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IJIE

http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

A Smart Iot-Based Prototype System for Rehabilitation Monitoring

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DOI: https://doi.org/10.30880/ijie.2023.15.03.010
Received 6 November 2022; Accepted 18 April 2023; Available online 15 August 2023

Abstract: Smart healthcare is growing significantly in the healthcare sector due to the Internet of Things. A remote monitoring system is one of the smart healthcare implementations for rehabilitating stroke patients. Nowadays, as the COVID-19 pandemic continues to spread, patients undergoing home rehabilitation have difficulty meeting with their physicians due to movement constraints. In addition, the healthcare facilities are devoted to treating patients with COVID-19. As a result, physicians and patients could not frequently meet to gather their rehabilitation progress. This study involves developing a prototype to monitor a post-stroke patient's rehabilitation process using the Arduino Nano 33 Bluetooth Low Energy (BLE) and force-sensing resistor (FSR). The prototype analyzes critical aspects of the rehabilitation process based on handgrip, heart rate, sleep, and step tracking measurements. The results of the handgrip, heart rate, sleep, and step tracking measurements are evaluated for various types of subjects and six testing approaches showed an accurate and consistent results. However, experiments partially success with a small error is detected while tracking the steps of each subject. Several recommendations are highlighted to improve the prototype using other sensors such as force sensing resistor and flex sensor for handgrip force transducer, electromyogram (EMG) sensor for stroke-patients rehabilitation, and others.

Keywords: Smart healthcare, internet of things, Arduino Nano 33 BLE, force-sensing resistor, post-stroke rehabilitation

1. Introduction

The concept of the fourth industrial revolution, mainly known as Industry 4.0, was launched by the German government in 2013 [1]. The manufacturing sector is undergoing its fourth revolution. It will build upon the third revolution's computerization and automation technology used. The next step is for industry 4.0 to use machine learning with data to enhance core features. In addition, one of the most promising intelligent machine application systems brought out by Industry 4.0 is the Internet of Things (IoT) [2].

The definitions of IoT are highlighted by the development of systems in various applications. In addition to being defined as a system of interconnected computing devices and unique identifiers of objects, IoT can transfer data through a network without needing people-to-people or people-to-machine interaction. Furthermore, IoT provides a bridge

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between the digital and physical worlds [3]. In the early 1980s, IoT was introduced when a student developed the first self-service machine that notifies the consumer if the drink sold reaches the level of coolness desired by the consumer [4]. In most organizations and applications, IoT is an essential component in developing intelligent systems. The IoT ecosystem comprises sensors, processors, and communication equipment to collect, evaluate and send the received data. IoT also uses intelligent machine learning or artificial intelligence (AI). Therefore, it can be developed without human interaction but can still be accessed by humans if needed [5].

The healthcare industry is one industry that is very much on the rise in using IoT applications. Globally, more than 60% of medical organizations worldwide are satisfied, and some have implemented IoT applications in their systems [6-8]. Applications in this industry have significantly improved healthy interactions between patients and doctors. For example, the IoT system has allowed regular patient monitoring by doctors while updating patient information in real-time. This concept will significantly facilitate the doctor's task of making appropriate recommendations.

The main contribution of this study is to monitor a post-stroke patient's rehabilitation process using the Arduino Nano 33 BLE and FSR. The following sections organize the paper: Section 2 highlights IoT applications in the healthcare system. The detailed description and development of Arduino Nano 33 BLE are in Section 3. Section 4 discusses the results and analysis, including some recommendations to improve the results in Section 5. Lastly, we conclude the paper in Section 6.

2. Internet of Things in Healthcare

Internet of Things is used for monitoring purposes. Data on patient health can be collected, interpreted, and exchanged with the help of IoT healthcare. Patients can keep tabs on their health status when not at a medical facility; providing accessibility equates to better health care for individuals and more open data for scientists. Healthcare apps can keep track of various health issues thanks to data gathered through the gathering process itself. Moreover, this technology helps humans monitor their activities using small devices and remotely.

2.1 Remote Monitoring

The most ubiquitous use of IoT now exists in remote healthcare monitoring. Hospitalized patients that need careful monitoring, for instance, can be tracked remotely using equipment powered by the Internet of Things. These devices automatically record patients' heart rate, blood pressure, temperature, and pain. Then, the medical staff will analyze them in the cloud. In addition, since the procedure is now automated, there is a reduction in the number of occasions that nurses need to visit patients to record their data [9].

Physicians can remotely monitor the patient data undergoing rehabilitation at home, utilizing IoT-driven devices. As a result, the physicians or caretakers can be notified immediately of any changes or disruptions. It will also help during the COVID-19 pandemic by decreasing the number of patient visits required for data gathering, improving both efficiency and quality of treatment.

The American College of Cardiology and the American College of Physicians published a joint statement on March 2, 2020. It encouraged governments to realize the importance of digital and virtual services in the COVID-19 pandemic [10]. In addition, the relevance of self-quarantine and social distance in preventing community spread has increased the importance of remote patient-care monitoring.

However, remote monitoring has some drawbacks, including lacking a good internet connection outside large cities. In addition, uninterrupted power in rural regions is not feasible for remote monitoring or data transfer [11]. Consequently, there will be a widening gap in health care access between urban and rural populations. Furthermore, the healthcare system will need to be reformed with technological advancements. For this reason, experts must be prepared and ready to follow up and respond following the information they have received.

The Ethereum platform is used to develop a permissioned blockchain that offers a safe and secure approach for remote patient monitoring [12]. Users can monitor their health data while keeping tabs on any changes, and the platform can also be used to keep tabs on patients who are being monitored remotely. The system maintains a safe, secure, and updated record.

The force-sensitive resistors (FSRs) were implanted beneath the pillow to capture breathing data for monitoring sleep [13]. A single-board computer called LattePanda was utilized to collect data. During initial testing, the data pillow could reliably transfer sleep data to a server without any issues. The IoT data pillow can distinguish between regular breathing, hypopnea, and apnea by analyzing natural sleep data. Sensors, wireless technology, and the Internet of Things (IoT) might enhance the data pillow system, making it easier for consumers to monitor their sleeping patterns at home while giving physicians online access to their patients' sleep data.

2.2 Stroke Rehabilitation Device

The stroke rehabilitation monitoring system is one kind of rehabilitation that makes use of the smart healthcare system. This project recommends making a prototype to keep track of a stroke patient's recovery. Home rehabilitation patients aiming to improve their posture and mobility through exercise can benefit from accessibility to a tracking device. Rehabilitative evaluations also track how well patients are doing. Users interact with this prototype to gather data. Sensors are embedded in the prototype to record data such as heart rate, muscle strength in the arms and legs, and sleep quality. The following section discusses prototype components and testing procedures.

Measuring and quantifying their home exercise movements might be helpful for patients who do not have physical assistance from a therapist. Sensor recordings of patients' therapeutic exercise performance can also guide patients and therapists in daily interactions. However, sensor-based systems for home rehabilitation have two significant challenges: minimizing sensor intrusion [14] and validating the effectiveness of exercises performed at the patient's speed [15].

A Virtual Reality (VR) system, including the RehabMaster platform, has been created to rehabilitate upper limb function post-stroke [16]. The device is a safe rehabilitation tool for improving motor function in individuals who have had a stroke at different stages of their recovery. Hospitals and physiotherapists are in great demand as medical resources for the elderly population grow.

The Action Research Arm Test for arm and hand function evaluated user acceptability and improvements in arm and hand function following technology-supported training at home with traditional exercises in chronic stroke patients [15]. Arm and hand exercises at home using a computerized gaming orthosis or recommended traditional activities from an exercise book were randomly allocated to six weeks of self-administered home training.

Real-time grip strength measurement, bend angle monitoring, and human finger gesture remote control are feasible with the self-powered piezoelectric sensors based on cowpea-structured PVDF/ZnO nanofibers (CPZNs) [17]. The spring grip was capable of holding PES firmly in place. The PVDF/ZnO NFs will detect the relevant electrical signal when pressure is applied to PES. The PES's output voltage adjusts correspondingly in response to applied pressure variations. Tactile sensing has a lot to gain by having such a precise way of measuring strength.

3. Arduino Nano 33 BLE for Rehabilitation Monitoring

Microcontrollers will be used as the computing device in the prototype to analyze the data gathered by the system's built-in sensors. The project's objectives influenced the selection of these sensors, which will provide the information needed to track a stroke patient's recovery.

The project selects the Arduino Nano 33 BLE as the prototyping board. The board improves the standard Arduino Nano. The project requires a redesigned Arduino Nano because it has the features required to develop the prototype. The main improvement is a faster CPU, which means more space for data and software. In addition to its low power consumption and integrated NFC pairing for Bluetooth [18], this board is valuable to our prototype. Board internal measuring devices include an accelerometer, gyroscope, and magnetometer, for a total of nine. This project benefits significantly from the BLE capabilities of the Arduino Nano 33 and its compact size [19].

A force-sensing resistor (FSR) is also included in the prototype to acquire the data to represent the hand strength of the stroke patient. The FSR will be used to measure the pressure applied by the patient to measure their grip strength. Grip strength is one of the essential rehabilitation processes of a stroke patient, so the prototype includes the pressure sensor. The sensor operates by changing its resistance upon the press applied to it. This sensor is low-cost and easy to use, but its disadvantage is that sometimes the reading it records is inaccurate. The sensor's output is expected to be in the range of outcomes [20].

In this prototype, the heart rate of a stroke patient is measured using the sensor's finger clip [21]. The importance of monitoring a stroke patient's heart rate cannot be overstated. Any change in the heartbeat rhythm is reported to physicians or caretakers, who evaluate whether the patient requires urgent attention. Data from this sensor is crucial to the prototype's operation.

The prototype is divided into parts, precisely four different parts based on Fig. 1. These parts will monitor other rehabilitation processes of the patient, which will make data collection more efficient and the troubleshooting process more accessible if the result is not desired. The three parts are depicted in Table 1.

Table 1 - Three parts of the prototype

Part	Sensor
A	It consists of Arduino Nano BLE 33. It is used to handle the electronic components of the prototype.
B	It consists of a pulse sensor. It is used to measure the heartbeats of the user.
C	It consists of an FSR to measure the force applied by the user.

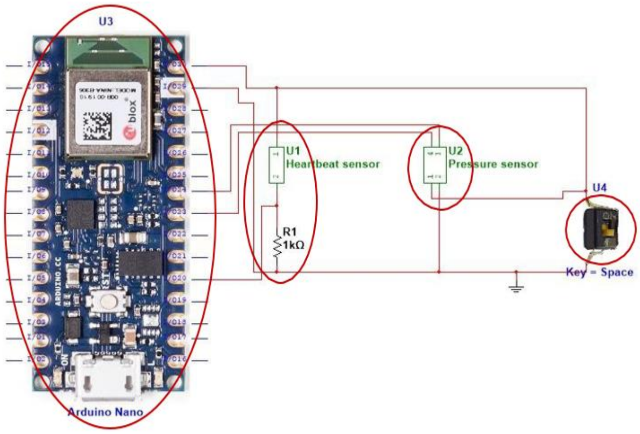
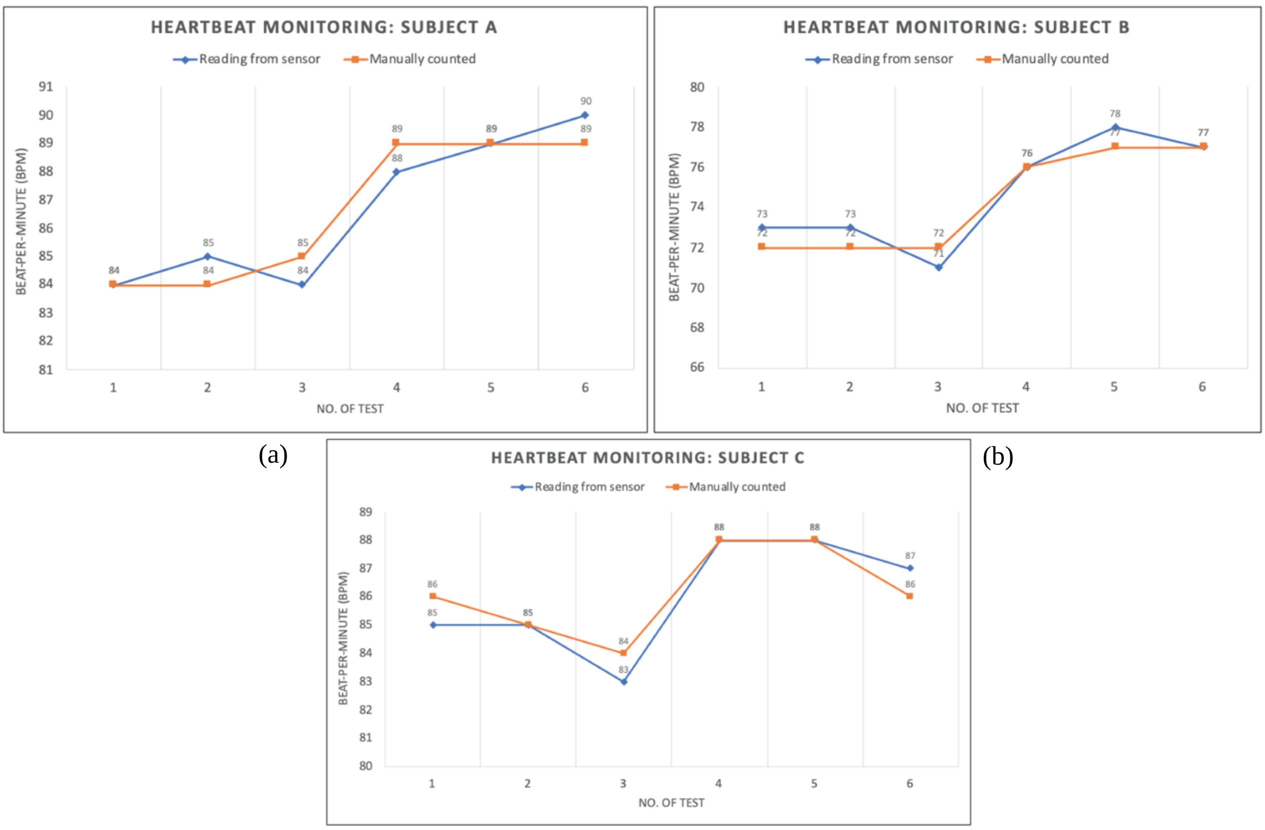


Fig. 1 - Arduino connection with the sensors

4. Results and Analysis

The results for heartbeat monitoring are plotted in Fig. 2, which shows the results obtained from each subject and are compared to analyze the sensor's accuracy with the manual counting method. Thus, the blue line in the graph indicates the sensor value, while the yellow line indicates the result obtained from manual counting. The introduced prototype can monitor a post-stroke patient's rehabilitation process that relies solely on traditional communication and data storage methods, such as cloud computing and relational databases.

Based on the comparison between the results obtained, it can be observed that the results obtained from the sensor and the manual counting did not have that much difference. Therefore, the program enabled the sensor successfully shows accuracy and consistency.



(a) (b)

(c)

Fig. 2 - Heartbeat monitoring for various subjects

Furthermore, the sensor requires the subjects to press the device for 5 seconds to determine the handgrip measurements. The pressure sensor registers the pressure admitted by subjects A, B, and C based on Table 2. The subjects' inconsistency is due to the test method, where they only grip the sensor using their fingertips. Thus, the inconsistency of results can be observed. The sensor is not yet ready to be implemented in the prototype as it needs more tuning to make the results more accurate and consistent.

Table 2 - Results of the handgrip measurement

No. of Test	Pressure Pressed (Newton)		
	Subject A	Subject B	Subject C
1	8.89	13.34	10.34
2	12.13	12.59	9.64
3	6.45	5.71	2.34
4	3.56	1.34	4.44
5	9.73	3.23	10.48
6	10.11	4.99	9.36

The rehabilitation procedure for those who have had a stroke relies heavily on the step measurement of the individuals. The Arduino Nano 33 BLE circuit's built-in accelerometer is used in a Python script to track the subjects' movements. The 20-step and 50-step benchmarks are compared first. Subjects then walk the steps while carrying the prototype. Fig. 3 illustrates the results of step tracking for all subjects, demonstrating that the accelerometer captures the subjects' steps.

The result remained stable throughout the test; however, the recorded steps are not as accurate as would be preferable. As the subject walks 20 steps, a minor mistake is detected. An accuracy error in the device or accelerometer software caused a considerable discrepancy in step recognition compared to 50 steps. As the sensor is not yet ready for usage in the prototype, the findings need to be modified and enhanced.

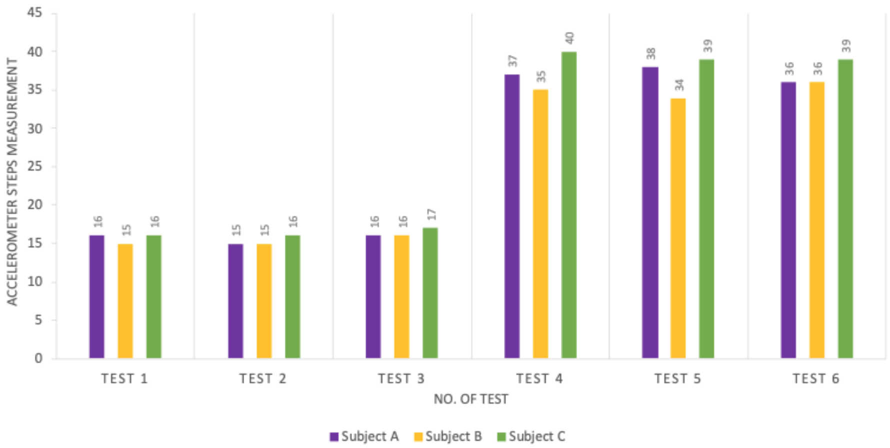


Fig. 3 - Steps tracking for subjects A, B, and C

Next is the analysis of the amount of sleep for each subject to simulate how stroke patients sleep. Sleep is also a crucial measurement to determine how well a patient is sleeping and whether or not they are having an irregular sleep pattern, which might be caused by pain or discomfort. Finally, the results of sleep monitoring are tabulated in Table 3, which shows that the sensor is accurate and works as desired. Therefore, the sleep monitoring sensors can be implemented in the prototype because it works, and the results are accurate and consistent throughout the subjects.

Table 3 - Sleep monitoring results

No. of Test	Subject A		Subject B		Subject C	
	Timer	Sensor	Timer	Sensor	Timer	Sensor
1	7:23:56	7:23:56	2:45:01	2:45:01	4:05:01	4:04:59
2	1:12:43	1:12:42	2:34:11	2:34:11	0:44:34	0:44:34
3	0:15:57	0:15:57	5:39:55	5:39:56	2:23:59	2:23:59
4	6:22:12	6:22:12	8:01:22	8:01:22	5:58:46	5:58:46

5. Discussion and Recommendation

The findings of an experiment conducted with existing prototypes are reviewed, and some recommendations are offered to enhance the prototype. Further improving patients' privacy by introducing anonymizers that would increase the difficulty of linking transactions together will also be a future study. This section discussed further depth to improve or augment the prototype and change the testing methodology.

The first recommendation is to change the prototype's upper limb strength measurement components or elements. The force sensing resistor used is insufficiently small, and the test method does not accurately reflect upper limb strength. Additionally, the strength of a subject is not accurately represented by a finger press, which needs to be enhanced.

Secondly, a handgrip strength transducer is the first proposed component for this application. The handgrip strength transducer is a strain gauge designed to measure grip forces. The device is preferable to a force-sensing resistor because it has a larger surface area. The surface accessible for detecting gripping force is a cylinder with a diameter of 30 mm and a length of 150 mm greater than the diameter and length of the force-sensing resistor utilized in the prototype. The measurement is divided into six components, with an accuracy of +/-1 percent for forces up to 250 N per segment. It increases the accuracy of the collected data in evaluating the subjects' grip strength. An example of a grip measurement transducer model that is commercially available is presented in Fig. 4. It is adaptable to the user's requirements to satisfy its application requirements [22].

Fig. 4 - Handgrip force transducer

Another recommendation for measuring upper limb strength is to employ a flex sensor. A flex sensor is used to determine the amount of deflection, more often referred to as bending. Generally, it is constructed of plastic and resistive carbon components. Flex sensors function similarly to variable resistors because their resistance varies in response to the applied bending force [23]. The smaller the bend radius, the greater the resistance value reported. Additionally, the sensor will offer a more accurate representation of grip strength since the prototype will evaluate subjects' ability to flex their fingers to grip. If the subject can grip, the bend on the flex sensor will significantly indicate high upper limb strength, while the patient with low upper limb strength can register minimum bend force on the sensor.

A further recommendation is to use an electromyogram EMG sensor. An electromyogram (EMG) is a sensor that measures muscles' electrical activity while moving [24]. This sensor has been used in a variety of clinical and biomedical applications. For instance, this sensor delivers signals that assist physicians in analyzing or diagnosing patients' muscle or nerve diseases [25] and detecting any disease, including preventing or treating patients early. Besides that, EMG signals can be utilized to operate prosthetic devices such as arm, hand, and lower limb replacements. The sensor will measure the signals filtered and rectified by the electrical signal created by the specified muscle, depending on the amount of activity performed by the strength.

Furthermore, the prototype's lower limb component must be enhanced [26]. The result indicates that the step counter sensor provided a less desirable response when the steps were carried out manually and the accelerometer varied. It demonstrates inaccuracy, showing that the prototype component should be improved. A suggestion for improving the outcome is to develop a standard testing method with a more controlled testing procedure. For instance, timed testing can determine how long a subject takes to complete the required steps. One may hypothesize that the time required for subjects to complete the requisite number of step counts reflects their lower limb strength variations. The shorter the time, the stronger the subjects' limbs.

Moreover, establish the course or direction subjects must follow throughout the test; thus, all subjects walk the same path without shortcuts or detours [27]. This could change the sample of data collected among subjects. The result can be more accurate and reliable when controlled by the testing condition.

Following that, the accelerometer must be appropriately calibrated and maintained between subjects. Next, the computer code created for this component must be specific and accurately calibrated for the data returned from the sensor to match the required benchmarks. Finally, it needs more testing to determine the optimal calibration for producing the most accurate results achievable during prototype testing.

Other sensors can also help in the data collection on lower limb strength. The FSR can measure the pressure applied by the subjects throughout their walk [28]. It can improve the analysis of lower limb strength data. The subject can benefit from a more rapid rehabilitation process if the measured pressure is high. The pressure imbalance can also be detected using this sensor to assess whether the subject's lower limb strength is imbalanced. The force sensing resistor can be combined to sense the pressure points where the feet touch the floor.

The FSR is connected to detect the pressure points under the foot to measure the amount of pressure applied by the test subjects [29, 30], as shown in Fig. 5. Combining these sensors can enhance detection, resulting in more accurate results. Thus, integrating the new testing method with new components will improve the accuracy of lower limb strength data.

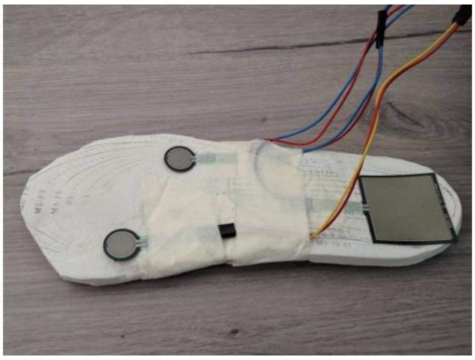


Fig. 5 - Example of force sensing resistor application to measure step pressure

6. Conclusion

The prototype was improved from the previous version, which is cost-effective and contains many new features compared to the old model. The results indicate that the prototype's pressure and step tracking sensors need to be upgraded because they produce unexpected results. For example, pressure sensors could not completely reflect upper limb strength. Thus the redesigned prototype could have a larger surface area to sense pressure. Moreover, there are a few hiccups in the tracking process. Therefore, greater calibration of the sensors and device, or with the code written to the device, can increase step tracking accuracy. The prototype's additional sensors are ready to deliver. Many individuals can benefit from this device, and it would be great if a prototype were ready and accessible for testing soon after the strokes began. Insights gained from this prototype can encourage further investigation of the Internet of Things inside the healthcare sector. In the future, we can use EMG sensors for handgrip, post-stroke patients, step tracking, flex sensors, and force-sensing resistors.

Acknowledgment

This work is supported by Universiti Teknologi Malaysia under UTM Transdisciplinary Research Grant Q.K130000.3556.06G45 for the financial support provided throughout this research project.

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