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Contactless Multi-Sensor Solution for E-Treatment of Musculoskeletal Disorders

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ABSTRACT The treatment of Musculoskeletal Disorders requires physical exercises to be executed regularly and correctly. This paper presents a technological solution to support this therapy consisting of on-body sensors and a supporting platform that captures and forwards the data automatically. We implemented wireless communication and charging in the sensor module. The wireless functionality enhances patient's comfort during movements and allows for easy and hygienic maintenance. Validation in a real-life case has demonstrated the suitability of the solution to monitor treatment remotely. Furthermore, it was shown to be easy-to-use by non-technical experts. The sensor has an autonomy of 20 hours, which contributes to its user friendliness. We explain and share the designs that have been realized with low cost IoT technologies including Micro-Electro-Mechanical System sensors, low power wireless connectivity and microcontrollers. The contactless multi-sensor solution can be broadly adopted both in medical cabinets and for remote treatment. The latter is of specific interest when the patient is far from the therapist, encounters mobility problems, or when safe distancing is needed.

INDEX TERMS Contactless sensing, e-health, motion sensing.

I. INTRODUCTION AND E-HEALTH CONTEXT

Musculoskeletal Disorder (MSD) is a collective term for medical problems concerning the musculoskeletal structures, the muscles, the joints, the tendons, the ligaments, and the nerves [1]. Tasks that lead to stress or injuries and repetitive movements are the biggest source for this kind of disorders, although multiple risk factors can be involved. An MSD results in pain and restraints which can strongly affect a patient, both personally and professionally. Typical examples are lower back pain resulting from bad posture, neck problems following sudden impact or stress, or injuries caused by heavy work or training load. By delaying any treatment, the disorder might worsen, and the consequences might become irreversible. MSDs are affecting an increasingly high number of people. They are the most common occupational disease in the European Union with a 2019 report indicating that no less than 60% of all workers suffer from an MSD [2]. The increasing proliferation also leads to high costs for society and companies. In addition, MSDs are common problems affecting the elderly, for whom a late diagnosis is associated with increased morbidity and mortality [3].

Exercises or various physical therapies can assist patients with complaints related to MSDs. For these to be effective, the physiotherapist must check the correctness in combination with visual supervision. This creates a high demand for low-cost monitoring systems, to be used both in the practice of the physiotherapist as well as at the patient's home. We further use the term *e-treatment* to denote (remote) therapy that is supported by measurements made by wireless sensors. Technological developments have resulted in motion sensors that are small, consume little power, and more importantly offer adequate precision. This evolution occurred not in the least thanks to the evolution in Micro-Electro-Mechanical System (MEMS) devices that offer the opportunity to integrate logic with sensing elements, into one Integrated Circuit (IC) and hence process signals resulting in smart sensors [4]. These motion sensors have raised the state of the art considerably and opened a variety of opportunities in human motion analysis [5]. Wearable-based applications include gait analysis [6], fall detection [7], and sport-and leisure related monitoring [8]. In a broader context these systems can be

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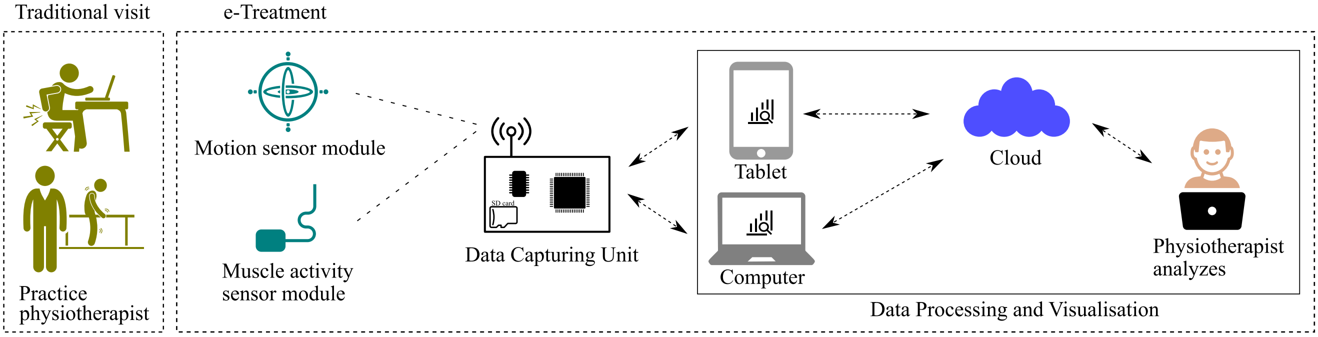

FIGURE 1. Overview of the system: Multiple sensor modules connect wirelessly with the *Data Capturing Unit (DCU)* and forward the data to the *Data Processing and Visualization Platform*. The physiotherapist gets access to the data remotely.

connected to cloud platforms and support real-time remote follow up. This could, for example, help to automatically report emergency situations [9].

In this paper, we propose a contactless multi-sensor platform for e-treatment of MSDs. The effectiveness of e-treatment in the case of MSDs is exhaustively discussed in [10]. The presented solution paves the way to an easy and low-cost deployment on a large scale. When it is cumbersome for patients to visit a physiotherapist, as encountered for example due to the COVID-19 pandemic, this system can support full remote treatment. We present the multi-sensor solution depicted in Fig. 1 with three specific contributions. First, we present a versatile Data Capturing Unit (DCU) that communicates with multiple on-body sensors to monitor movements and muscle activity. The collected data is forwarded for further processing and visualization, to be interpreted by the physiotherapist and the patient. Secondly, we designed a contactless Inertial Measurement Unit (IMU) sensor module. It includes both wireless communication and charging, and thus is electrically fully contactless. We provide the results of experimental validation of the new hard- and software and share them via an open source GitHub repository [11]. Thirdly, we indicate how the platform can be used in the e-treatment of MSDs, especially relevant in times of the COVID-19 pandemic. Note that the muscle activity sensor module, depicted in Fig. 1 is still in the design process and thus not yet realized.

The remainder of this paper is organized as follows: section II provides the detailed design requirements of the sensor platform. Section III presents the system architecture and its operation. In section IV, real-life monitoring experiments are described validating the relevance in physical rehabilitation. Section V provides the evaluation of the contactless sensor module with respect to the design requirements. Section VI introduces how the new system can enable effective e-treatment of MSDs. Future extensions are suggested in section VII. The final section summarizes the main conclusions of the paper.

II. DESIGN REQUIREMENTS

A multi-sensor solution to support physiotherapy for MSDs must, at the same time, meet the functional motion sensing requirements, while coming at low-complexity and cost. Importantly, to support e-treatment, the system must be easy in use for both the patient and the physiotherapist. The following design requirements were established in the frame of a collaboration of engineers with experts in physical treatment [10]:

- **Non-interfering with the treatment.** The sensor modules should be small, lightweight, easily attachable and without wired connections to ensure that the exercises (imposed by the physiotherapist) are not disturbed. A range of approximately five meters will be sufficient to wirelessly connect to a device in the vicinity.
- **Versatile sensing functionality.** With highest priority, the sensing modules need to accurately monitor motion parameters on multiple axes. Depending on the exercise, one wants to measure up to six positions on the body of a patient and capture the corresponding data simultaneously. For specific syndromes, the solution should be able to simultaneously measure muscle activity or other parameters such as distance to the ground or executed force.
- **Data transfer.** The amount of data generated by one motion sensor is less than 10 kBit/s. Accumulated for up to six sensor modules, the combined data to be sent for further processing and visualization is still limited to less than 100 kBit/s. Data sharing must be possible in a remote way, for example when the patient exercises at home.
- **Wireless energy provisioning.** Depending on the mode of operation, an autonomy of minimum one hour to a full day is required. Recharging of sensor modules is performed through a preferably wireless technology to avoid contacts that complicate cleaning and disinfection and easily lead to defects due to incorrect handling.
- **Affordable.** The system must be affordable for the patient and the physiotherapist, making it attractive to a wide audience. We target the full platform, including multiple sensors and modules collecting and transmitting the data, to cost considerably less than existing IMU devices typically used for biomechanical analysis in sport or clinical settings [12].

- **Smooth installation and operation.** The patient must be able to independently perform the measurements at home. Complicated manuals and installation operations are therefore undesirable. A confirmation of the correctness of the measurement is desired. The physiotherapist should get a clear view on the measured data without any notion of data post processing.

The above combination of design requirements for a platform suitable to be deployed at large scale including e-treatment is not met by existing solutions. Current state-of-the-art researches like [13] and [14] limit their study to the upper and lower limbs respectively, with a device that is designed to examine one body part specifically. We design our sensor to fit any body part. Additionally, human motion tracking systems exists in different commercial devices. Many of them provide a 3D representation of a person. High-end professional systems are often visual based tracking systems (e.g., cameras with or without joints on the body) [15], while other systems are non-visual (e.g., based on multiple IMU sensors placed on the body). Current commercial systems are expensive even for professionals [12], and clearly not affordable for most individual patients. We estimate that our design can be three to ten times less costly. We deliberately opted for standard interfaces for data exchange and wireless communication and charging. Hence, the solution can be easily extended with other sensing modules. The designs are available via an open repository [11] for anyone who wants to experiment with or develop e-health systems. To the best of our knowledge, the system is the first design to address the requirements for full remote treatment. It has been validated under realistic conditions to be fit for this purpose both functionally and regarding ease of use for technological laymen.

III. SYSTEM ARCHITECTURE AND OPERATION

This section presents the architecture and operation of the multi-sensor solution, and discusses the elements shown in Fig. 1. The central sub-system is the DCU and can connect to several sensor modules. In this paper we focus on the implementation of an IMU sensor to track human movements and how to connect wirelessly to the DCU. We thereby take advantage of the opportunities offered by recent sensor technologies, wireless communication and charging standards.

A. CONTACTLESS SENSOR MODULES

Figure 2.1. illustrates the main components of the motion sensor module: the sensor, the Microcontroller Unit (MCU), the wireless data link and the power solution. The ATMEGA328P from Microchip is selected as the MCU and needs a connection with the wireless communication solution and the motion sensor. The rotation data reaches the DCU through a Bluetooth Low Energy (BLE) link. While other suitable wireless body networks exists [16], they do not allow for easy integration with current solutions such as smartphones. Although this feature is not currently implemented, the ease-of-use for non-technical users could be further improved by using a smartphone application.

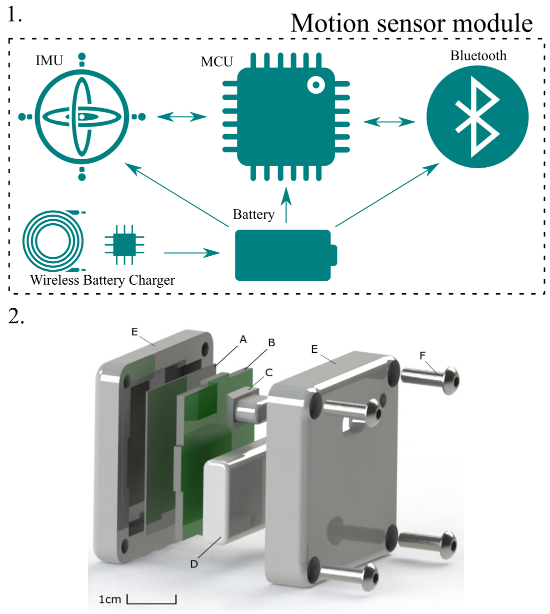

FIGURE 2. 1. Functionality of the motion sensor module. The motion sensor sends the data through the Micro-controller (MCU) to the Bluetooth Low Energy (BLE) module. 2. Casing of the motion sensor module, consisting of a "wake up" button and a status LED. Explanation of the labels: A) WPT coil - B) PCB - C) Button - D) Battery - E) Casing - F) Bolts.

The motion tracking is done via an IMU sensor with six degrees of freedom and measures accelerations [m/s^2] and angular velocity [grad/s]. We opt for sensors based on MEMS technology as these reduce the Bill-Of-Materials (BOM) and have a small form factor [17] [18], and there are devices available with very good performance and reliability. The MPU6050 is selected as IMU. The sensor fusion-on-chip with the integrated Digital Motion Processor (DMP) combines the accelerometer and gyroscope data into a motion fusion output. A quaternion represents the orientation and rotation in three dimensions with respect to an initial position. The measured quaternions are forwarded to DCU through a BLE modem. The Proteus II modem includes a Nordic Semiconductor's NRF52832 System on Chip (SoC) with a build-in Arm Cortex M4 CPU. The communication between the MCU and Proteus II is accomplished with an Universal asynchronous receiver-transmitter (UART) interface. A 250 mAh Lithium Polymer (LiPo) battery together with a voltage regulator ensures that all components are powered. The overall operation voltage is 3.3 V. The MCU can monitor the battery voltage through a switchable voltage divider. Hereby, the DCU has a view of the battery voltage of all connected sensor modules. The battery management system circuit protects the system from overcharging, over discharging and short circuits.

We implemented a wireless charging solution compatible with the Qi standard based on the BQ51050B[1] IC [19]. This design choice avoids additional development costs, as no

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[1] The BQ51050B is a wireless power receiver IC with a build in battery charger that supports the Qi v1.2 standard.

dedicated charging equipment needs to be developed. The combination of a coil, resonance circuit and controller IC compose the main parts of the WPT receiver circuit. The charging current limitation is set with resistors for safety reasons [20]. Both hard- and software were further optimized to achieve a high autonomy of the sensor modules. This will results in a longer battery lifetime and reduce the amount of charge cycles over time.

Figure 2.2. illustrates an exploded view of the sensor module. The three main elements inside the case are the WPT coil, the PCB, and the battery. The system fits in a 3D printed enclosure with dimensions 40 × 40x15 mm. A fully sealed housing could be developed in the future. In total, each sensor module weighs 30 grams. A push button ensures power saving when the module is inactive. Pressing this button wakes up the module via its central controller. The module can reconnect to the DCU and execute a new instruction, e.g., start new measurements, read out the battery voltage or change the sampling frequency. An LED indicates the status of the module, e.g., battery is charging, performing a calibration, or transmitting data over the wireless link.

We have also developed an surface Electromyography (sEMG) sensor module to measure muscle activity, following the same design principles followed and communicating and charging via the same interfaces. It is based on the concept presented in [21]. An sEMG sensor measures the electrical activity of muscles at rest and during contraction. The level of the measured voltages is only a few millivolts. The design of this sensor module hence required special care to accurately process these very low voltages as it must be able to do a qualitative measurement that is precise enough to make correct statements about the muscle activity. It should be noted that sEMG measurements are quite sensitive to the exact placement on the body [22]. Therefore, the self-monitoring of muscle activity is not straightforward for a layperson.

B. IMU SENSOR SETTINGS AND CALIBRATION ALGORITHM

As the movements during the exercises are slow, the IMU is configured with a sensitivity range of ± 2 g and ± 250 °/s, respectively for the accelerometer and gyroscope. A higher accuracy is obtained when using a smaller range compared to the other less-sensitive ranges. This setting is the most sensitive option to track movements accurately [23].

An external 19.2 MHz clock with a high frequency stability of 10 ppm is used to drive the DMP with a clock signal. During start-up, the user performs a calibration. The calibration algorithm measures the DC bias from the accelerometer and gyroscope in all directions. These offsets are written to the appropriate registers and added to each new sample to compensate the sensor output. To measure the relative rotations from a reference state, the DMP is reset, resulting in the creation of a new reference.

C. DATA CAPTURING UNIT

A block diagram of the DCU is shown in Fig. 3. The DCU can connect via wireless links to maximum six sensor modules to capture the real-time data. The data contains the actual measurements of the sensors, e.g., 3D rotations in case of motion sensing or muscle activity for the sEMG. It further includes the package number, the timestamp, and the battery voltage. A tablet can communicate with the sensors through this DCU and get access to the data. The DCU is equipped with a female type-A USB connector to exchange both power and data. Power can also be supplied via a DC jack. A maximum input voltage of 24 V is allowed. A connection between the micro-A USB and a PC is an alternative solution to save the data and perform real-time measurements. Additionally, an SD card slot is provided on board such that measurements can be stored locally.

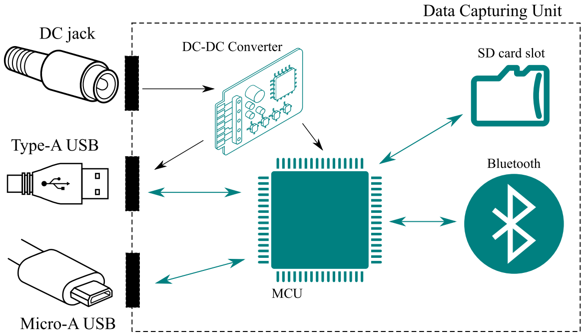

FIGURE 3. Block diagram of the data capturing unit. Black arrows denote energy transfer, coloured arrows denote data transfer.

D. DATA PROCESSING AND VISUALIZATION

There are several options to log the data and to present it visually for the physiotherapist. The user makes a trade-off between ease of use, real-time visualization, and real-time processing. The incoming data on the DCU can be processed as follows:

1) **PC/Tablet** - The physiotherapist can download the data from the cloud and analyze it. Visualization and processing in real-time are performed with scripts developed for specific exercises.
2) **MicroSD card** - This is a useful option if additional connections to the DCU board are not desired. Exercises performed at home can be saved directly, without the need for an internet connection.
3) **On Board Processing** - The MCU of the DCU can analyze the incoming data immediately and give an indication through LEDs or other connected peripherals.

The user can configure which samples from the sensor module, i.e., accelerometer, gyroscope and quaternion, are transferred wirelessly to the DCU and as a consequence stored on the on-board microSD card. For the considered exercises, we had to store only quaternion samples to determine the relative motions. However, accelerometer and gyroscope measurements can be used for other applications and purposes. Python was used to read, process and visualize the captured data.

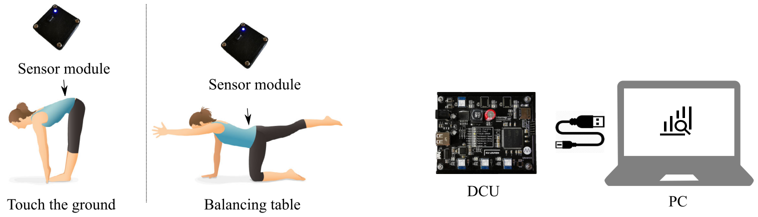

FIGURE 4. **Representation of the motion sensor module fitted to a patient's lower back. Two exercises demonstrate the capabilities of the module[2]. The patient performs the exercise in the neighbourhood (can be a few meters) of the DCU, which is connected with a USB cable to a PC.**

E. DATA EXCHANGE BETWEEN THE THREE SUBSYSTEMS

We explain the data exchange between the three subsystems for the typical case of motion sensing. The motion processor of the IMU generates interrupts at a frequency of 100 Hz. The MCU reads the measured data from the IMU and stores only the quaternions on the MCU. After ten saved samples, a BLE packet is sent and the data arrives at the DCU. Each quaternion consists of four 16-bit numbers. The BLE packet size is 80 data bytes, as calculated in Equation 1.

$$2\,\frac{bytes}{number}\cdot 4\,\frac{numbers}{sample}\cdot 10\,\frac{samples}{packet} = 80\,\frac{bytes}{packet} \tag{1}$$

For a sampling frequency of 100 Hz, the number of packets per second with the data bytes per packet results in an exchange of 800 data bytes every second. As specified in the design requirements, the data rate is lower than 10 kBit/s. Further, the DCU captures this data, converts it to Yaw-Pitch-Roll angles and can combine multiple datastreams and store or forward them respectively on the SD card or to the PC or tablet.

IV. VALIDATION OF THE FUNCTIONALITY AND USER-FRIENDLINESS

The functionality and the user-friendliness of the contactless sensing solution have been validated under real-life conditions. We thereby received guidance from a supportive physiotherapist. The devices were installed and exercises were carried out without the designers of the systems being present. These experiments offer clarity about the operation of the contactless sensor system and verify whether the design requirements are met.

Two typical back rehabilitation exercises are visualized in Fig. 4, the first one is called 'Touch the ground', the second one 'Balancing table'. In both cases, the sensor is fixed with double-sided tape on the lower back of the patient. A PC, connected with the DCU, captures the data wirelessly from the on-body IMU. The IMU sensor is calibrated before every performed exercise. In the following, we discuss the graphical outputs as the physiotherapist will receive them.

The pitch and roll output of the first exercise are shown in Fig. 5. The yaw component is not shown because it is almost constant during this exercise and thus irrelevant.

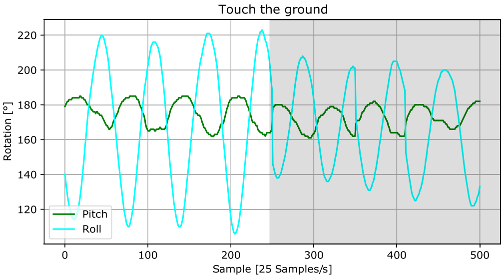

FIGURE 5. **'Touch the ground' evaluation. The relevant axis rotations pitch and roll are shown with the yaw omitted. The gray area shows a reduced angular deflection, which indicates a possible failure to touch the ground.**

The exercise has been repeated eight times, starting from a standing position, clearly visible in the eight peaks in the graph. Interesting in this result is that the last four repetitions have a lower amplitude, meaning that the patient is not executing the movement to its full extent, shown by the gray area.

The second exercise is evaluated by its roll, pitch and yaw component shown in Fig. 6. Knowing that the back of the patient should be quite stable while performing the 'Balancing table', the result of the second sequence can be classified as unstable and thus results from a badly executed exercise.

Both exercises show how a physiotherapist can evaluate the execution of a rehabilitation exercise, even without visual validation. This is particularly valuable in the case of remote treatment where a video connection is not feasible. The numerical output is useful to evaluate the execution in a more objective manner. Other analysis parameters such as the frequency of the movement or the entropy could bring the evaluation to a next level.

V. TECHNICAL EVALUATION OF THE CONTACTLESS SENSOR MODULE

This section revisits the design requirements from Section III and validates that they are indeed met. Other requirements that are not specifically discussed here, have been met, as demonstrated in the previous sections.

A. POWER CONSUMPTION OF THE SENSOR MODULE

The contactless sensor module can operate in three states: IDLE mode, RUNNING mode and POWER DOWN mode. In IDLE mode, the module can execute and answer

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[2] Images provided by Pocket Yoga (www.pocketyoga.com).

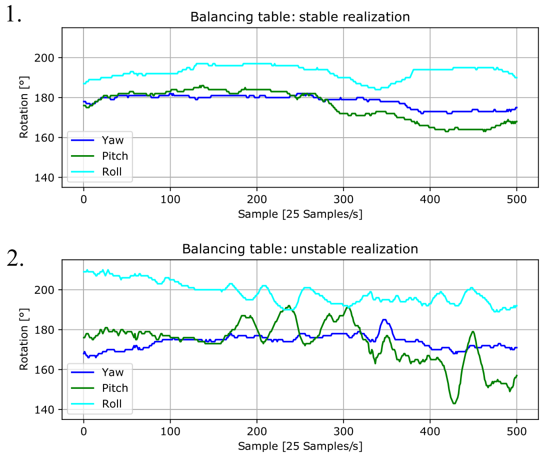

FIGURE 6. **The 'Balancing table' exercise is aimed at keeping the back as still as possible. 1. The exercise was performed correctly. 2. Unstable execution with relatively larger angular rotations as a result.**

instructions imposed by the DCU. In RUNNING mode, the MCU measures the body movements and forwards the IMU data to the DCU. The current required is approximately 12 mA. In POWER DOWN mode, a transistor disables the power to the IMU and the BLE module and subsequently the MCU goes to sleep mode. The current drawn from the battery is reduced to approximately 50 μA. The sleep current of the MCU, BLE module, Qi charger and voltage regulator are responsible for this low standby current.

If the sensor is constantly in RUNNING mode, the battery will last for a minimum of 20 hours. Assuming one patient practises for an hour a day, the module will achieve an autonomy of 20 days. Notice that for these long-lasting measurements, the yaw result will have to be corrected for the rotation of the earth. This can be performed with adequate post-processing. If the module is inactive for a long time, the battery will be completely drained out after 208 days. This robust power usage makes sure that charging is not frequently needed.

B. BATTERY CHARGER

The 250 mAh battery is charged with a maximum measured current of 254 mA. The current and voltage values were inspected over an entire charge cycle. After a charging time of 80 minutes, the battery is almost fully charged. The charging circuit stops charging after 94 minutes. This is an acceptable charge time for this application.

C. COST ESTIMATE

An affordable price is an important prerequisite to lower the threshold for technology adoption and pave the way to a large-scale deployment of the e-treatment devices. Thanks to the spectacular progress on MEMS and semiconductor integration capabilities, many components with excellent performance have become inexpensive. A first-level system cost estimate based on the BOM learns the following:

- The most expensive part is the Bluetooth integrated radio which sells for approximately 10 EUR.
- The motion sensor, WPT coil, and the battery come at prices between 3 and 5 EUR. The MCU and WPT charge controller sell at less than 2 EUR each.
- We expect that the cost of remaining components such as resistors, capacitors, 3D casing, and Low Dropout Regulator (LDO), do not exceed 10 EUR.

In summary, the component cost for one contactless sensor module is below 40 EUR. Clearly this could be significantly lowered in volume production. The DCU consists of similar component and its cost is comparable. The BOM of a basic platform with one sensor module and a DCU is well below 100 EUR, while a more sophisticated systems with four sensor modules can be built for less than 200 EUR.

D. EASE OF USE FOR PATIENT AND PHYSIOTHERAPIST

Throughout the paper, several aspects of the sensor module that contribute to the ease-of-use of the system for both the patient as well as the therapist have been discussed. Here we highlight a few more features to support that the criterion is indeed met. First, we have included a warning LED indicating when the battery of the sensor is low, which helps the user to know when to charge timely. Secondly, the sensor module is equipped with an easy button interface to avoid difficult set-up routines. Calibration happens automatically when the system is switched on and the sensor modules are put on a table for a short while. Also, the system comes with a user manual that explains the operation step by step.

VI. E-TREATMENT, PREVENTION, AND E-LEARNING

The cost of healthcare in our ageing society creates a need for remote treatment solutions. The COVID-19 pandemic and its resulting lockdown measures have accelerated this need. Worldwide, people are forced to look at alternatives for their daily job, including physiotherapists. In addition, there is the combination of long-term telework and the restrictions on sport activities, which can lead to more cases and more severe consequences of work-related MSDs. Hence, we expect that the need for physical and remedial therapy is growing in times that physiotherapists are more difficult to reach.

Independently of the COVID-19 restriction, remote treatment can be a support or even replacement of conventional face-to-face consult, when a physical visit is not possible or not convenient. For most people, remote treatment can be accomplished over the internet, or thus e-treatment. E-treatment can be realized in two ways: non real-time or real-time, depending on the availability of appropriate infrastructure. Examples are non real-time exchange of exercises by manual or videos, and live (real-time) conference call. In all cases, the main shortcoming is the lack of feedback on the quality of the execution of exercises as well as the duration. The multi-sensor platform presented in this paper offers a solution by providing the information needed to evaluate the patient's execution.

The proposed system serve as a curative solution for patients with an MSD, and they can also be used as a preventive solution. People with a desk job, for example, can be monitored during their work for up to 20 hours. In this way, the system can provide information about the nature and duration of the movements of a person while working. Based on this information, physiotherapists can propose precautionary measures or exercises so that musculoskeletal disorders can be prevented. In addition, the system can be used when investigating people with prosthetics or paralysis and research of better treatments in this area.

Another context where the system can contribute is the education of physiotherapists. While this application was at the origin of the development of the new system, the need to have access to e-treatment systems to assist learning has become much more important and urgent since the outbreak of the pandemic and many educational institutes had to switch to partial or full remote education. A positive consequence of the crisis is the accelerated development of technology for remote education. We hope that the open-source system built with common and relatively low cost components may also help people in developing countries in the future to get access to appropriate education.

VII. FUTURE EXTENSIONS

We foresee future extensions to the multi-sensor systems regarding the hardware, the sensing functionalities, and the data processing environment. Particular directions are pointed out here below.

A. HETEROGENEOUS SENSING FUNCTIONALITIES

The proposed platform is designed with the opportunity to communicate with different kinds of sensors. In this paper, the operation of the system is detailed for a motion sensor module. We also designed an sEMG sensor to measure muscle activity to fit in the framework. In a next step we will integrate both types of sensors on one module to perform simultaneous co-located measurements. The latter offers interesting opportunities in the study of possible muscle activity in case of paralysis. Experts helping people with disabilities to move with the help of an exoskeleton could hence optimize systems on an individual basis. Other types of sensor modules can be developed to support the assessment of specific exercises. For example, in a bending forward exercise, physiotherapists are interested in measuring the distance from the fingers to the ground.

B. RICHER LEARNING FROM THE DATA

In the current design, the DCU collects the data and transfers it for further processing and visualization. This board performs no local data processing. To assess more complex movements or learn more from them, advanced data analysis can be performed. This analysis can be executed based on the raw data received from the DCU.

The multi-sensor motion monitoring system will be used in the research of the entropy and the variability of a movement. A lack of variability is often the cause of problems. Ideally one should not use the same part of the muscle for a certain movement all the time. Interpretation of the measurements with the motion sensors could demonstrate and evaluate the gravity of such problems. The further treatment could be optimized, or in the future patients could receive measurements-based and automated messages to take action on time and prevent serious nuisance. New learning algorithms considering large amounts of data resulting from longer term measurements can help assess how effective a treatment is. If studies involving many patients are performed, a better understanding of and maybe new insights in specific syndromes can be found.

The current system allows the data to be processed in three different ways: by a PC, by a microSD card and by a tablet. To view the data, it first has to pass the DCU. A direct communication between the sensor modules and a smartphone using BLE could be an interesting extension. An app that provides basic and patient-oriented feedback, can help and motivate people to exercise more effectively. Avoiding the intermediate data transferring step can further lower the hardware cost of the system.

VIII. CONCLUSION

We have presented a solution for e-treatment of MSDs based on various contactless sensor modules and a unit that captures and forwards the data. The designs are built with low cost yet good performance components and meet all functional and other design requirements put forward for precise monitoring of movements of patients. The sensing modules have been realized without any electrical contacts, which offers both practical and hygienic benefits. They communicate via BLE technology, and can be charged through an interface compatible with the Qi standard. They can operate for a minimum of 20 hours, effectively allowing a full day of continuous monitoring if desired or only requiring recharging once a month if daily exercise sessions of half an hour would be carried out. Data from several, possibly heterogeneous, sensors can be captured simultaneously.

We have validated both the functionality and the user-friendliness of the new sensing solutions. A non-insider to the technology was able to install and operate the system. The read-outs bring a clear and correct representation of the performed exercise, providing adequate precision and time resolution.

The technology can improve current practise by providing physiotherapists more precise feedback on exercises carried out. Patients can be monitored for longer periods and under more natural conditions, for example while at work. The combination of the user-friendly operation and the low cost, both regarding the hardware system and the expert-time, paves the way to help many more people and help them better, even when they are not able to come to the office of a physiotherapist. The system can also contribute to the formation of physiotherapists, especially when remote education is needed.

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