IRIS - A WEARABLE DEVICE FOR MONITORING MOVEMENT DISORDERS

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Neurodegenerative diseases affect brain neurons by progressively losing structure or function, including death of neurons. To improve or sustain a patient's quality of life, monitoring their condition and constantly adjusting their treatment based on their home state is crucial. At the moment, there is no objective measurement for monitoring neurodegenerative diseases and the decisions that are being made are biased. This project aims to realize a solution that monitors people with movement disorders and helps the doctors in the process of diagnosing and changing the medication of their patients. We created the IRIS application along with the IRIS wearable devices that analyze the data needed to diagnose and monitor people with movement disorders, such as Parkinson's Disease. The parameters combined can help the doctors and patients in the process of diagnosing and monitoring movement disorders. The product is able to objectively assess a patient and to offer the data in a processed manner so that the doctor can prescribe new medication to control the symptoms of the patient.

Keywords: wearable devices; movement disorders; activity monitoring

1. Introduction

Nowadays, the technology that is continuously evolving is aiming to revolutionize each domain where it can be applied: from agriculture and education to healthcare and finances. There is a wide range of projects, researches and companies that are trying to either improve the current processes or build a disruptive innovation in their field. One of the most interesting and delicate, but does not enjoy the popularity of other domains, is the research and innovation in the healthcare system. It all started with a very simple pedometer created by Thomas Jefferson in 1788 [1] and it has come to medical devices that diagnose our diseases or even to more advanced solutions, such as nanobots

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implants [2]. All this new technology in the medical field is trying, at the end of the day, to improve the quality of life of humans.

Despite increased digital technology accessibility and a growing number of apps for the elderly, adoption is low [3]. According to the World Health Organization, there will be 1 billion people over 60 in 2020, and that number will double by 2050 [4]. Aging will impact society and healthcare. Cognitive, physical, and sensory deficiencies worsen with age, raising health concerns. Most seniors want to age in place as long as possible [5]. Elderly people with limited mobility will have trouble getting medical care.

Neurodegenerative diseases affect brain neurons by progressively losing structure or function, including death [6]. These diseases are incurable. To improve or maintain a patient's quality of life, monitor their condition and adjust their medication based on their home state. No matter how good a medication is, a patient's condition degrades over time. Self-monitoring and treatment improvement are key until a cure is found.

Movement disorders are common neurodegenerative diseases. Parkinson's Disease, Essential Tremor, MS, Huntington's Chorea. Symptoms include tremor, poor gait, loss of balance, and bad posture [7]. These parameters must be constantly monitored, and the doctor must change treatment based on improvements or worsening.

2. A Medical Overview

2.1. Diagnosis

Movement disorders are neurodegenerative diseases characterized by abnormal movements and motor symptoms [7]. Loss of balance, poor posture, hand or finger tremor, and gait abnormality are common symptoms. A patient with gait issues has difficulty walking from A to B.

Patients with a specific movement problem experience all of these symptoms to varying degrees. Patients may have a combination of mild or severe symptoms, or all of them. We chose the four most common movement disorders for this study: Parkinson's Disease, Essential Tremor and Huntington's Chorea [8].

General practitioners refer patients with movement disorders to neurologists. The doctor will perform a CT scan to confirm the patient's neurodegenerative condition. After confirmation, patient diagnosis begins [9]. All of the patient's symptoms must be considered by the doctor. Balance, gait, posture, and tremor must be examined to diagnose Parkinson's. In the next sections, we'll discuss what parameters must be reviewed and how technology can help doctors.

First, balance issues The Romberg and Unterberger tests are used to assess balance. There are two ways to perform the Romberg test:

• Simple Romberg - patient must stand still for 20 seconds with eyes closed while back-to-front movement, side-to-side tilt, and gravity center in plan are assessed [10].

• Romberg Sensitized - patient must stand still for 20 seconds with eyes closed while putting one foot in front of the other; back-and-forth movement, side-to-side tilt, and evolution of gravity center in plan are all measured [11]-[14].

The neurologist can determine the patient's condition based on the results and visual observations. Unfortunately, clinicians don't use technology at this level. Electroencephalography is used to determine tremor frequency.

2.2. Monitoring

The next phase after being diagnosed with a neurodegenerative disease is the monitoring of the patient. Unfortunately, there is no cure for movement disorders, so the only way to control the symptoms that the patients have is to continuously monitor them and change their treatment regularly, based on their state at home.

This process of monitoring starts from the first day of diagnosis. A doctor or a nurse perform a test on the patient called the Unified Parkinson's Disease Rating Scale (UPDRS) to define the current state of the patient [15]. This test is consisting in 50 questions about the patient's life and how easy he or she can use the hands or the body to perform simple actions. In order to have objective results, the answers to the questions can be given in 5 numbers from 0 to 4.

Following this evaluation, the neurologist prescribes a basic first-line treatment for the patient and asks him or her to return in 6 months for another evaluation. During this time, the patient is advised to keep a journal at home and record all observations regarding his condition and key symptoms, which include balance, posture, gait, and tremor.

After the specified number of months, the patient will return to the hospital and undergo the aforementioned tests, including the Unified Parkinson's Disease Rating Scale [16]. Based on the observation diary and the new tests, the doctor will determine which symptoms have improved and make changes to the treatment. Depending on the patient's condition, the doctor may urge them to return in 6 or 12 months.

The biggest issue with this procedure is that all home monitoring is usually performed by the patient and sometimes by a caregiver. This results in a subjective evaluation and, as a result, unsuitable and delayed treatment for the patient.

3. Literature Review

When it comes to self-monitoring in the healthcare system, wearable medical gadgets have always been the innovation aim. This category includes accessories that we regularly wear that have been turned into smart accessories via technology (e.g., sensors, microchips) [17]. Of course, the smart watch or smart band is one of the most common and simple to use in this industry. It typically detects and tracks our vital signs, such as heart rate, pulse, and oxygen level. However, with the advancement of technology, we can now discuss applications that can prevent and detect heart attacks, as well as more unconventional wearables such as smart belts or smart rings [18].

3.1. Tremor analysis

Movement disorder patients' tremor is usually assessed at the wrist and one finger (usually the index). As mentioned, frequency, amplitude, and symmetry must be studied. The doctor can monitor the simmetry, so patients don't need to. Because any change in tremor affects treatment, the first two parameters require a high level of precision in the study. The easiest way to treat tremors is with a wristwatch and smart ring.

The Parkinson Kinetigraph [19] uses accelerometers and gyroscopes to continuously record data for three weeks. Lack of short-range communication technology extends battery life (e.g. Bluetooth, Zigbee). After a month, the patient should send the wearable device to the manufacturer, who will send the results to the neurologist. The watch's microSD card stores the data.

This product's main drawback is that patients can't access real-time tremor data. They must ship the gadget back to the manufacturer to collect the data, which is inconvenient. Individuals with a more prominent finger tremor are at a disadvantage when using this wearable.

Apple and Intel have used tremor analysis to address this issue. On existing hardware (e.g. Apple Watch), they're creating Parkinson's disease monitoring apps [21]. Smartwatch sensors aren't very precise and can only measure general daily activities (like walking and jogging). The smartwatch can't analyze dyskinesias, sudden involuntary movements.

3.2. Gait, Posture and Balance Analysis

In the second category of medical devices, some monitor gait, balance, and posture. In this scenario, the solution architecture and data collection method can each be approached from different angles. Most wearable technologies that address this issue examine the patient's upper body (e.g. back, spine).

Xsens is the first wearable gait analyzer. It's a set of smart bands with sensors that, when worn together, create a patient's digital skeleton and monitor movement [23]. Bands are placed on the thighs, legs, arms, forearms, wrists, and spine. This solution uses accelerometers, inertial gyroscopes, and MEMS gyroscopes. The sensors are expensive, and their software lacks a medical perspective, despite being appropriate for this use case. Using the product daily is also difficult for patients.

4. **Proposed Solution**

In order to better understand the proposed solution, we need to comprehend how will the device be used by the doctor and the patient. The patient uses the wearable devices (smart back device, smartwatch and smart ring) minimum a day per week following their usual behavior - going to work, working out or doing chores. These devices record the data from the patient in order to monitor and analyze hand and finger tremor, gait and balance. All of these data will be displayed in a friendly environment so that the doctor can prescribe a better suited treatment and that the patient is involved in their self-monitoring.

We have built two devices: one to monitor the patient's wrist tremor and another to evaluate gait, balance, and posture. The wristwatch comes with a smart ring that monitors finger tremor.

Our solution consists of a smart ring worn on the patient's wrist and a device worn on the back. Bluetooth will be used to connect primary devices and software. This mode of communication transmits accelerometer, magnetometer, and gyroscope data. This data is sent to the cloud, where algorithms process it anonymously. Raw sensor data can't easily reveal a patient's gait, balance, tremor, and other symptoms. That's why.

When all the data is processed, it's transferred to the software application so the rendering thread can begin. Visual graphic elements make it easier for patients and doctors to see patient progress and symptoms. Our software solution will include charts and artworks that show in real time how the patient moved during a test or activity. The solution's streamlined architecture is shown in Figure 1.

5. **Implementation**

5.1. **Hardware Overview**

The goal of the physical part of the solution - the wearable devices, was to build hardware that is high-autonomy, low weight, affordable and ergonomic for collecting the data from patients. When developing these devices we need to take in consideration both the practicality in a day-to-day usage and the wish of patients to have discrete wearables. One of the most unexpected psychological traits of a patient is that they do not want to feel as a person suffering from a disease. They want to be involved in their monitoring process and they do not want devices or products to wear or use that make their incurable condition obvious.

As Inertial Measurement Unit (IMU) data is generally noisy, data collected from a patient during normal daily activities will have numerous artefacts, and the signal must be heavily pre-processed [24]. This can be done in both software and on the hardware device level.

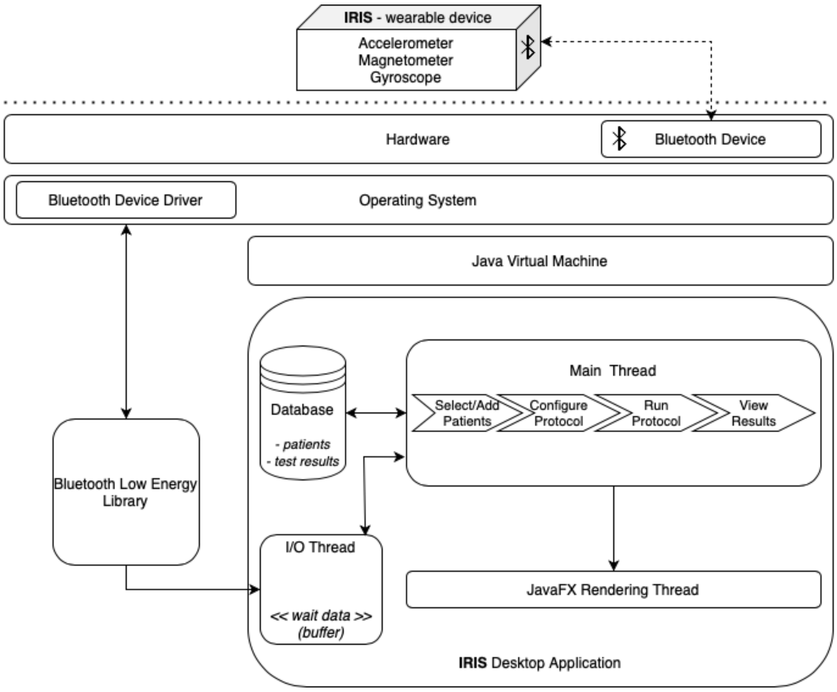

FIGURE 1. Software architecture for IRIS.

For the microcontroller and Bluetooth Low Energy (BLE) module we picked an option that is low weight and it measures 6.4 x 8.4 x 1.75 mm. The model is MDBT42V-512KV2 from Raytac and its highly flexible multiprotocol SoC ideally suited for Bluetooth Low Energy, ANT+ and 2.4GHz ultra low-power wireless applications [25]. Therefore, a microcontroller that is ideal for a medical wearable device designed to be worn at least once a week for 24 hours.

IMUs combine accelerometer, gyroscope, magnetometer, and orientation software. The IMU measures tremor, gait, balance, and posture. The smart sensor BNO055 is a System in Package (SiP) that integrates a triaxial 14-bit accelerometer, a close-loop triaxial 16-bit gyroscope, a triaxial geomagnetic sensor, and a 32-bit microcontroller running BSX3.0 FusionLib software. The BNO055 is ideal for augmented reality, immersive gaming, health and fitness, indoor navigation, and more. It's ideal for AR, navigation, gaming, robotics, and industrial applications [26].

Wearable devices that have to be charged very often and have a difficult way of charging (e.g. deprecated standards for the connecting cable or charging slots), are not an ideal product to be used, especially by patients that are majority elderly. Therefore, we chose the Li-ion polymer battery Hypercell HPL402323-2C, on 3.7V and 190mAh [27]. Together with a wireless charger [28] and an LTC that constantly measures battery charge state, battery voltage and chip temperature [29], we managed to build an optimal environment for a wearable device's battery.

5.2. Graphical User Interface

The software solution includes a GUI, a communication layer between software and hardware, an I/O unit, a runtime environment, and a post-processing database. Each component has its own thread and is handled differently.

The Graphical User Interface (GUI) is a single, static unit that provides monitoring and testing features. JavaFX structure, a product stage for building desktop applications that can run on a variety of devices, was used to build the GUI technology (GUI). JavaFX supports PCs and browsers running Windows, Linux, and macOS [30]. It's a bundle of graphics and media that lets engineers configure, develop, test, and examine workplace apps. This structure is ideal for visualizing biomedical data, according to studies [31].

First, the doctor mounts the necessary devices on the patient, depending on the test. One device will be worn as a smartwatch on the wrist, and another will be worn on the back with a waist-molding harness. Next, the doctors connect the devices.

Following this step, the physician will choose the Resting Tremor Assessment for the test to be performed on the patient's hand. In Figure 2 we can observe the frequency and amplitude of the hand's and finger's tremor. The doctor can choose the live display of data of either finger or hand tremor.

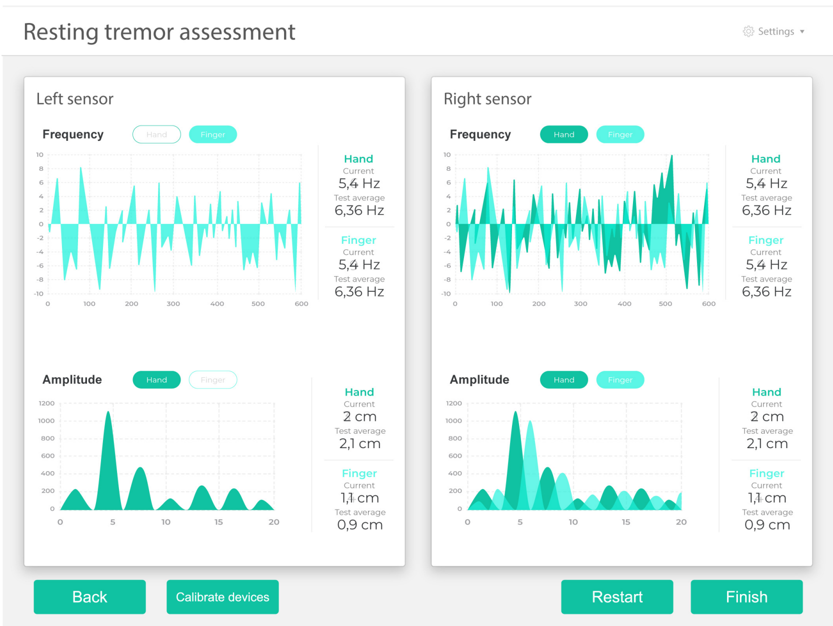

FIGURE 2. Representation of the GUI on the tremor assessment.

The doctor will then decide which balance tests to perform. The Romberg test flow was described in a previous section. The patient must remain still for twenty seconds with their eyes closed so devices can assess their balance and posture.

One device is on the patient's wrist and the other on their back. The physician must calibrate the patient's devices before each evaluation. After calibration, the test will begin, and the doctor can observe the patient's movements in real time. The Romberg test requires the patient to close his eyes and remain stationary for two minutes while his lateral and front balance are evaluated. Standard, sensitived left, and sensitived Romberg tests can be evaluated.

According to this study [32], the Romberg test is merely a diagnostic tool that a medical professional would use to establish whether or not a patient is suffering from any kind of disease. This test has the potential to detect vertigo at first glance; nonetheless, it will always be necessary to do additional investigations, such as the sensitized Romberg test or Unterberger's Stepping test [33].

Finally, the data will be presented, and the attending physician will be able to examine the patient's medical history, as is demonstrated in Figure 3. On the left side of the screen, we can see general data about the patient, such as his identification number, height, weight, date of birth, and the official diagnosis of his condition, as well as the time when it first appeared and any unique symptoms that he may be experiencing. Additionally, any linked conditions, past testing, and current medications are considered to be relevant, and as a result, they are presented in green boxes and framed.

On the right-hand side of the screen in Figure 3, we have the patient's medical history, which includes the IRIS tests that have been performed on them in the past. The tests that the patient has successfully passed are marked in green, whilst the tests that frame potential problems with symptoms that the patient may have are noted in red.

6. **Results**

In this chapter, we will provide a knowledge acquired of the section of the product that is dedicated to feedback and testing. Our objective was to conduct the implemented tests of specific symptoms on patients and to obtain feedback from the attending physician. The concept and the prototype for this project were developed in conjunction with medical professionals so that they could be tested and validated.

We are able to examine the whole outcomes of the Romberg tests by looking in Table 1. These were carried out under the supervision of medical professionals, and the diagnoses obtained were compared with one another in order to ascertain the degree to which they diverge from the results of other

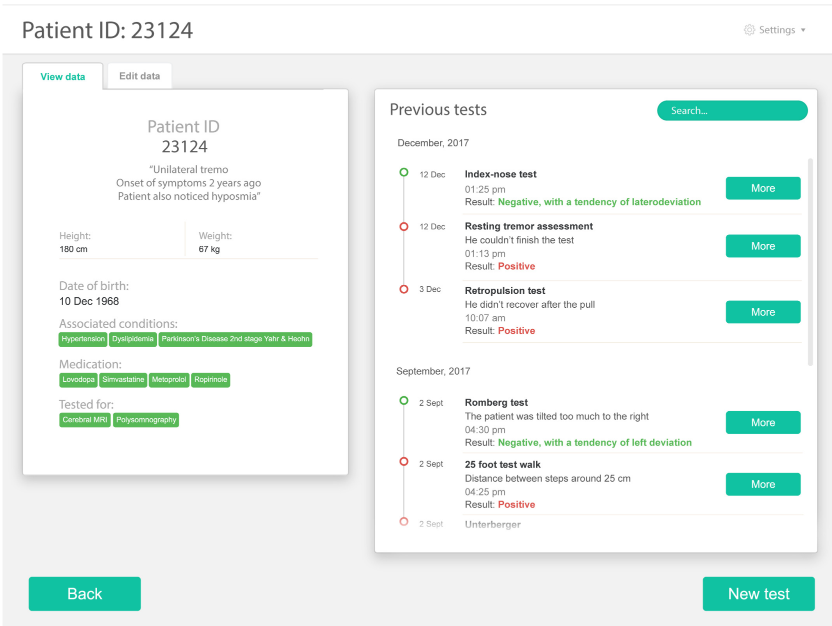

FIGURE 3. Representation of the GUI with the medical results screen.

Romberg tests. The conclusions reached as well as the diagnoses reached were the same.

Tests	Rotation - average		Frontal Balance - average		Lateral Balance - average	
Side	Left	Right	Left	Right	Left	Right
Patient 1	4.27°	1.89°	0.49°	0.81°	1.53°	1.18°
Patient 2	1.03°	3.34°	0.22°	0.54°	0.91°	1.12°
Patient 3	7.36°	4.99°	2.95°	3.12°	1.78°	2.31°
Patient 4	3.66°	1.12°	0.89°	0.98°	1.39°	0.89°
Patient 5	6.25°	4.98°	1.42°	1.89°	2.72°	1.72°
Patient 6	2.34°	1.36°	0.62°	0.91°	1.34°	1.63°
Patient 7	4.10°	2.37°	0.55°	0.83°	1.28°	1.18°
Patient 8	7.88°	5.87°	11.98°	2.48°	4.57°	2.73°
Patient 9	1.09°	1.92°	1.29°	0.99°	1.83°	0.29°
Patient 10	2.36°	2.28°	0.93°	1.29°	1.48°	0.93°

TABLE 1. Results for the Romberg test.

We decided to use the Unterberger test for the second set of evaluations that we carried out. Marching in place with one's eyes closed for a period of two minutes is required of the patient during this procedure. The following criteria will be evaluated: lateral and frontal stability; frontal and lateral balance; and left-to-right and right-to-left frontal and lateral balance. When evaluating a patient for his or her balance and gait, which refers to how the patient walks from point A to point B, this test is very crucial to perform. It could appear to be a straightforward examination at first glance, but in reality, when performed in a room that has been soundproofed, the patients have a tendency to move away from where they started and form an angle. The rotation of the patient as well as their starting position and their final position at the conclusion of the test are the two aspects of this assessment that are given the most weight by the attending physician. The outcomes of the Unterberger test carried out on 10 different patients are shown in Table 2 for your perusal.

Tests	Stability - average		Frontal Balance - average		Lateral Balance - average	
Side	Lateral	Frontal	Left	Right	Left	Right
Patient 1	98.12%	98.89%	1.27°	1.79°	2.10°	1.98°
Patient 2	98.89%	99.95%	0.38°	0.74°	0.82°	1.32°
Patient 3	98.45%	99.78%	0.73°	0.98°	1.76°	1.24°
Patient 4	99.01%	99.92%	0.53°	0.82°	0.91°	0.89°
Patient 5	99.78%	98.89%	1.38°	1.01°	1.29°	0.25°
Patient 6	99.56%	99.78%	0.63°	0.91°	1.23°	1.02°
Patient 7	95.45%	91.12%	11.69°	3.48°	4.37°	1.05°
Patient 8	98.45%	97.56%	2.08°	3.65°	1.72°	2.12°
Patient 9	98.89%	99.12%	0.84°	1.46°	1.29°	0.72°
Patient 10	98.99%	99.95%	0.55°	0.89°	1.61°	1.19°

Table 2. Results for the Unterberger test.

As we can see, each of the solutions considered has benefits and disadvantages. The majority of state-of-the-art technology, regardless of cost or portability, can only evaluate one or two aspects. Both doctors and patients seek a solution that includes all of the necessary tests, symptoms, and parameters. They do not want to use various gadgets made by different companies that produce different types of output.

7. **Conclusions**

Our research revealed that there is no comprehensive solution for diagnosing and monitoring movement disorders. All current solutions either don't monitor all symptoms or can't be worn at home. We created a wearable device with current technology to treat this condition.

Firstly, the specifications were prioritized to meet all needs. Secondly, a solution and product design were proposed. Consumer research and development was the third step, followed by creating an architecture and technical specifications.

Customer development is the best way to validate a problem solution and refine components and features. We did so with our primary target users, allowing us to define a flexible, modular, and easy-to-deploy roadmap and architecture. We decided that an ideal device would be built on an Inertial Measurement Unit, which includes an accelerometer, magnetometer, and gyroscope.

IRIS helps doctors and patients diagnose and monitor movement disorders using cutting-edge technology. The tool may objectively examine a patient and provide processed data so the doctor can prescribe new medication. Existing techniques for analyzing desired criteria use outdated technology or patients' and doctors' perceptions. IRIS assesses a patient's symptoms thoroughly.

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