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SENDING AND STORING DATA FROM A SMART SCOLIOSIS BRACE

Master’s thesis (30 EAP)

Robotics and Computer Engineering

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ABSTRACT

Sending and storing data from a smart scoliosis brace

Scoliosis is a widely known disease that troubles many people globally. Scoliosis is treated with a specialized brace and assigned therapy, which consists of exercise routines that are recorded in patient journals. Often the exercise routines incorporate the medical brace. Outside of patient trust and therapy results, there is no universally agreed upon method of monitoring brace usage and therapy exercise routines. The aim of this thesis is to provide an example of how modern technology can be used to improve scoliosis therapy and help both patients and doctors see better results when treating scoliosis. The thesis aims to provide more scientific data for doctors to more effectively treat the disease.

CERCS: T115 Medical technology; T120 Systems engineering, computer technology [1]

Keywords: medical technology, scoliosis brace, programming, pressure sensors, Unity Game Engine, Bluetooth

Targa skolioos korseti andmete edastamine ning talletamine

Skolioos on ülemaailmselt levinud ning tuntud haigus. Skolioosi ravitakse spetsiifilise korsetiga ning teraapiaga, mis sisaldab erinevaid füüsilisi harjutusi. Harjutuste tegemist ning teraapia kava täitmist talletatakse patsiendi märkmikutes. Tihti peale peavad patsiendid tegema harjutusi kandes skolioosi korseti. Väljaspool patsiendi märkmike ja teraapia tulemusi, ei ole olemas ühtset süsteemi, mille alusel arstid saaksid jälgida patsientide teraapia kulgemist. Selle lõputöö eesmärk on pakkuda võimaliku lahendust, kuidas tänapäeva tehnoloogia saaks kaasa aidata skolioosi teraapiale. Lõputöö annab arstidele pädevamaid andmeid, mille alusel saab teraapias vajalike muudatusi teha kiiremini.

CERCS: T115 Meditsiinitehnika; T120 Süsteemitehnoloogia, arvutitehnoloogia [1]

Märksõnad: meditsiinitehnoloogia, skolioos korsett, programmeerimine, surve sensorid, Unity Game Engine, Bluetooth

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ABBREVIATIONS

AIRE - Artificial Intelligence and Robotics Estonia [17] ;

AI - Artificial Intelligence;

ESP32 - system on a chip type microcontroller [2];

C# - simple, modern, general-purpose, object-oriented programming language developed by Microsoft [3];

MongoDB - cross-platform document-oriented database program [4];

BSON - Binary JSON document;

JSON - JavaScript Object Notation; lightweight data-interchange format [5];

SpO2 - measure of the amount of oxygen-carrying hemoglobin in the blood [6].

1 INTRODUCTION

Modern medicine is a phenomena that has been exponentially growing in every direction from the beginning of the 20th century. The history of medicine, albeit fairly barbaric at times, has given a holistic understanding of how the human body works down to the genetic level. These developments in understanding, along with developments in technological capabilities, have generated much needed modern medical technology. The 21st century has seen a boom in medical equipment used by hospitals around the world. From laser surgery to scanning devices and prosthetics, the medical industry has become fairly tech savvy. The aim of this thesis is to provide a smart addition for a well-known medical problem - scoliosis.

1.1 Overview of Medical Problem

In this chapter the need for new solutions is described from the viewpoint of a medical problem. According to the Mayo Clinic, scoliosis is “a sideways curvature of the spine that most often is diagnosed in adolescents”. [7] It is a disease, which causes an individual’s spine to curve in an unwanted manner, leading to other health complications. However, it is not limited to adolescents or children, for instance adults above the age of 60 have a 40% chance [8] to develop degenerative scoliosis - a form of scoliosis which occurs due to natural aging. Degenerative scoliosis begins when, when a person’s spinal discs and facet joints degenerate faster from one side of the body, causing the spine to carry body weight load asymmetrically [9]. As degenerative scoliosis typically occurs in older individuals, most of the assistive braces and devices are targeted toward adolescents who are still developing. Scoliosis braces are long-term wearable devices used by children and teens, which help shape their spine as they grow by applying pressure on the spine at the point of the curvature, causing the person to stand up straight [10]. According to a study conducted in 2015, 76% of adolescents with scoliosis had the curvature of their spine stabilized by a medical brace [11].

Because scoliosis is a condition which usually cannot be fully healed, doctors need to manage their own expectations when treating this disease. The severity of scoliosis is measured by the Cobb angle, which is a measure of the degree of side-to-side spinal curvature. In really rare cases, the Cobb angle does go back to 0°, but this is treated more as an exception than an expected outcome. The aim of treatment is to correct the curvature of the spine over time, helping the patient’s spine to grow in a manner which decreases the Cobb angle. This means therapy ends when bone growth ends. If the condition worsens after bone growth ends, there are typically 2 options - surgery or specific exercises, which aim to stabilize the situation. All therapy sessions are based on doctors assessments and patient medical journals, which contain data about how often they wear their brace and for how long. [13]

2 STATE OF THE ART

In this chapter the review of existing solutions are presented. The fast growth of modern technology has expanded heavily into the medical sector as well. Firstly, scoliosis braces are manufactured with more precision and can be personalized based on each patient's needs. In addition to that, there are devices, which can be classified as a harness, not a brace - such as the ScoliSmart harness [12]. The ScoliSmart harness uses the body's natural torque pattern to create new muscle memory and help redirect the spine. It is designed to mimic resistance training on the spine. It gives the promise of being more comfortable than a traditional brace and is less restrictive than a rigid brace. 79% of patients have had a 6-degree curve reduction while using this solution. [12] An image of the harness can be seen in Figure 1.

Figure 1. ScoliSmart harness solution [12]

With the rise of sensorics and sensory technology, more technologically advanced solutions are also being researched. Boston Orthotics and Prosthetics have developed a sensor named the Boston sensor [14], which can be placed inside the patient's brace to measure body temperature and monitor wearing routines therein. The sensor is the size of a coin and takes readings every 15 minutes. It helps to monitor how patients wear their brace, which is especially important for children. Figure 2 is an example of the sensor compared to a coin and Figure 3 shows the accompanying smartphone app that can be used to monitor data received from the sensor.

Figure 2. Boston Sensor size [14]

Figure 3. Boston Sensor app [14]

A study conducted in 2021 researched cost-effective pressure sensors available for scoliosis braces [15]. They created a pressure sensor using a piezoelectric pressure sensor between two foam pieces, which was then mounted within the brace. The result of the study was a cost-effective pressure sensor ready to be used in clinical trials, however, it has yet to be tested for long period clinical trials. The study did, however, find interesting pressure readings, which can be used to understand pressures affecting a patient's spine when doing certain activities, such as sitting, proning or breathing. A graph comparing different pressures on the brace in different actions can be seen in Figure 4.

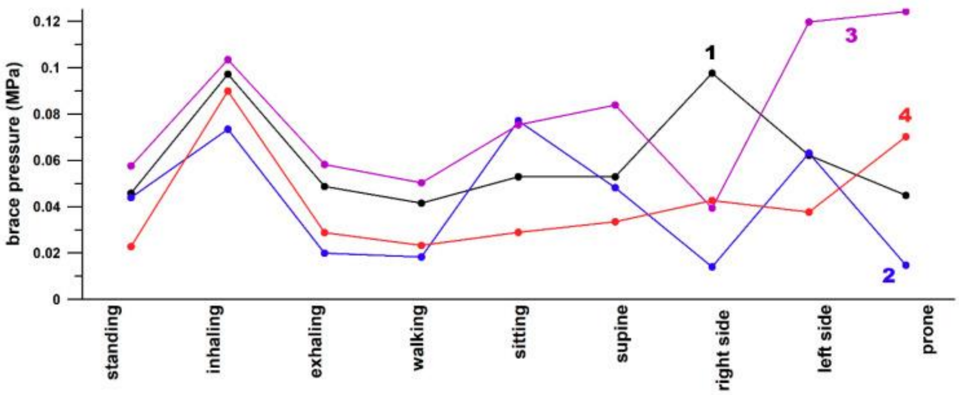

Figure 4. Pressures on the brace related to different actions [15]

Another study conducted in 2010 researched into remote measuring devices used for scoliosis braces [16]. It describes a device named the Cricket, shown in Figure 5, which records temperatures in order to accurately determine wear time of a scoliosis brace. The study found that the mean error in wear time recorded within the patient diary and wear time recorded by the Cricket device was 2%. Therefore, an electronic measuring device could give fairly accurate results of wear time to the practicing doctor.

Figure 5. The Cricket device [16]

3 MOTIVATION AND PROBLEM STATEMENT

The aim of this thesis is to provide a technologically advanced addition to scoliosis therapy.

3.1 Project description

The new, AI and Robotics Estonia (AIRE) backed development, the AIRE Smart Scoliosis Corset, aims to enhance existing scoliosis braces with sensors and artificial intelligence. This is done to give more accurate data readings to both patients and doctors in real time and long-term. The solution would give doctors more accurate information about scoliosis brace wear time and therapy progress in general. AIRE states in their mission statement: "AIRE, or AI & Robotics Estonia, is a technology hub dedicated to making Estonian manufacturing more competitive by helping businesses to introduce artificial intelligence and robotics solutions." [17] As a development condition for the project, AIRE insisted on the usage of Artificial Intelligence in some aspects. This condition will be met in later stages of the project and will therefore only be mentioned in the "Discussion and Future Research" chapter of this thesis.

The focus of the project is a technical solution applied to the corset. The aim is to update existing solutions, modernizing them and utilizing technology to improve current solutions. Clinical testing and real patients are not within the scope of the project. Upon successful finish, patients will be involved in potential future stages.

This project was done in cooperation with Tartu University and TalTech.

3.2 Author involvement

I, as the author of this thesis, was charged with data upload and management of this project. It was my assignment to collect sensor data via Bluetooth and store it in a database. An additional task was to guarantee access to all parties involved, so the same data could be used in all aspects of this project. It was my responsibility to write the code that takes the data from the microcontroller and uploads it. The download of data was handled by the frontend developers of the smartphone application and the desktop application developers respectively. The restrictions for the data collection and management were set by the user interface designer and the general project manager. The main restriction for the assigned task was that the listener and upload program had to be compatible with Unity Game Engine and that data readings would be taken via Bluetooth from a smartphone.

4 METHODOLOGY

The idea for the smart scoliosis brace was to use a previously made scoliosis corset and apply a newly developed sensor package to it. The sensors would gather information and pass it to a microcontroller, in this case an ESP32 microcontroller, shown in Figure 6.

Figure 6. An ESP32 microcontroller

The sensor package had to consist of as few sensors as needed. The data readings would then be used in various ways. A pressure sensor, which can be seen in Figure 7, was used to obtain different readings. 3 main parameters were to be derived from a pressure sensor reading: strap pressure, wear time and breathing depth. The readings would be taken on the corset and passed along via the microcontroller and bluetooth to a smartphone. The data read from the pressure sensor would then be viewed and used by both doctors remotely and patients locally.

Figure 7. Thin film pressure sensor used on the corset

4.1 Parameters

Since the data will be used by both patients and doctors, the different parameters derived from the pressure reading are useful in multiple ways:

- **Strap pressure** gives the patient the understanding whether their brace is worn correctly. It also gives the doctor the same information, thus making it possible to make necessary changes faster for more effective therapy.
- **Wear time** allows both the patients and doctors to have a reliable source of information about whether or not the scoliosis brace is actually used. As mentioned in the Introduction, currently most all scoliosis therapy uses patient journals and patient-doctor trust as a means to measure brace wear time. The pressure sensor would give an objective measure of this parameter.
- **Breathing depth** gives the doctors information about whether the strap is worn correctly or is it limiting the patient's ability to breathe. Normally, an individual should be able to exercise easily while wearing a scoliosis brace. Breathing depth gives the measure of chest expansion during breathing, allowing the doctors to objectively assess whether the brace is worn correctly or if it is even the right size corset. Since corsets are used during growth periods, primarily in children and adolescents, they need to be changed periodically to adjust with growth.

All 3 of these parameters help make necessary changes more effectively.

4.2 Data Management

The parameters described in the previous chapter would be read by the smartphone via Bluetooth and also be uploaded to the cloud-based database. Figure 8 depicts this data movement chart. This enables the data to be viewed real time on a smartphone by the patient. It also enables the doctors to view the patient data remotely since the data is stored on a cloud. The data would be transmitted from a microcontroller to a smartphone via Bluetooth and from there uploaded to the cloud via a Unity Web Request. A Unity Web Request is a Unity built-in method that provides communication with web servers [18]. Finally, the data will be downloaded from the cloud via Unity Web Request to be viewed on the desktop view.

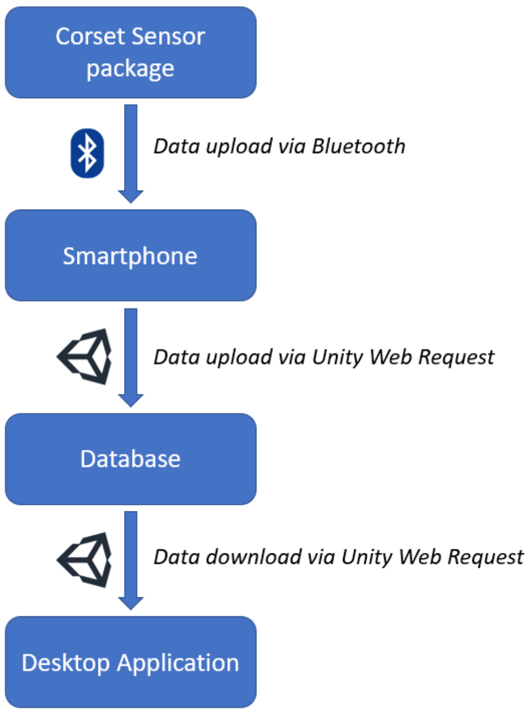

Figure 8. Updated data movement chart

4.3 Software solution

Since the phone application and user interface were done using Unity Game Engine, a requirement for the data movement was that a Unity compatible C# script was needed. Since Unity does not offer an out-of-the-box solution for Bluetooth devices, a plugin was purchased to assist in this capability. The Arduino Bluetooth Plugin [19] was used to connect a simple ESP32 microcontroller as a test case. The ESP32 was configured to transmit 3 numbers at a constant rate. nRFCloud Gateway was used to connect the ESP32 via Bluetooth to a smartphone in order to confirm the data transmission. Figure 9 shows the successful connection between a smartphone and the ESP32 as well as transmitting data.

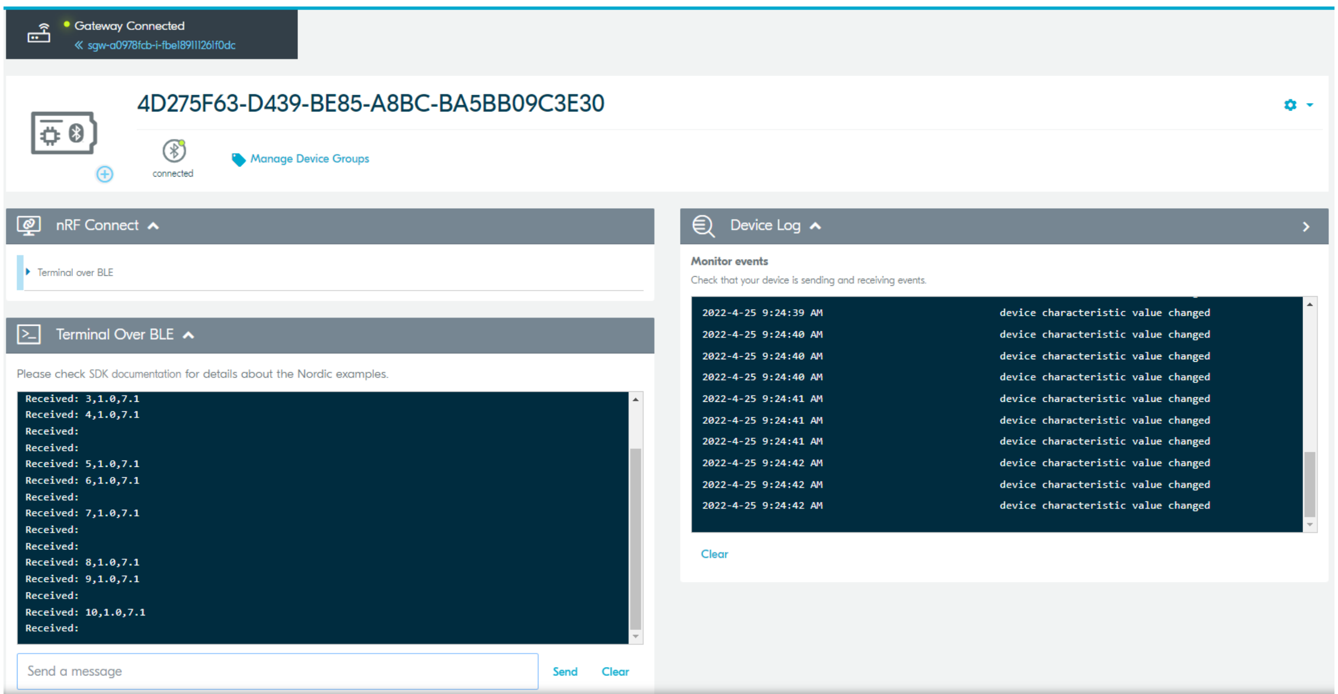

Figure 9. nRF Cloud Data reception

As can be seen on Figure 9 the data transmitted by the ESP32 increases over time. The terminal window on the left side shows the continuous transmission of data and the terminal window on the right side displays connection parameters to the ESP32 device. This was made to simulate a real-life situation where varying data values will be read from the Smart Scoliosis brace.

4.4 Cloud selection

The database for storing the Smart brace data must fall under the regulations that govern patient data. As patient data is regulated heavily with consent forms and security requirements, the final database selection was assigned to a dedicated work group, which in unison with the author will solve the issue of consent and proper data management. As a test database for the initial trial period, MongoDB cloud was selected, as the second criteria for the database was that it must be easily accessible using Unity and C# programming language. A cloud-based database was used. Figure 10 displays the console for the online MongoDB client interface. The Collections tab seen in Figure 10 is where all data stored into the cloud can be viewed. The Filter offers the user an option to search through the data for specific datasets.

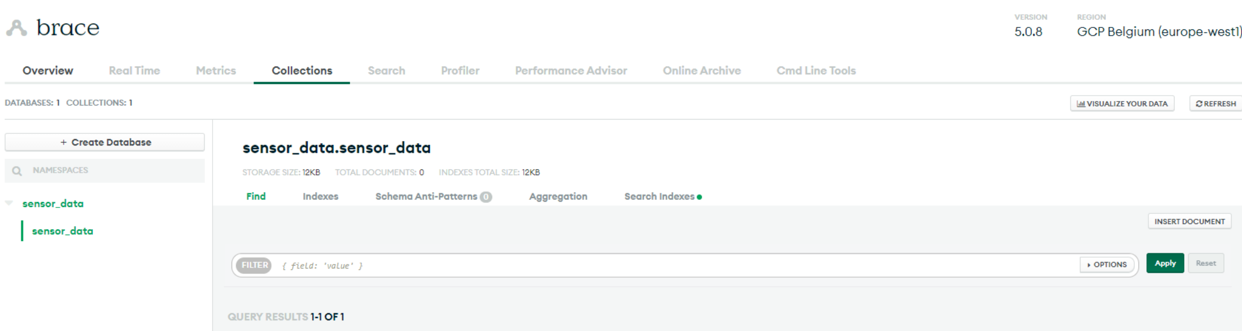

Figure 10. MongoDB User interface

MongoDB stores data as Binary Javascript Object Notation (BSON) documents. An example of the data structure stored within these documents can be seen below:

{

"paramater_name":parameter_value,

},

where *parameter_name* is the name of the parameter and *parameter_value* is the value of the parameter. For the current project, the test data structure consisted of the three parameters all of which are of data type Double. The initial data was hardcoded and the structure for the test data was as follows:

{

"_id": {
    "$oid": "patientTest1"
},
"breath": {
    "$numberDouble": "0.0"
},
"pressure": {
    "$numberDouble": "0.0"
},
"worn": {
    "$numberDouble": "0.0"
}
},

where the field *_id* is the name of the BSON document within the cloud. The parameter *breath* is the value for breathing depth, *pressure* is the strap pressure and *worn* is the indication whether the corset is worn by the patient or not. The hardcoded test data is displayed in the MongoDB cloud in the following manner:

_id: "patientTest1"
    breath: 0
    pressure: 0
    worn: 0

4.5 Cloud Connection to Unity

The data was sent to the cloud via Unity Web Request, which is a Unity game platform specific utility. The necessary C# coding was done in Microsoft Visual Studio, but the project was run through a Unity project. The Unity Editor testing interface can be seen in Figure 11. The files listed on the bottom of the screen display the packages and files used within the Unity project. The C# script file on the screen is the one written within the scope of this project. The dropdown menu on the left panel displays the objects used in this Unity project. Since this particular aspect deals with the backend portion of the project, only 1 object is needed to run the script. The panel on the right hand side displays the parameters of the object selected on the left side dropdown menu. The bottom menu of the right hand side of the project is where the connection between the Unity object and the C# script is defined. Therefore, everytime the Unity project is played from the top menu bar, the C# script is initiated.

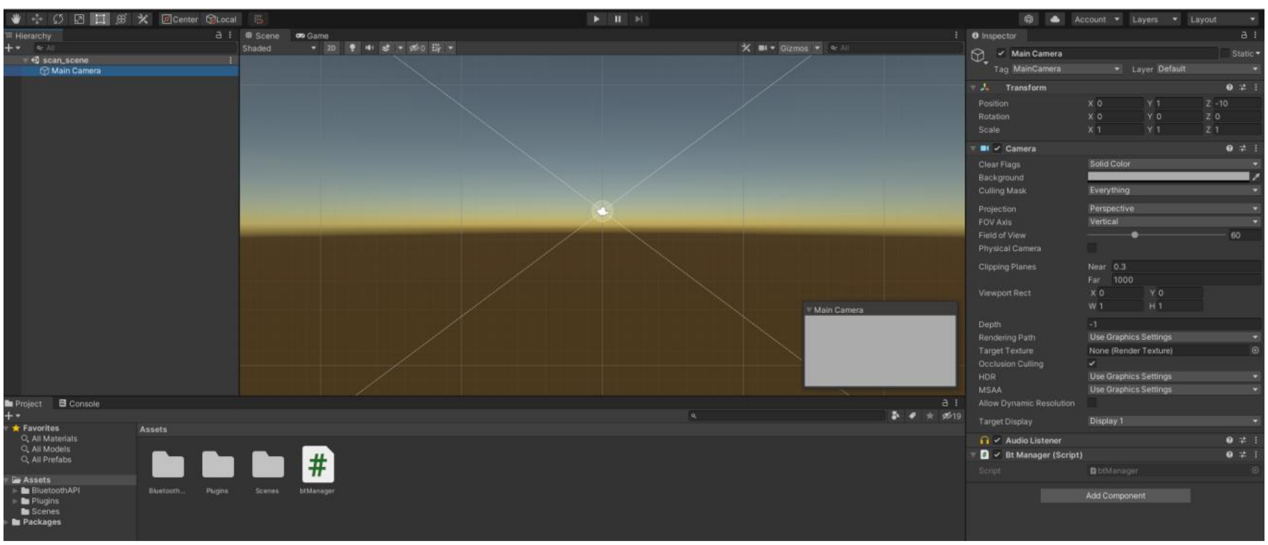

Figure 11. Unity Editor user interface

The aim of the initiated C# script in the Unity project is to read data over Bluetooth from a microcontroller and upload it to the MongoDB cloud. The first test was to send hardcoded data to the cloud, displayed in the “Cloud selection” chapter. The second test was to read data from a text file before using Bluetooth connection to the ESP32. The schematic for data upload from the text file to the MongoDB cloud can be seen in Figure 12.

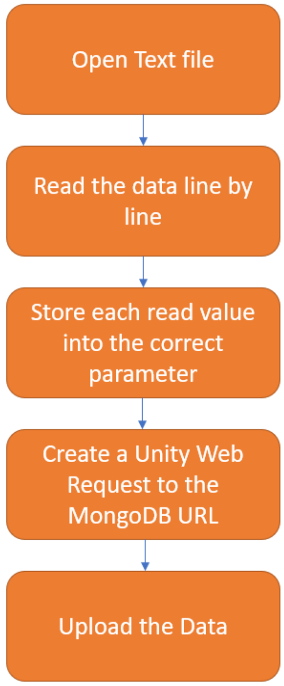

Figure 12. Flow chart of upload schematic

After the data was uploaded from the text file to MongoDB, it could be seen in the MongoDB browser, as can be seen below:

_id: ObjectId("6273de12e0fa124949b34a19")
breath: 16.31
pressure: 0.0438
worn: 1

The data above is not to scale with the real sensor data that the thin film pressure sensor gives. The aim of this data was simply to show the possibility of uploading data from a file to the MongoDB cloud. The parameters and their explanations are given above, in the "Cloud selection" section of this chapter.

The final assignment was to read data via Bluetooth from the ESP32 microcontroller and process it in Unity. From there, the data was to be sent to the MongoDB test cloud. The schematic for the final test case can be seen in Figure 13.

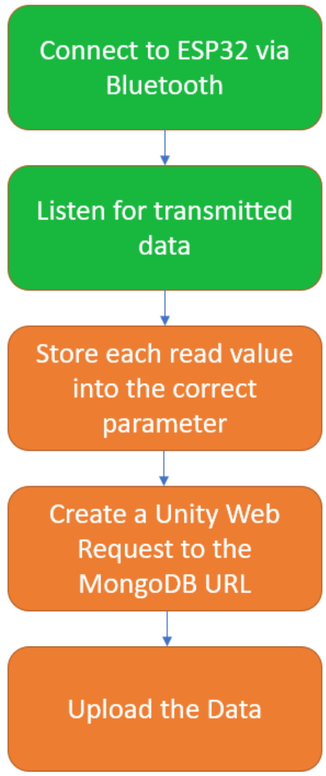

Figure 13. Final use case data upload schematic

5 RESULTS

The aim of this thesis was to provide a technologically advanced solution to scoliosis treatment. The project described in this thesis provides a technically advanced addition for treatment and provides a possible solution for doctors in the near future to use technology to improve patient care. This would help them optimize treatment plans, creating better suited plans for each individual.

The project described in this thesis is still unfinished, as the deadline for the project has not yet been reached. A working prototype with data transmission from brace to end user, both doctor and patient, must be finished by 30.06.2022. The deadline of this thesis, however, was 20.05.2022, therefore more than a month of work is yet to be applied.

This thesis mainly deals with the data collection and storage aspects of the project. However, taking into consideration other aspects of this project, the end prognosis is a positive result. The research group in charge of building the sensor package and configuring the ESP32 microcontroller to transmit data have sent working test results that can be seen in Figure 14.

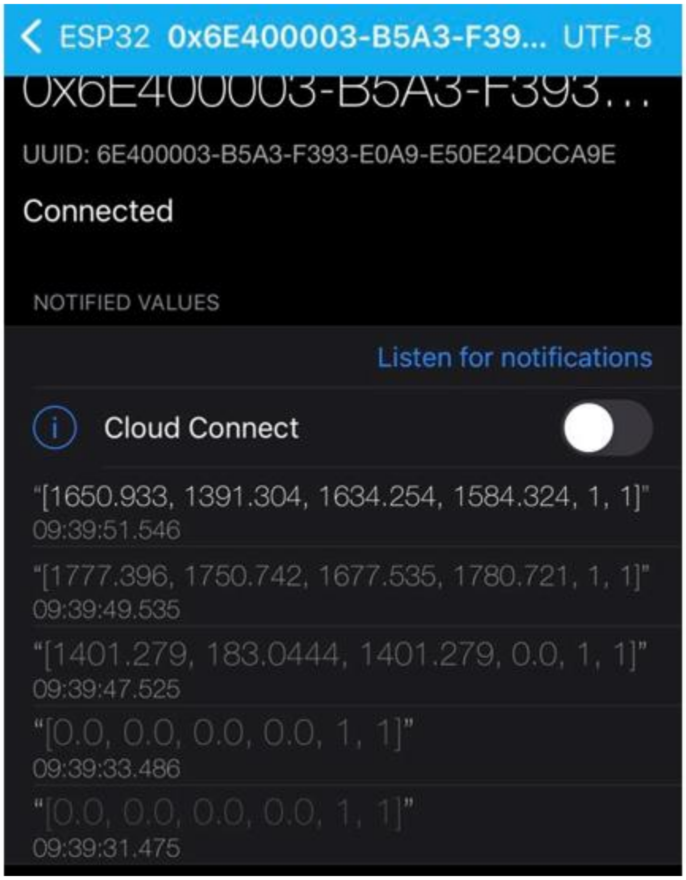

Figure 14. Example of data transmitted by final sensor package

The image in Figure 14 shows a Bluetooth connected ESP32 microcontroller that is transmitting data received from 4 thin film pressure sensors described in the Methodology section of this thesis as well as 2 button sensors. The figures below the title “Cloud Connect” display an array of numbers. This array is an example of data transmission from the ESP32 microcontroller, where the first 4 numbers are pressure sensor values and the final 2 are the boolean type button values. The aim of the button sensors is to give clear evidence as to whether the corset is worn or not. The sensor data displayed in Figure 14 is still in millivolts and must be converted to kilograms, which will be done by the research group in charge of building the sensor package. This helps the doctors see if a part of the patient’s body receives the correct amount of load. Over time, it will provide an accurate overview of how much weight was applied to which body part.

5.1 Conclusions

The author of this thesis was tasked with creating a system which reads data from the ESP32 via Bluetooth and uploads it to a cloud or data storage system. The restrictions for this task were set by the user interface designer and the general project manager. The main restriction for the assigned task was that the listener and upload program had to be compatible with Unity Game Engine and that data readings would be taken via Bluetooth from a smartphone. This goal has not yet been reached, as Unity Game Engine has not provided an official support or methodology of establishing connections to Bluetooth devices. This has led the Unity development community to create and sell their own plugins. The plugin used in the framework of this project [19] was not developed or released by Unity itself. The plugin was assured to work with ESP32, but when it did not, the original developer was contacted. At the time of writing this thesis, the plugin developer is still solving the issue of connecting the ESP32 device to Unity.

In order to confirm the validity and provide an example program, a parallel Python program was developed, which follows the schematic of Figure 13. The aim of this program is to prove a working scenario of the data movement and create a backup in case the Unity errors persist and the project must be moved to a separate platform.

In general, the project can be counted a success, as establishing a connection to read data from a microcontroller and uploading the data to a cloud was achieved. The technical difficulties created by the Unity platform can most likely be overcome in the near future, therefore finalizing the data bridge between corset wearer and cloud. The parameters read from the sensors can easily be used by doctors to create better treatment plans and by patients to follow the created plans. Therefore, once the sensor data is configured and conversions from millivolts to kilograms finalized, the project will grant access to reliable, patient assisting data.

6 DISCUSSION AND FUTURE RESEARCH

As mentioned in the “Results” section of this thesis, the project is not yet fully completed, further development and additional features are planned. After finishing the working prototype, which deals with the 3 parameters described in the “Methodology” section of the thesis, there are plans to add more parameters. One such parameter would be oxygen saturation (SpO2), which would enable all parties involved to see if the corset restricts the patient’s breathing in any way. It would also give doctors the ability to see if the patient is regularly exercising, which is often a part of the patient’s therapy program.

Another future goal for this project, as mentioned in the “Motivation” chapter, is the involvement of Artificial Intelligence (AI). It has been discussed with all parties involved, that AI could be applied when determining a patient's baseline data readings. It would help create the range of data for each parameter, which would be marked as a “safe zone” for each patient. This “safe zone” means that each sensor would have a permitted range of values, which are considered normal. If a sensor exceeds or goes far below this norm, an alert would be displayed. An example of this would be if too much pressure is exerted to one part of the body by the corset. The patient would get a notification that they would need to loosen a certain corset strap to lessen pressure in that area of the body. Another example of this would be the application of AI combined with SpO2 - if the patient is exercising and their SpO2 level goes out of the normal range, the app displays a warning. If the range is far exceeded and the patient does not react to a notification, emergency services could be notified as it may indicate a dangerous situation.

The smart corset solution is novel and unique, as there aren’t any solutions created like the one in this project. This opens up many future possibilities and applications outside of the field of medicine. It has been discussed that future applications and possible routes to pursue may be in the field of warfare, aquatics and many more undiscussed potential fields.

The warfare application would involve integrating the created sensor system to a bulletproof vest to give status data about a soldier in an active situation. It would help commanding officers to see if soldiers have been wounded on the battlefield or if they have reached safe zones successfully. Further market research is required on this topic. The parameters read by the sensor may differ slightly, as the main data read from the bullet proof vest would most likely be pulse, SpO2 and heart rate. However, using the same configuration to read this data is possible. An issue with bullet proof vests may be that, when shot at, the fragile sensors may break. In addition, the vests are worn on top of thick fabrics and uniforms, making skin contact and sensor readings difficult to obtain.

The aquatics area would involve applying the sensor package to a life vest. This would give lifeguards, naval base operators and rescue service responders a clear indication of how long people stranded at sea have before their life is at serious risk. The sensor package could send a notification via app, when a life vest is deployed or comes into contact with water. This notification would reach emergency services or nearby lifeguards, who could then react fast. If a stranded person's body temperature gets dangerously low, the emergency services would be notified again, indicating an imminent and deadly threat. The parameters needed to be transmitted for this configuration would involve heart rate, pulse, SpO2 and core body temperature. A restriction for this may be water, as the microcontroller and sensors are not waterproof.

This project can then be used as a template for many other projects that aim to modernize existing solutions. The idea of "making things smart" with sensors is part of the developing world. The solution developed and documented within the AIRE Smart Scoliosis project is one that could be used as a gateway to the future in many fields. It would simply take time, dedication and vision to modernize and improve the solutions, which are already essential to the modern age.

7 SUMMARY

The main aim of this thesis was to provide a modern addition to the existing scoliosis therapy routines. Firstly, an overview of what scoliosis is and how it is treated was given to introduce the problem. Long-term therapy is largely based on patient journals, which often lack empirical data supervision. Solutions from companies and research papers were presented to further show interest in the field and provide motivation for this project.

The proposed solution was a sensor package that can be applied to existing corsets.

The thesis dives further into the data management and storage aspect of the proposed solution as the author of the thesis was in charge of those fields. The result of the thesis was presented as a working data upload and management system, upon which a working sensor system can be applied. The thesis is concluded with establishing final goals for the future solution prototype. More development ideas and potential fields outside of medicine are also presented.

8 KOKKUVÕTE

Antud lõputöö põhiline eesmärk oli pakkuda modernset lisandit skolioosi teraapiale. Esiteks antakse ülevaade skolioosist ning selle teraapiast, et probleemi rohkem avada. Pikajalised teraapia kavad baseeritakse patsiendi märkmikutel, milles tihti puudub empiiriliste andmete järelevalve. Töös käsitletakse erinevaid lahendusi, mida on loonud ettevõtted või mida on kajastatud teaduslikes artiklites. See näitab huvi antud valdkonna vastu, pakkudes projektile rohkem motivatsiooni

Lahenduseks pakuti sensori paketi, mida saab kinnitada olemasolevatele skolioosi korsetidele.

Töö keskendub metoodika osas rohkem andmete kogumise ning talletamise meetoditele, sest lõputöö autor oli vastutav nende valdkondade eest. Lõputöö tulemustes esitletakse töötavat andmete üleslaadimise ning talletamise süsteemi, mille peale saab ehitatavat sensori paketi rakendada. Lõputöö kokkuvõttes seatakse eesmärgid prototüübi lõpuni ehitamiseks. Samuti tuuakse esile tuleviku arendusplaane ja näidatakse meditsiinist väljaspool olevaid valdkondi, kuhu saaks potentsiaalselt antud lahendust rakendada.

9 ACKNOWLEDGMENTS

As this thesis is written as part of a larger project, the following people are acknowledged. The author extends His thanks to:

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- Alar Kuusik - TalTech leader of creating the sensor package and electronics;
- Jakob Rostovski - Lead sensor package engineer;
- Simone Luca Pizzagalli - User interface and Digital Twin lead;
- Marietta Gavriljuk - User interface and Digital Twin engineer;
- Aleksi Kalandia - User interface engineer;
- Geithy Sepp - Medical data informant representing hospital interests.

Scan of thesis author's signature:

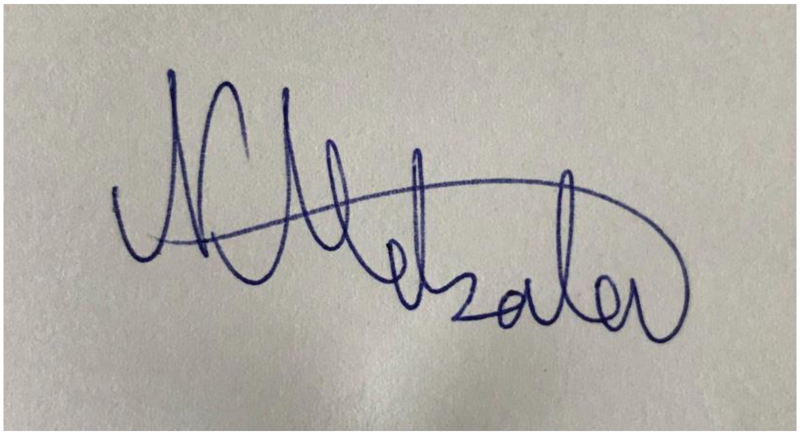

Figure 15. Thesis author signature

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APPENDICES

GitHub link to written code and Unity project:
https://github.com/namets/aire_corset_files/

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