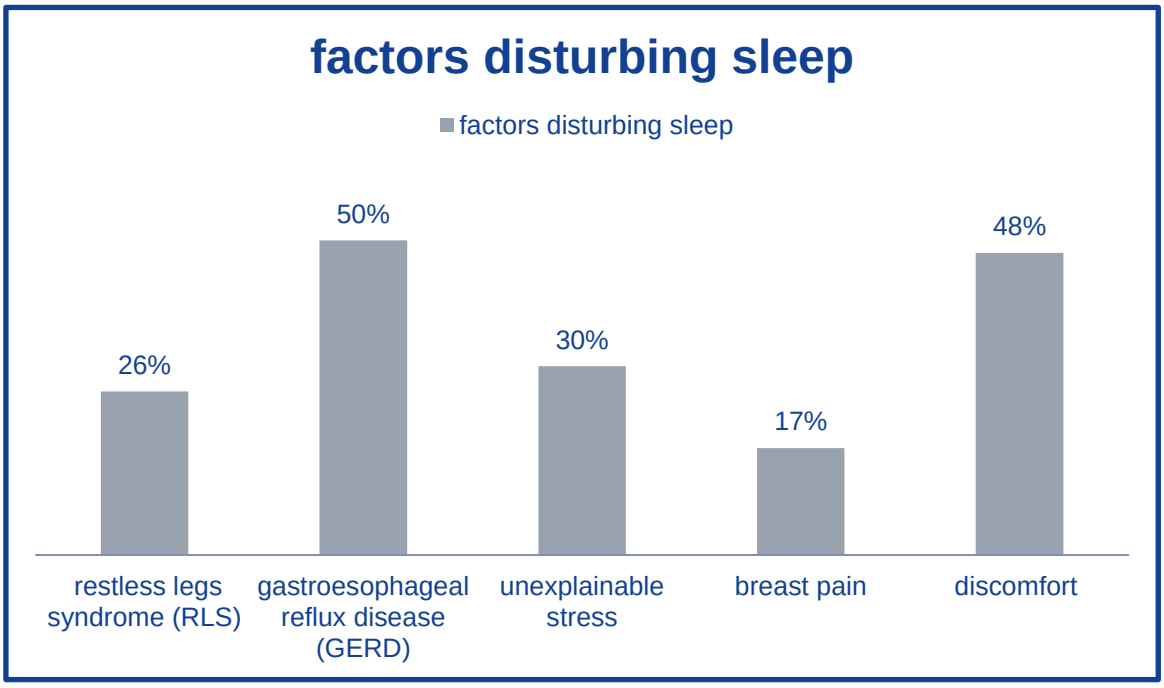


Figure 2; reasons behind sleeping disorder of 600 pregnant women

Figure 2 displays the factors that had disturbed the pregnant participants of the same study mentioned above. These factors had caused the majority of the 600 participants get less sleep than needed. Indeed, it is completely normal for a pregnant woman to suffer from them yet medical recommendations could improve their sleeping patterns. This further supports the importance of continuously getting medical advice.
In conclusion, all the information and health data tracked by the MBSW reinforce the fact that this watch can be both a Main Health and a Gynecology Doctor that ensures that the pregnant mother is safe and healthy.

3.2.2 Collecting the Fetus' Health Data

Currently, a pregnant mother could make sure of her fetus' health by using an ultrasound device that is present in hospitals. These devices are non-portable, sophisticated thus expensive. However, recently new, less-expensive, wireless ultrasound devices had been released into market. Yet, the idea of a continues fetus' health tracker is not available. This is where the MBSW differs and distinguishes.

To begin with, one of the most important health data of a fetus that all Gynecologists focus on is the heart beat. A low heart beating rate of a fetus can indicate health problems that can mostly be dangerous. As a result, the MBSW is programed and designed to track such information.

The Optical Heart Rate Monitor found on the back of the watch will make reading the mother's impulses possible. The watch would be able to read 2 slightly different signals sent from both mother's and baby's hearts. However, the signal sent from the heart of the fetus is neither that strong nor recognizable thus the data collected regarding the fetus' heart beat rate will not be accurate. This had led us to look for a new solution which was finding links between a mother's heart beat with the fetus'.

Yet there was no relation. This could be understood by the fact that in some cases, a fetus dies inside the mother's womb therefore the fetus' heart stops while the mother's heart is not affected. This had made us think and research more deeply to understand how the fetus' health is related to the mother's health. According Brown et al., who had studied maternal heart rate variability and fetal behavior, "maternal hypertension is considered one of the main influences on FHR." In other words, if a mother's blood pressure is high, the fetal heart rate is influenced in which the heart rate becomes exceeds the normal range. This implicitly shows that there is a relation between the blood maternal pressure and the fetal heart rate. This was further supported by research article showing the 'RELATIONSHIP BETWEEN FETAL HEART RATE AND MATERNAL BLOOD PRESSURE' done by Moawia Gameraddin, Suzan Abdelmaboud, Suliman Salih and Abdalrahim Alsayed; Department of Diagnostic Radiologic Technology, College of Medical Applied Sciences, Taibah University. Their research article had deeply looked into the FHR and the mother blood pressure and as a result they were capable of finding the ratio of the mother's diastolic blood pressure to the fetal heart rate. The ratio is the following:

This means that if a mother's diastolic blood pressure was 80 mm Hg (normal/ within range), the FHR would be 80 * 1.456178 = 116.5 beats per min (also within normal range).

Using this formula, the MBSW is capable of finding a fetal heart rate using the blood pressure of the mother.

Moreover, according to the research article: 'Influence of paced maternal breathing on fetal–maternal heart rate coordination' by P. Van Leeuwen,[a,1] D. Geue, M. Thiel, D. Cysarz, S. Lange, M. C. Romano, N. Wessel, J. Kurths, and D. H. Grönemeyer, it was found that the respiratory rate of the mother is correlated to the FHR. The researchers observed the respiratory rate of 6 pregnant mothers and their fetuses' heart rate at 4 different period of time.

The results were the following:

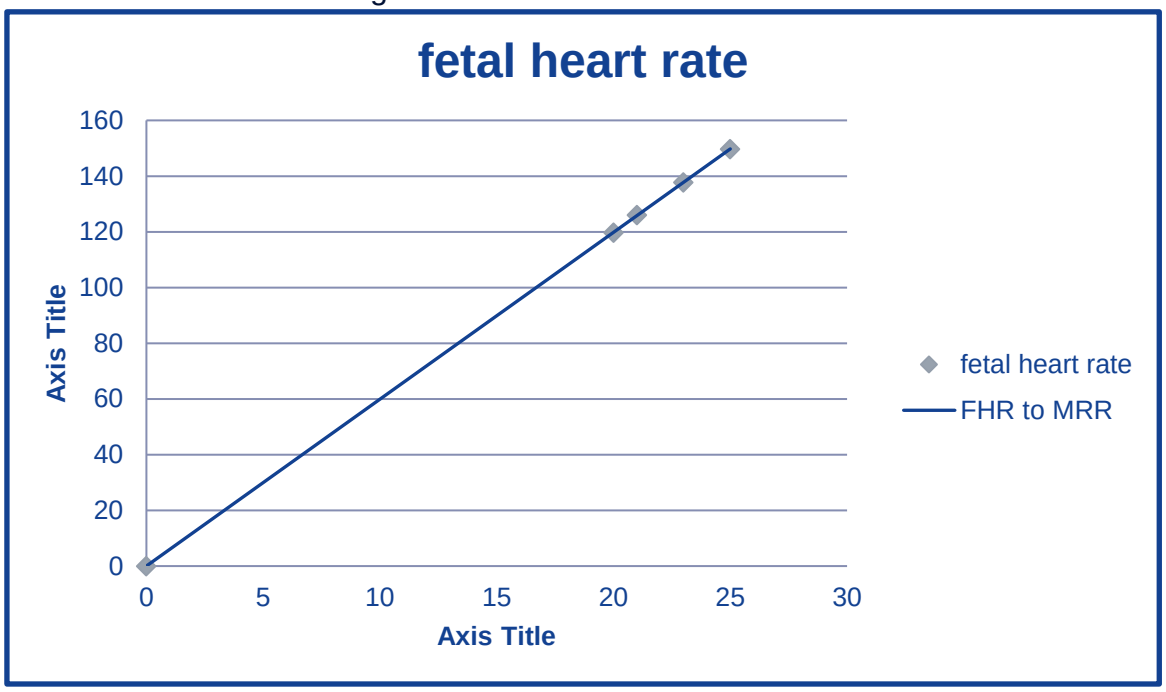


Figure 3; correlation between maternal respiratory rate and FHR

Given the above, it is clearly shown that there is a positive correlation between mother respiration and the heart rate of the fetus thus there is a formula relating both data. The ratio of mother's respiration rate to FHR is the following:

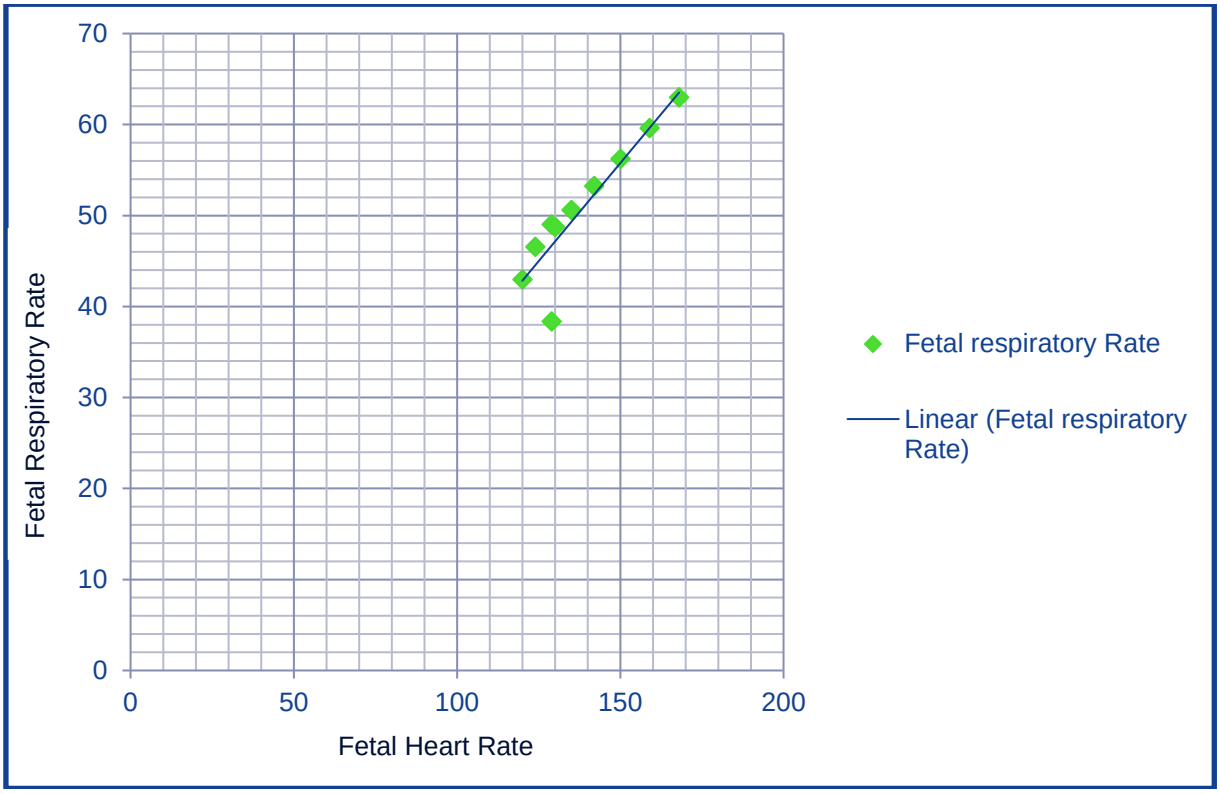
$$1 : 5.98802$$

This ratio makes calculating the FHR possible without the use of ultrasound device thus the MBSW is capable of displaying the heart rate of the fetal by using the respiration rate of the mother.

Moving on, knowing the breathing rate of the fetus is equally important to the heart rate. A low breathing rate could indicate serious health problems therefore tracking breathing rate of a fetus is very important in order of ensuring that the fetus is healthy.

As a result, one of the most important functions of the MBSW is being capable of reading a fetal breathing/respiratory rate by using the formula that links the

cardiovascular rate (heart rate) with the respiratory rate. Researchers from The Department of Maternal and Child Health in the USA, the Department Of Biomedical Engineering as well as Johns Hopkins University had made a study to investigate the correlation between the fetal heart rate and the respiration rate of a fetus in 10 different healthy fetuses in 10 pregnant women.
The results of this investigation are shown in the following scattered graph:



Given the above, it can be understood that the fetal heart rate and the respiration rate is related. This idea is supported by the formula that links both of these health data which was part of the study's results. The formula is:

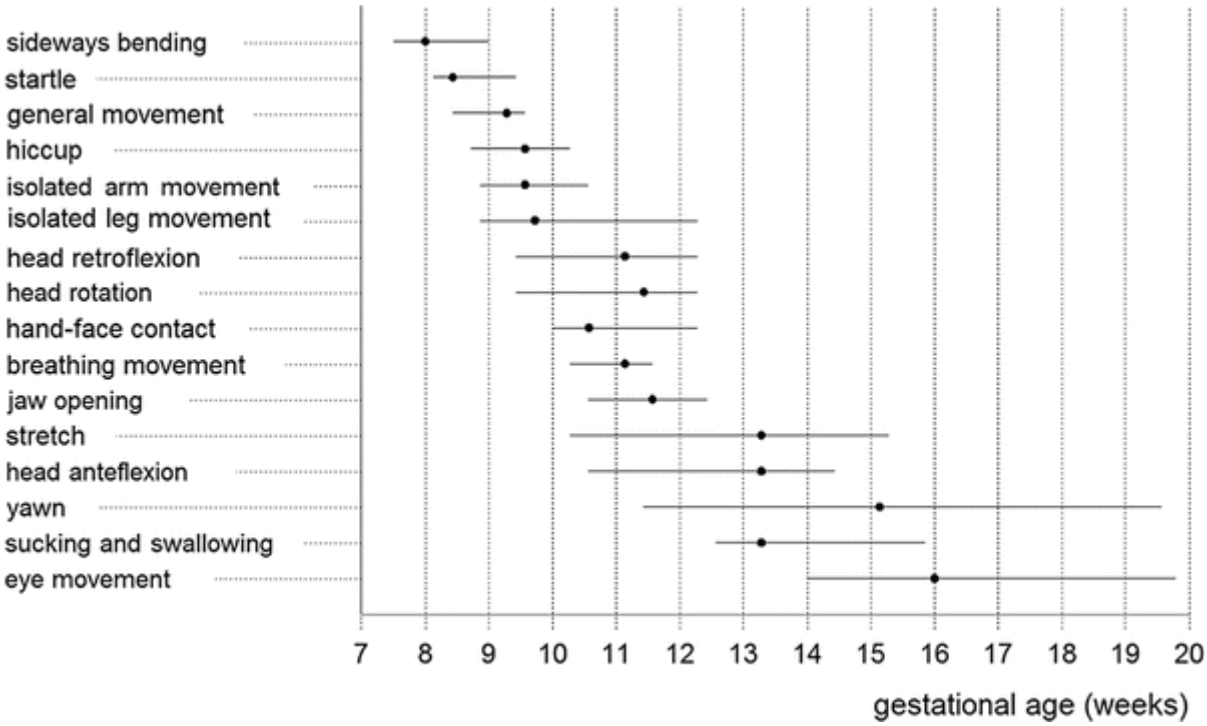
$$FRR = (0.431 * FHR) – 8.8857$$

Key words: FRR (fetal respiratory rate), FHR (fetal heart Rate)

Another ratio was mentioned in the study linking fetal heart rate to fetal respiratory rate however it is much generalized:

Using the formulas above, the MBSW is capable of reading a fetus' respiratory rate thus display a daily analysis of the rate of respiration for both the mother and the fetus.

Finally, the movement of a fetus inside the mother's womb is a very important signal that could indicate the health of the fetus. The unborn baby starts moving differently depending on the gestational age. The following diagram summarizes the normal movement of the fetus:



Reference: https://link.springer.com/chapter/10.1007/978-3-319-22023-9_5

The normal movement rate of a fetus is about five movements in an hour, or 10 in a two-hour period. However, a sudden stop or decrease in the fetal movement may be a sign of fetus' distress thus it is important to keep tracking the health of the fetus.

The MBSW is designed to be able of interacting with the mother in which it questions the mother regarding her baby's movement so that it records the daily movement rate of the fetus. The fetal movement is also tracked by the daily checkup system of the MBSW which will be discussed after. Any concerning results will be directly sent to the doctor to keep up with her/his patients. If a mother didn't feel movement of her fetus or felt a decrease in rate of fetal movement the MBSW will ask the mother to visit the doctor as soon as possible to clear all the doubts regarding the fetus' health.

These three health information will be continuously tracked by the MBSW therefore any health problem could be discovered and cured as soon as possible.

3.2.3 Device Design

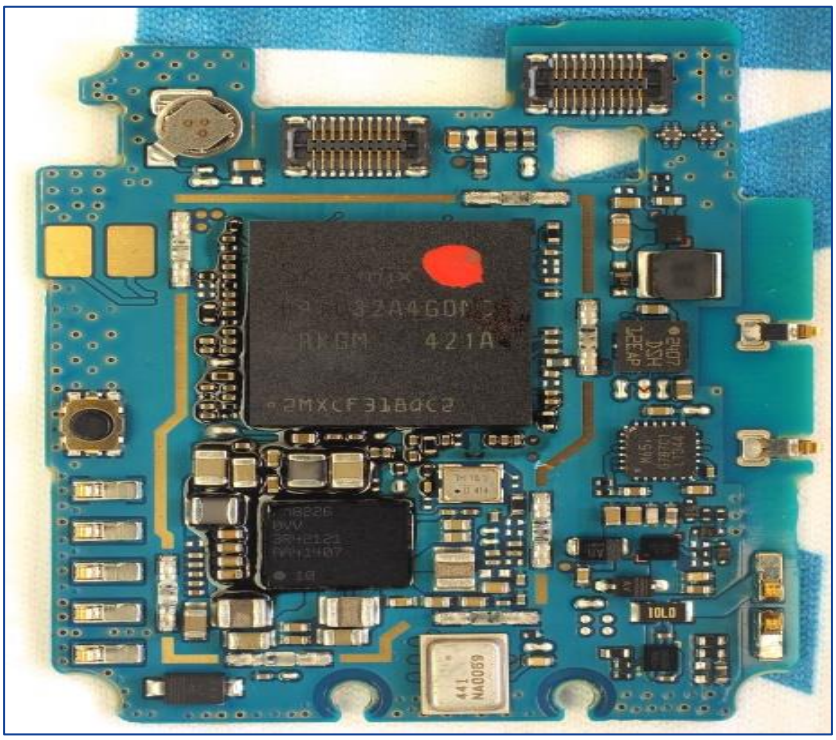
3.2.3.1 The internal hardware design comprises of three parts:

- The smart watch the pregnant woman wears. The function of the smart watch is to collect the health data of the pregnant woman and her fetus.
- The smart phone that contains an application connected to the smart watch. The purpose of the smart phone is to preform analysis on the data collected by the smart watch and display the analyzed health data.
- The ultrasound device of the daily checkup system.

3.2.3.2 The external hardware design consists of:

- The monitors and sensors within the smart watch. As mentioned before, each sensor collects a specific health data regarding the mother's health. Therefore, it is understood that the role of the sensors is to gather different health data of the mother.

External hardware of a Samsung wearable fitness tracker smart watch



Picture reference:
https://www.anandtech.com/show/8228/inside-the-first-android-wear-devices-lg-g-watch-samsung-gear-live-teardown

3.2.4 Software Design

The software of the MBSW is composed of two applications:

- The mobile phone application. The application on the smart phone makes the smart phone capable of analyzing and displaying data. It also efficiently implements algorithm and notifies critical conditions.
- The program on the smart watch. The program is the software that will use the formulas and ratios in order of calculating the health data of the fetus. Without this program, the MBSW will be a normal smart watch that measures the health of any normal person.

3.2.5 Daily Checkup

The MBSW is unique because of its ability of tracking the health of an unborn fetus. This is possible because of using scientifically proven medical formulas. However, although the formulas used are mostly accurate, there must be a daily checkup to make sure that everything is sufficient and functioning perfectly. As a result, we have decided to add an extra part in the process of health tracking which we call a 'daily checkup.'

Each day, in a specific scheduled time, the application on the mobile phone will notify the mother to do her daily checkup in which a mother is asked to use a wireless ultra-sound device that finds out the health of fetus including the FHR and the FRR. The data collected are then sent to the MBSW application on the mobile phone.

Now, the app will have 2 closely related readings: from the smart watch using formulas and from the daily checkup using wireless ultrasound device. Accordingly, the smart phone application will work out the mean of these two readings thus display the mean result of the two readings. Indeed, the data collected from both sources will be close to each other. This will make the health data of the fetus more accurate as well it reduces the small possibility of any error or false data.

3.2.5.1 Daily checkup algorithm:

a. Start
b. If time = ___ then,
    i. Inform mother for 'daily checkup'
c. Enter data collected from wireless ultrasound (FHR, FRR) scan device
d. Compare data from watch and data from ultrasound
e. If data from smart watch = data from ultrasound then,
    i. Display health data (no change applied)

    If else, then
    ii. Calculate mean of both data from both sources, then
    iii. Display mean result on application
f. Compare health data to normal range

3.3 System Analysis and Description

The MBSW is a healthcare system that generally assists pregnant women in rural areas who are in desperate need of help and assistance during pregnancy. The system's main aim is to reduce maternal and fetuses' mortality rates worldwide. The MBSW's hardware and software will work together forming a complete healthcare system. To begin with, the watch will collect the information and health data dealing with the mother using the sensors and monitors. The watch collects the following information:

- Blood pressure
- Heart rate
- Respiratory rate (found from heart rate by formula)
- Sleeping patterns
- Daily steps and movement rate

The information will be transferred automatically to the application on the smart watch. This is where the data are displayed and compared to the normal range each data is supposed to be within.

3.3.1 ALGORITHM

a. Start
b. Enter age of mother and month of gestation into the application
c. Start receiving information from smart watch using sensors (heart rate, blood pressure, etc.)
d. If age falls between 16and 35, then
   If heart rate does not fall in range 66-85,
   Condition is not normal.
   Notify mother and doctor
   Else if age falls between 36 and 50, then
   If heart rate does not fall in range 67-87,
   Condition is not normal.
   Notify mother and doctor
   If heart rate<60, then
   Patient shows symptom of Bradycardia
   Notify mother and doctor
   Else if heart rate>100, then
   Patient shows symptom of Tachycardia
   Notify mother and doctor
   Else Heart rate is found to be normal
e. If month<5, then
   If pressure does not fall between 115|70 and 130|95 then
   Mother's condition is not normal
   Notify mother and doctor
   Else if month>=5, then

If pressure does not fall between 130|80 and 140|90, then
Mother's condition is not normal then
Notify mother and doctor
Else Blood pressure is found to be normal.

f. If mother's respiration rate < 20 breaths per minute then
Mother's condition not normal/emergency
Notify doctor/ hospital
If respiration rate > 27 breaths per minute then
Mother's condition not normal/emergency
Notify doctor/hospital
Else respiratory rate is found to be normal

g. If wrist movement shows sleeping < 6 hours per day then
Mother is not getting enough sleep
Notify mother
If wrist movement shows sleeping > 11 hours per day then
Mother is sleeping more than usual
Notify doctor and mother

h. If walking < 30 minutes per day then
Mother is not getting enough exercise
Notify mother
If walking > 30 minutes per day then
Mother is doing more exercise than needed
Notify mother
Else walking/exercise is normal – within range

Given the above, it is clearly understood that if anything not within the normal range, the mother or the doctor or both are directly notified to keep in track. Moving on, what differentiate the MBSW from other smart watches is its' ability of tracking the:

- FHR (fetal heart rate)
- FRR (fetal respiratory rate)
- Fetus' movement

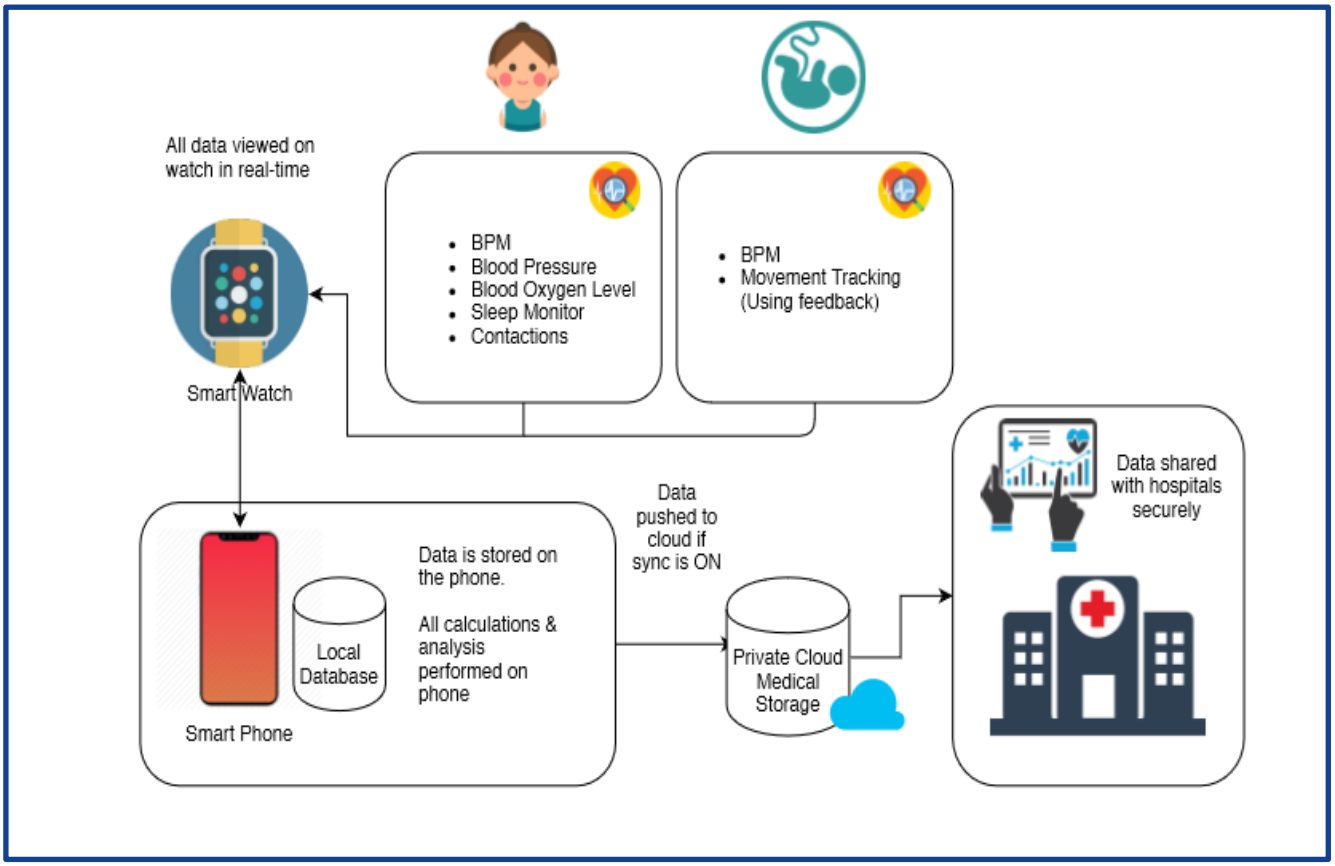
Taking in mined the MBSW is programmed to use specific medical formulas to find the FHR and the FRR.

1. Start
2. Enter gestation age into the application
3. Find mother's respiratory rate
4. Multiply Mother' RR by 5.98802
Result = FHR
Or find mother's diastolic pressure then
Multiply by 1.456178
Result = FHR

5. If FHR < 120 beats per minute then
   FHR is not normal/ emergency if less than 100
   Notify doctor/hospital
   If FHR > 160 beats per minute
   FHR is not normal/ emergency if more than 170
   Notify doctor/hospital
   Else FHR is found normal
6. Use this formula (0.431 * FHR) – 8.8857
   Result = FRR
7. If FRR < 40 breaths per minute then
   FRR is not normal/ emergency if less than 35
   Notify doctor/hospital
   If FRR > 60 breaths per minute then
   FRR not normal/ emergency if more than 70
   Notify doctor/hospital
   Else FRR is found normal
8. If gestation age >= 4 months then
   Ask daily question: “did you feel any movement of the fetus?”
   Record answer: “yes or no”
   If answer = “no” for 5 days then
   Notify doctor/ ask mother to visit doctor soon
   Else movement normal
   Inform doctor about daily movement rate weekly

Using the information above, it is explicitly shown that the fetus’ health is continuously tracked thus any emergency can be dealt with very quickly. This will reduce the rate of fetus and maternal death during pregnancy.

Figure 1; summery of the system / process scenario



3.4 Experiment/ results and discussion

In order of ensuring that the formulas the MBSW is using are reliable, an experiment was conducted which compares between the results of the FHR from both the formula the MBSW is using and the results from a wireless ultrasound device connected to an application on smart phones.

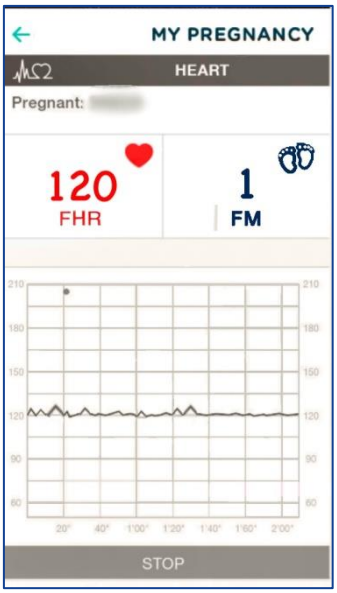
A Wireless Ultrasound Device that is connected to a mobile application

The experiment starts off with measuring the diastolic blood pressure of a number of normal pregnant women. Next, using a wireless ultrasound device, the heart rate of the fetuses of each mother is noted. In this case, 4 pregnant women's diastolic blood pressures were recorded thus 4 fetal heart rates were observed.

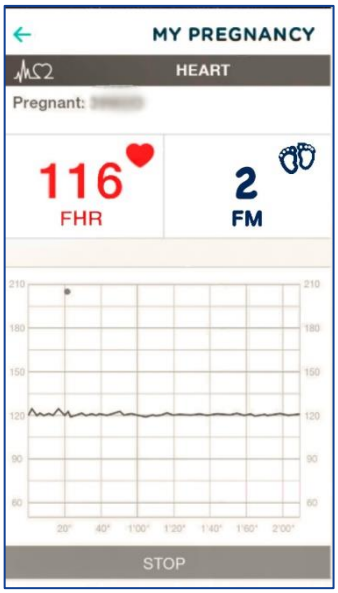
Using the same formula measuring the FHR from the mother's diastolic blood pressure that the MBSW uses, the FHR is calculated. The final step is to compare between the results of both the formula and the ultrasound in order of discovering the reliability of the MBSW Fetal health data.

3.4.1 Results:

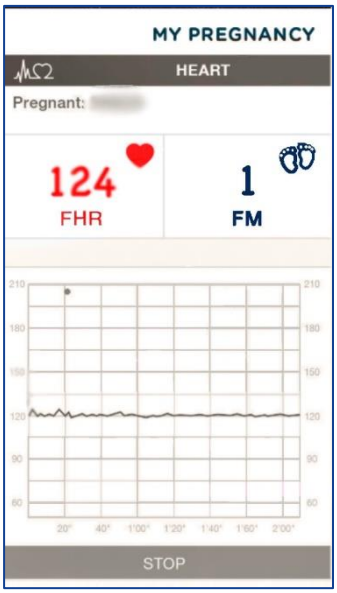
Festus 1



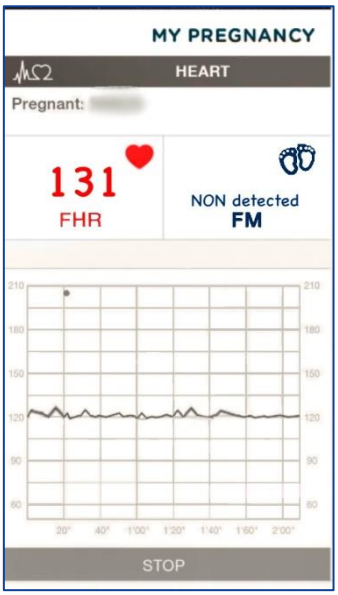
Fetus 2



Fetus 3



Fetus 4



Maternal Diastolic blood pressures:

Experiment participant	Mother 1	Mother 2	Mother 3	Mother 4
Results	82 mm hg	80 mm hg	85 mm hg	90 mm hg

Moving on, since the MBSW is provided with many sensors, it is capable if calculating the blood pressure of the user.

For instance, if the user's blood pressure calculated was 115/90, just like the case in experiment 4, the MBSW's next step is using the diastolic blood pressure of the mother to calculate the FHR by the following formula:

FHR = Mother's diastolic BP * 1.456178

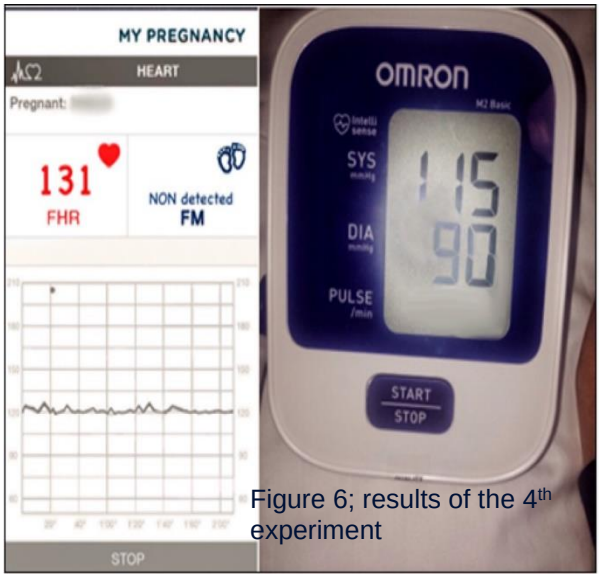


Figure 6; results of the 4th experiment

Therefore, the heart rate of the fetus of a mother with a diastolic blood pressure of 90 mm hg will be 131.05 according to the formula. This result is very close to the FHR result found by the wireless ultrasound device which is 131.

FHR results using the formula (MBSW):

Experiment Participants	Mother 1	Mother 2	Mother 3	Mother 4
FHR	119.5	116	123.7	131.05

FHR result using ultrasound device:

Experiment participants	Mother 1	Mother 2	Mother 3	Mother 4
FHR	120	116	124	131

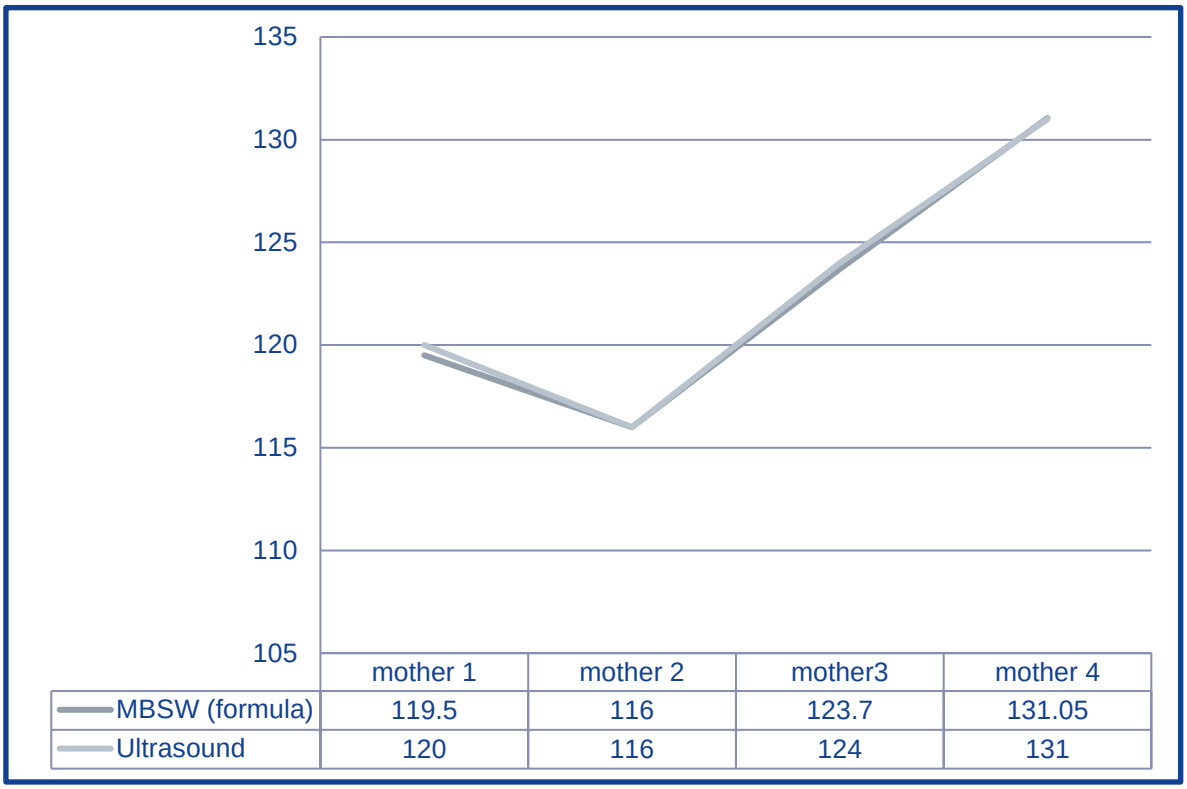


Figure 7 shows the correlation between both results

As shown above, both results are highly correlated therefore it is understood that the formulas the MBSW is using are reliable. In other words, the MBSW is the first wearable reliable health care system that tracks the health of a fetus without the use of ultrasound device. This was also acknowledged by doctor Sana Habib who we have talked with to discuss such information.

One of our meetings with doctors and experts

3.4.2 Experimenting the Smart watch and mobile application:

Using Java and Kotlin as a programing language and Google Fit as a framework, we have designed an application on Huawei Smart Watch 2 that preforms the following:

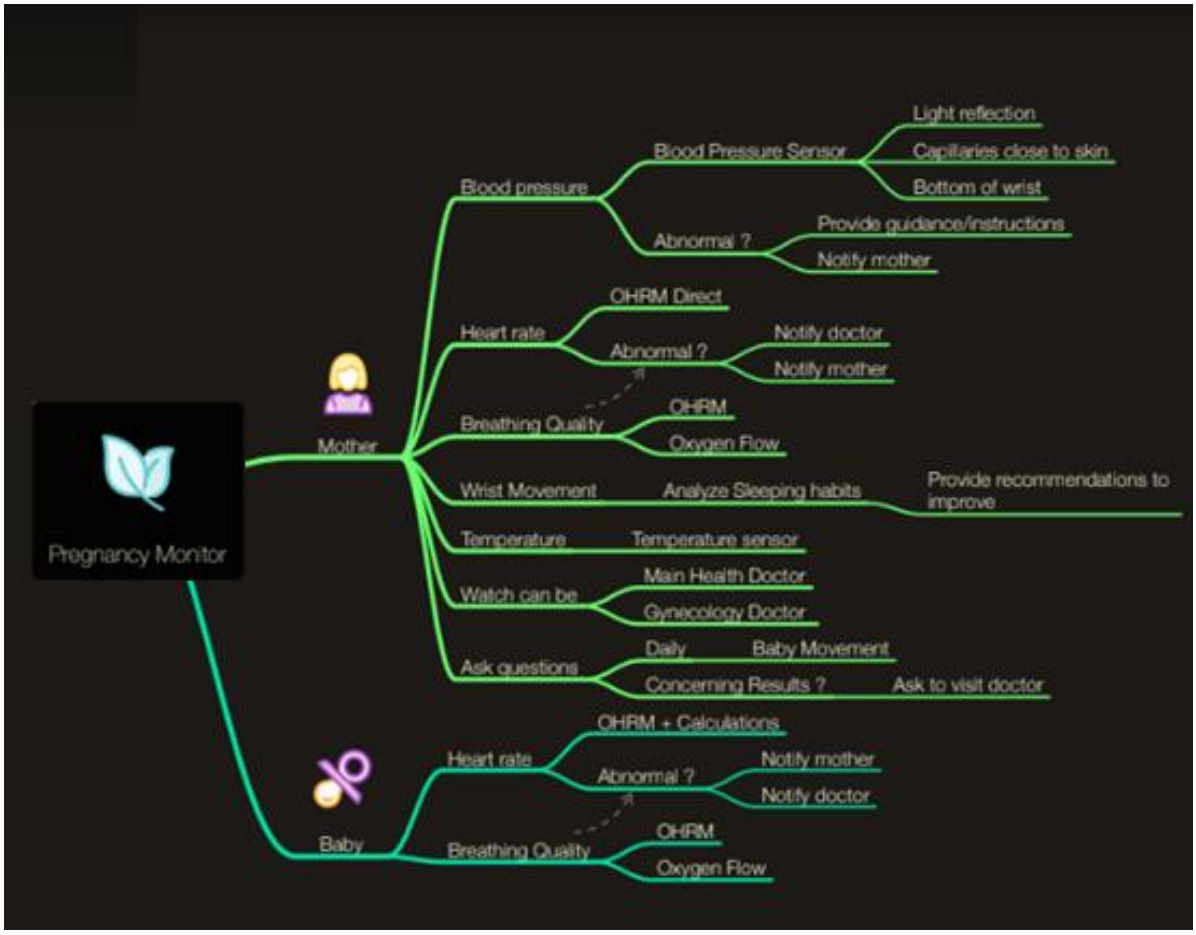
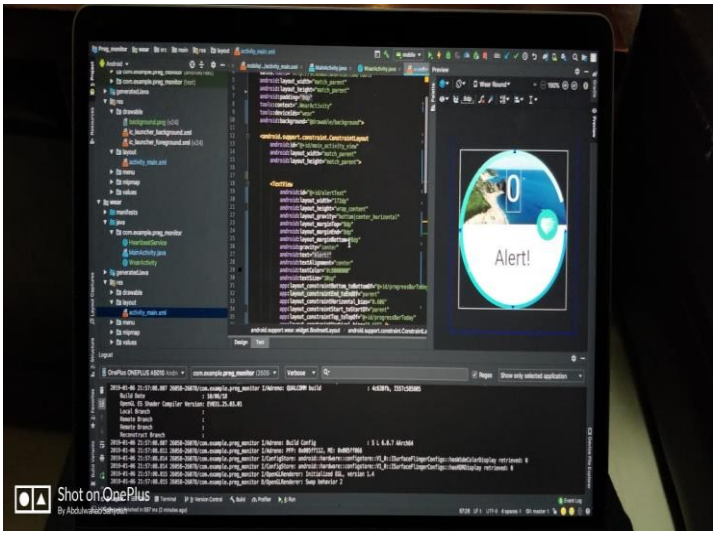


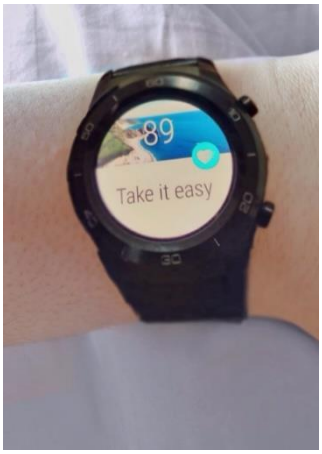
Figure8; summary of what does the pregnancy monitor preform

The application on the watch starts off with some simple steps of programing the timer of the daily checkup and the emergency alarm. The pregnancy monitor that is responsible for what is mentioned in figure 8, comes next with more complicated programming and coding.

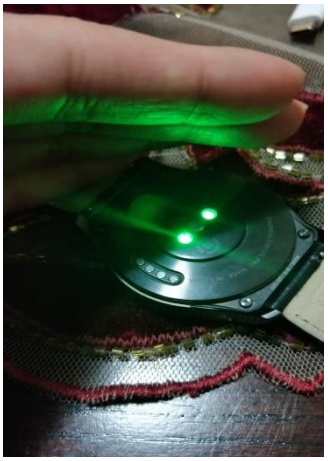
Picture while programing the pregnancy monitor

Pictures while the process of coding the application using the help of Mrs.Abduallwahab Sahyoun





← Our first trial of the MBSW application

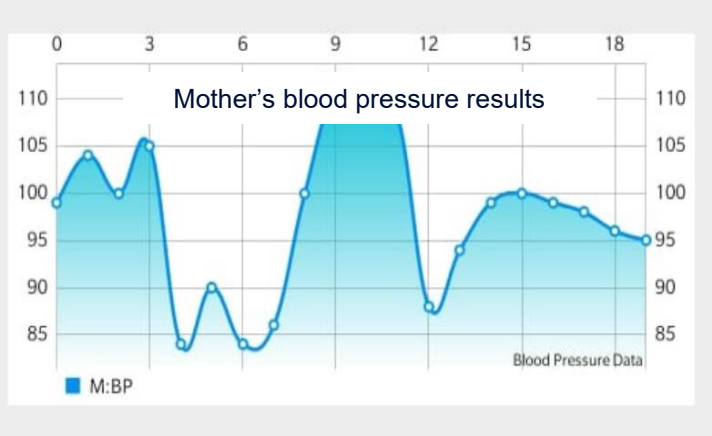


➔Testing the process of collecting data from sensors

The first MBSW experiment was done in order of testing the functionality of the application and its' ability of collecting health data. Results were the following:

Mother's HR	87 bpm	75 bpm	81 bpm	94 bpm	84 bpm	93 bpm
FHR	120 bpm	104 bpm	112 bpm	130 bpm	116 bpm	129 bpm

The next test was examining the MBSW ability of calculating the blood pressure of the mother. Results were the following:



First MBSW test's results

According to the data results collected from the MBSW, it is understood and acknowledged that the application is capable of continuously tracking the health of the mother and her fetus. Additionally, the MBSW seems to be using reliable formulas according to the conducted experiment. Although the MBSW has shown such satisfactory results, whatever it had preformed is only a very small percent of what it is supposed to function. As a result, we are still experimenting to get more analytical data that could display more nourishing health data of the fetus and the mother.

4. Conclusion and Recommendations

The majority studies of maternal and fetus 'mortality is based on cases observed in hospitals' Nevertheless, in developing and undeveloped countries, many such deaths do not occur in hospitals but in homes, therefore hospital data and statistics do not reflect the true extent of the number of maternal or fetuses' mortality. Likewise, the socioeconomic and demographic influences affecting these death rates are seldom identified. Yet it is proven that poor infrastructure and unsuccessful health care services are responsible for such high mortality rates worldwide.

The MBSW's aim is to provide high quality health support for pregnant women of both undeveloped and developing nations. In other words, it is an 'always-available' doctor that has the potential to assist women suffering from poor health care. Fortunately, the MBSW is the first device that can continuously track the health of a pregnant woman and her fetus without the use of ultrasound. The data collected can be considered accurate and reliable since it uses accurate sensors, and scientifically proven formulas in which doctors and researchers had spent a lot of time in order to find truthful formulations. However, it must be noted that the MBSW does NOT replace doctors. MBSW's function is simply to track the health of the mother and the fetus and warn doctors for any emergency therefore it is very important for a pregnant woman to keep in touch with her doctor and not fully depend on the smart watch.

One of the limitations faced in this project was finding the formulas needed in order to find the health data of the fetus in which it needed a lot of time and research since such information is neither frequently needed nor used. Opportunely, some universities and researchers had shed a light on such data and as a result, researches and studies had been made to provide these formulas thus the MBSW became capable of tracking the health of the fetus without the use of ultrasound.

When we first started researching for a way of calculating the FHR, we completely focused on finding a formula linking the heart rate of the mother with the fetal heart rate. This made us ignore the fact that in some cases, a fetus dies thus the heart stops while the mother's heart rate is completely healthy. We have spent and wasted time trying to find the non-existing formula. After a lot of research, we gave up on the idea of using formula, instead we thought about building a built that contains an ultrasound to track the health instead. However, this idea did not differ from existing inventions. As a result, we started thinking 'outside the box' to come up with a solution thus we finally found a research done by Department of Diagnostic Radiologic Technology, College of Medical Applied Sciences and Taibah University that discusses the relation between the mother's blood pressure and the FHR. Their report built on the fact that the heart of a fetus of a mother with hypertension (high blood pressure) beats faster than normal. Accordingly, a formula linking the diastolic blood pressure with FHR was found. Moreover, with more research, we found that a mother's respiratory rate is also correlated to the FHR thus a formula. This was an excellent solution for our problem for we could finally

track the fetus’ health. However, if we thought differently from the beginning, we would have not wasted time and would have started working on the watch immediately.

5. Acknowledgement

This research was approved by Dr. Sana Habib, a Gynecologist who had supplied us with many valuable information regarding pregnancy, fetuses and pregnant women.

We are really grateful for Maplet Mobile Company who provided us with their proficiency that had greatly assisted our project as well as for providing all the necessary facilities.

Not to forget mentioning our gratitude towards Mr. Abdulwahab Sahyoun who had lend us a hand with programing the smart watch and the mobile application as well as for sharing his wisdom with us during constructing our project.

A huge thank you goes for our Teacher Abir Obeid for supporting us towards the fruitful completion of the project. We do believe however, that any inaccuracies or mistakes are our own and should not besmirch the esteem of these respected people.

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