Patient Monitoring System

Nikolaos Karapoulatidis
e-mail: nikolaos.karapoulatidis@stud.hshl.de
Electronic Engineering, Hochschule Hamm-Lippstadt, Marker Allee 76-78, 59063 Hamm

***Abstract*—The innovations and research in technology led to smaller sensor technology. There have been various attempts to increase the quality of life for humans all around the world utilizing small sensors. Especially the healthcare sector benefit a lot of that technology. Nevertheless the healthcare industry in our modernized world lags behind giving a good and specialised medical assistance to patients and doctors. The main problem of current systems is the lack of efficiency when it comes to usability and automation. There is especially room for improvement regarding independent execution without the frequent need of medical staff.**

I. Introduction

The characteristic of any Patient Monitoring System (PMS) is the continuous measurement and observation of physiologic parameters like heart rate, oxygen saturation, respiratory rate and so on. It is crucial that such systems react very accurate in real-time to ensure effective care for an critical ill patient. Monitors are used to display data next to the patients bed. This physiological data has to be stored and analyzed either by the system itself or/and by the medical staff. Especially for intensive care units(ICUs) or operating rooms(ORs) Patient Monitoring Systems are significantly important for modern and successful health care.
The first thoughts which come in mind when you here the term Patient Monitoring System are a system which watches and warns about serious and life-threatening events. It should also provide guidance for care of the critically ill.

The system which will be highlighted in this report should be specialized especially for old people which often suffer from high blood pressure and diabetes. Since such patients are not necessarily on ICUs or bedridden the system should be also portable. So called mobile patient monitoring (MPM) is very helpful for patients which suffer from chronic diseases like diabetes. Chronic diseases lead to high health care costs and decreased productivity of humans in society [1]. Especially diabetes is responsible for 15 percent of national health care budgets [2]. Patient Monitoring plays a significant role for ensuring the quality of care and thus the quality of life.

Many hospitals today are fully occupied due to staff shortage. So it is even more important to design a portable system to have the opportunity that a patient can take it at home. This would provide the opportunity of remote medical diagnosis from a doctor. Mobile health is an important aspect for overcoming barriers of health service personnel, continuous access to health information and to prevent delays and errors in suitable treatment. Also the patient can engage in his daily activities in a comfortable atmosphere.

When it comes to designing such a system many decisions have to be made. First you need to decide which functions should be covered. Of course the initial thought of the perfect system would cover every use-case, would monitor every physiologic parameter and would assist for many medical treatments. The result of such a solution would be very expensive, complex and thus maybe also vulnerable for errors since the meet of many components can lead to unpredictable conflicts (noise, heat..). Third world countries often cannot afford enough of such expensive systems which makes the cost factor even more important since these countries lag already behind regarding sufficient health care. In addition to that depending on the patients medical condition many functions would be redundant. The better approach is to design PMSs which are sufficient for a more specific use case or patient case.

June, 2022

II. Medical Backround on Diabetes

Diabetes is a chronic disease that occurs either when the pancreas does not produce enough insulin or when the body cannot effectively use the insulin it produces. Insulin is a hormone that regulates blood sugar. Hyperglycaemia, or raised blood sugar, is a common effect of uncontrolled diabetes and over time leads to serious damage to many of the body's systems, especially the nerves and blood vessels.

A. Type 2 diabetes

Type 2 diabetes (formerly called non-insulin-dependent, or adult-onset) results from the body's ineffective use of insulin. More than 95 percent of people with diabetes have type 2 diabetes. This type of diabetes is largely the result of excess body weight and physical inactivity.
Symptoms may be similar to those of type 1 diabetes but are often less marked. As a result, the disease may be diagnosed several years after onset, after complications have already arisen.

B. Type 1 diabetes

Type 1 diabetes (previously known as insulin-dependent, juvenile or childhood-onset) is characterized by deficient insulin production and requires daily administration of insulin. In 2017 there were 9 million people with type 1 diabetes; the majority of them live in high-income countries. Neither its cause nor the means to prevent it are known.

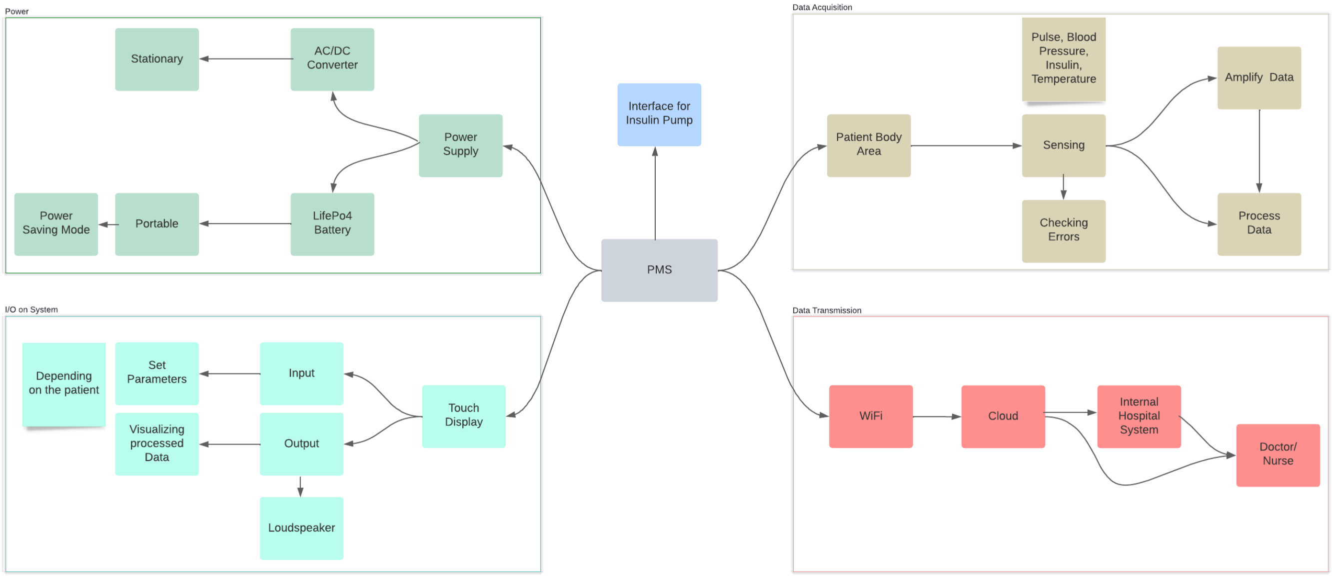


Figure 1. Concept Map

Symptoms include excessive excretion of urine (polyuria), thirst (polydipsia), constant hunger, weight loss, vision changes, and fatigue. These symptoms may occur suddenly. [3]

III. Overview of the Concept

The Patient Monitoring System (PMS) proposed in this paper is tailor-made for older people which suffer of diabetes and/or high blood pressure. In order to match their needs we should consider the persona of such people.

Definition 1. ***Persona*** *The persona is a fictitious description of a person that describes in detail potential customers, their circumstances, wishes, needs, goals and so on. The persona is used in design thinking, in marketing, and sometimes also in Scrum. It helps you to define a typical representative, a typical example of your target group.*

I analyzed many personas of people with diabetes which i found on the internet. I recognized some intersections. First thing i recognized is that affected people are worried about that diabetes will control their life. They are afraid of missing a worthy life because they always need to pay attention on their insulin levels. Especially the fear of Hypoglycemia (too low blood sugar level) is very common. Many people also do not have the time to go frequently to the doctor. The tracking of data was also important for some people.
Depending on the needs of the patients the main goal of the system is to support affected people with glucose level data and other important parameters. The system should also create a feeling of safety so that they are protected from critical conditions.

The concept i came up with defines the system to be portable and stationary. If the system is connected to mains power it uses an AC/DC converter for powering the electrical components. In addition the internal battery will be charged. If the system is used portable a power saving mode is activated to increase battery life. This mode will deactivate the data transmission block. Instead the data is stored locally and will be transmitted as soon as mains power is connected. Furthermore the back-light of the screen is adjusted depending on the ambient light.
The system uses a touch display for visualizing data and for entering parameters which are depending on the patient. These parameters help the system to detect anomalies. A loudspeaker should mainly act as an alarm in case of too low insulin levels or other critical situations.
Sensors are attached on the body of the patient for sensing the pulse, blood pressure, glucose levels and temperature. The reason behind choosing this particular parameters is that the combination of them allow a more precise diagnosis of the cause for specific vital events. The sensors are frequently checked if they are working properly. The data of the sensors may need some amplification before having a usable signal. A micro-controller is used to read and process the data.
To enable remote medical diagnosis the data is transmitted via WiFi into a cloud which is accessible for the responsible doctor. The cloud also acts as a backup. This requires a server. The system should also have the opportunity to control an insulin pump to ensure a sufficient glucose level. Thus the system has also an interface for an insulin pump. However such a pump is beyond the scope of this concept and should be an useful opportunity.
Figure 1 shows a rough overview of the concept.

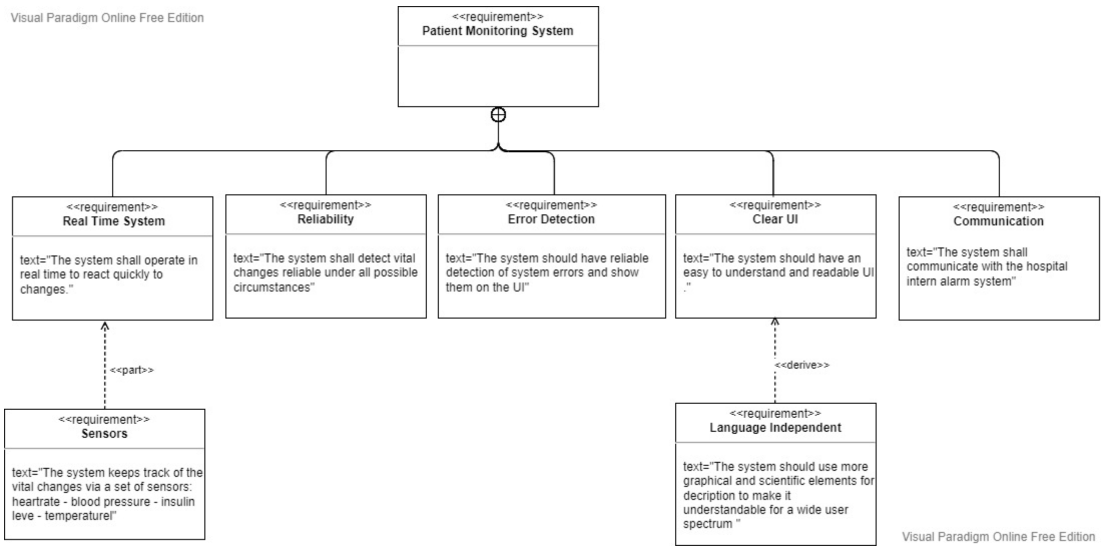


Figure 2. High Level Requirement Diagram

IV. Designing of the Concept

A. System Requirements

In addition to the high level requirement diagram in Figure 2, more specific requirements are mentioned below.

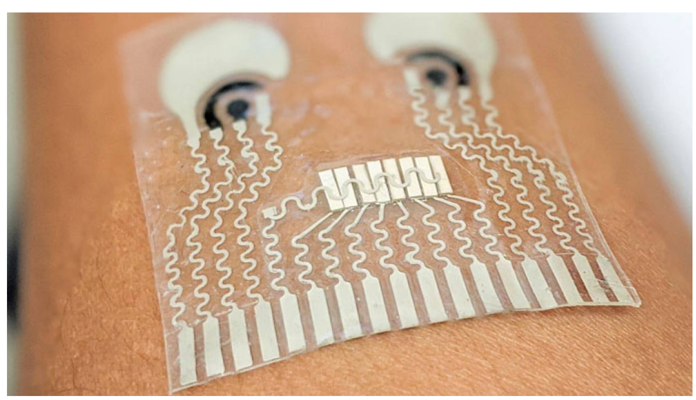
1) Security for Personal Data: The use of portable devices to record, store, and transmit patient data to a central server means that personal health records now extend beyond the hospital or doctor's surgery. These devices need secure ways to transmit recorded data, through Data Security, at high speed to ensure that personal records cannot be compromised at any point. Additionally, it is increasingly important to provide Design Security to protect the design implementation from reverse engineering or tampering that could counter the Data Security of the system. Flash-based FPGAs have several key features that help protect design IP from attack. Furthermore standard cryptographic functions are needed to protect data transferred to, from, or stored within the personal healthcare monitor.

2) Power Efficiency: Portable devices typically run off of batteries and need to stay in service for as long as possible. Minimizing the power consumption of these portable devices is critical, and the challenge gets more difficult with the addition of liquid crystal display (LCD) technology and other peripherals that simultaneously threaten to push system energy requirements even higher. Many portable ultrasound scanners feature LCDs that support color and high resolution, and can consume as much as 50 per cent of the application's power budget. It is possible to significantly reduce battery drain in these situations by placing the LCD and control logic into power-saving mode whenever possible. Furthermore the active time of high power functions should be minimized as much as possible.

3) Comfort: Personal comfort is important in the design of systems and objects. However, as comfort is a subjective experience, it is a very challenging aspect to design for. On the one hand the system should not be designed too big or heavy in order to not restrict the patient in any ways. On the other hand the system must have a big enough screen so that also old people can read the information and interact with the system. In addition the battery should last long enough so that the patient has more freedom regarding trips without to worry about having access to mains power every couple of hours.

B. Suitable Hardware

1) Sensors: During my research for suitable sensor technology especially one new innovation attracted my attention, developed by engineers at the University of California. We are talking about a soft, stretchy skin patch that can be worn on the neck to continuously track blood pressure and heart rate while measuring the wearer's levels of glucose as well as lactate, alcohol or caffeine. [4]

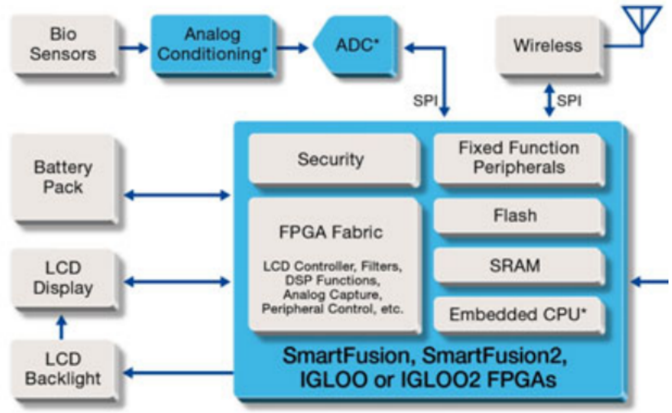


all-in-one-patch

For my use case the measuring of lactate, alcohol or caffeine is not needed. Instead the system should measure the temperature and pulse which would not be a big engineering challenge

to add on such skin patch. This statement is valid since a temperature sensor can be just a small resistor changing its resistance depending on the temperature. Also Transmission type pulse sensors measure pulse signals by generating IR or red light from the surface of the human body. The signals can be generated by detecting the change in the flow of blood throughout heartbeats. Such a sensor can be also very small.
The patch is a thin sheet of stretchy polymers that can conform to the skin. The main advantage of such a compact skin patch is a great comfort compared to individual sensors distributed on the body. Instead of needing many cables only one cable consisting of many strands is required.
The blood pressure sensor sits near the center of the patch. It consists of a set of tiny ultrasound transducers that are connected to the patch by a conductive ink. A voltage applied to the transducers causes them to send ultrasound waves into the body. When the ultrasound waves are reflected by an artery, the sensor detects the echoes and transmits the signals to a processing unit which converts them into a blood pressure reading.
The glucose sensor is an electrode, which is printed on the left side. It works by passing a mild electrical current through the skin to release interstitial fluid and measuring the glucose in that fluid.
The biggest engineering challenge of such a patch is to separate and shield the individual senors from each other to prevent inaccurate readings caused by interference. To solve that problem the researchers used a solid ultrasound gel.
Apart from sensing the body of the patient a light sensor (photoresistor) should detect the intensity of the ambient light. This data should be used for increasing or decreasing the display to guarantee efficiency and readability.
Of course every sensor needs a proper calibration with a lot of testing and comparison to already approved sensors.

2) Processing units: To make a selection for CPU, FPGAs or Analog to Digital is very difficult because the offer of suitable components is huge. Apart from that selecting the perfect components in a right way is a very complex decision. Since this PMS should be designed on a more higher level such more low level decisions are in detail beyond the scope of this paper. Nevertheless i found a very promising company called Microsemi which sells Systems on Chip (SoC) solutions which are very mature. The SoC i would select is called Smart Fusion [5].
The advantages of utilizing FPGAs are that they are cheap, very fast with custom programming, flexible and also re-programmable after installation. This allows future updates of the PMS.



@Microsemi

3) Power: For powering and charging the system on mains a I think it would be very practical to allow common AC/DC chargers for smartphones. However they should have enough power to run the PMS and charge the battery simultaneously. Otherwise the PMS will notify the user that the power adapter is too weak.
The battery chemistry type i would choose is LiFePO4 since it is one of the safest battery types [6]. Furthermore they have a very good energy to weight ratio and lifetime compared to other battery types. For cell balancing and protection a suitable battery management system is needed. The battery capacity should be initially around 50wh and thus would weight less than half a kilogramm [7]. The real power draw of the system over the day has to be tested in order to optimize the battery size.

4) Data Transmission and Storage: For transmitting the patients data to a cloud a low power WiFi module should be used. A suitable module could be the Sterling-LWB+ which contains a fully featured WiFi 4 radio. Furthermore it provides easy integration with any Linux or Android based system.
In order to map the data to the belonging patient a unique ID is provided. In addition every patient should have a unique account where either the doctor or the patient himself needs to log in with a private mail address and password. This is required because we are sending and storing private data.
A hard disk with a capacity of 64gb is used to store data locally on the device.

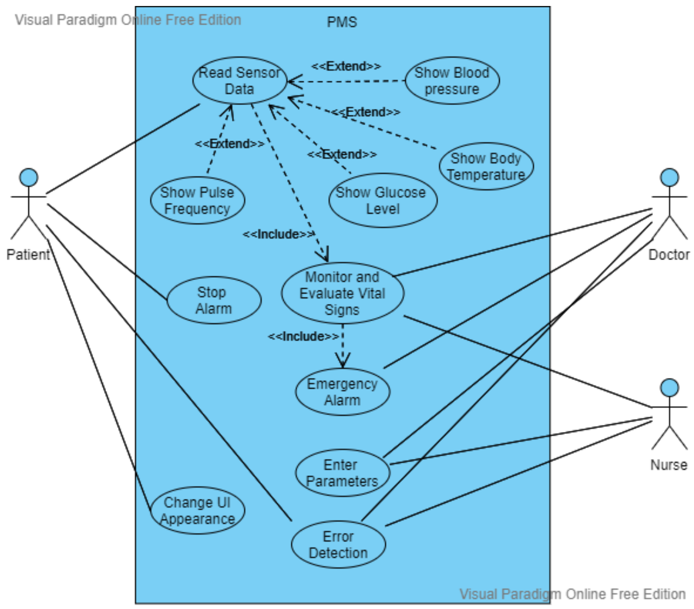
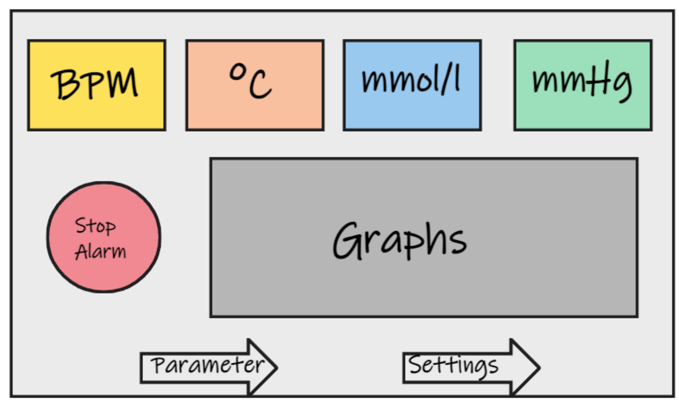


Figure 3. Use Case Diagram

5) User Interface: As already mentioned the PMS has a LCD-Touch-Panel acting as a user interface. The advantages of a LCD-Panel are low cost and good power efficiency. The size of the screen and thus also approximately the size of the PMS should be 7inch with a 16:9 ratio.
The User Interface displays the current value of each parameter (Glucose Level, Blood Pressure, Temperature, Pulse Frequency) and updates it every 5 seconds. In order to ensure a good readability big text-boxes in different colors for each parameter are displayed. Several graphs with different colors matching them of the text boxes show the history of the parameters. The graph section can be displayed on the same page or on a second page to allow more space for bigger text-boxes (advantageous for old people). If a parameter reaches an abnormal value the corresponding text box will start blinking.
Figure 3 shows a use case diagram of the possible interaction between the PMS and the patient, a nurse or a doctor.
The patient has the ability to change the size and position of different text-boxes to be able to prioritize his most important parameter. In case of a false alarm because a sensor is not working properly or external interference causes false data, the patient has the opportunity to turn of the alarm and reboot the PMS. It is also possible to turn off the loudspeaker completely on your own risk. Some users may be in a meeting there they have to be sure that the PMS stays quiet.
The doctor or nurse can enter the patient parameters by using the user interface. For changing them, the unique log-in data of the patient is required.



User-Interface Concept

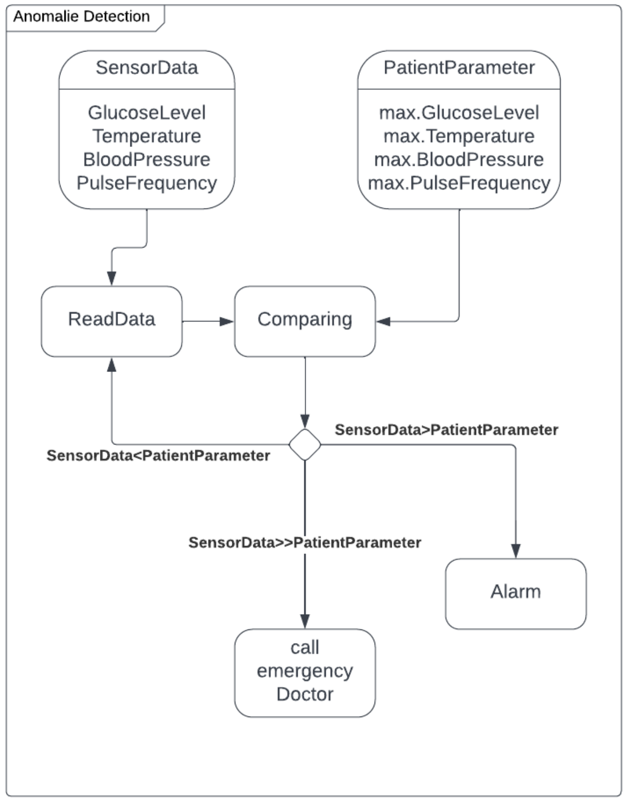


Figure 4. Alarming

6) Alarming for Vital Scenarios: A small speaker is used to produce alarm sounds if a sensor parameter is reaching a level which is threatening. Each parameter causes an unique alarm, so that the patient and people around him immediately know what is going on. For the case that a parameter is way more higher or lower than the reference parameter (depending on the patient and entered by a doctor) so that it could be life threatening the PMS will spell the words ”call an emergency doctor”. Also advises on how to help the patient as a normal person are shown on the display. The activity diagram in Figure 4 shows an overview of the alarming behaviour.

V. DISCUSSION

During the design phase of the PMS i recognized that the complexity of such a system is huge. Although this paper is at some points very specific, many aspects are still not covered. For example the decision of the operating system is not made. Also this paper does not cover any programming or software. In order to develop a market ready PMS a team of electrical, electronic and software engineers has to work closely together. Challenging is also keeping the weight and size of such a system low. Tailor-made PCBs and cases are needed.
In addition such a system requires a long and intense testing phase since the data it shows has to be very reliable.
It is also not clear how expensive the PMS is. As i mentioned in the beginning it is important that this system is cheap so that also poor countries/patients can afford such a system.
The concept proposed in this paper is a good guideline for developing a comfortable PMS. Especially the sensing hardware (skin patch) will play a big role in upcoming systems.
During the exercises i changed my concept from a very general idea to a more specific one. This was necessary to be more detailed without losing the overview. I also changed the hardware for the processing units and for the sensors.

VI. CONCLUSION

The PMS is a helpful system for people who are suffering from diabetes. It allows them to constantly track their glucose level, blood pressure, pulse rate and temperature. To ensure safety the PMS consists of several alarm mechanisms. Especially older people need a readable, easy to use and adjustable User-Interface. The PMS has a very minimalistic though sufficient UI which can be personalized. Furthermore the patients data is uploaded frequently to a cloud and can be analyzed by doctor. Thus remote and more precise treatment is possible due to the big amount of available data.

Last but not least the PMS has an interface for connecting an Insulin Pump which can actively control the glucose level of the patients blood. Such a pump and the communication can be an add-on for the PMS.

REFERENCES

[1] M. Engelgau, S. Rosenhouse, S. El-Saharty, and A. Mahal, "The economic effect of noncommunicable diseases on households and nations: a review of existing evidence," *Journal of health communication*, vol. 16, no. sup2, pp. 75–81, 2011.

[2] P. Zhang, X. Zhang, J. Brown, D. Vistisen, R. Sicree, J. Shaw, and G. Nichols, "Global healthcare expenditure on diabetes for 2010 and 2030," *Diabetes research and clinical practice*, vol. 87, no. 3, pp. 293–301, 2010.

[3] "Diabetes who," Available at https://www.who.int/health-topics/diabetestab=tab$_1(15/06/2022)$.

[4] L. Labios, "New skin patch brings us closer to wearable, all-in-one health monitor," Available at https://www.universityofcalifornia.edu/news/new-skin-patch-brings-us-closer-wearable-all-one-health-monitor (29/05/2022).

[5] "Smartfusion," Available at https://www.microsemi.com/product-directory/soc-fpgas/1693-smartfusion (15/06/2022).

[6] "3 essential lifepo4 battery features that promote product safety," Available at https://relionbattery.com/blog/3-essential-lifepo4-battery-features-that-promote-product-safety (28/02/2016).

[7] "Lithium iron phosphate battery," Available at https://en.wikipedia.org/wiki/Lithium$_iron_phosphate_battery(15/06/2022)$.