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Research Article

An Innovative Design of a 3D Game-Supported Physical Therapy Device for Wrist Disorders

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ABSTRACT

Functional disorders can severely affect a person's quality of life, making even simple daily activities a challenge. Especially finger, hand, and wrist disorders can cause problems even in the daily necessities, which are very simple. Patients with reduced mobility should go to physical therapy centers and receive treatment to regain their lost mobility. Physical therapy and rehabilitation treatments are processes that give results in long-term and require patience and persistence. In recent years with the effect of growing computer science technologies, there has been a growing interest in the use of game-supported treatments for hand and wrist functional disorders like in other fields. These new-generation treatments use interactive games to deliver sustainable treatments that make the process fun and engaging. These games are designed and developed to make patients do some specific movements to gain their functions again by making their muscles stronger. With the infrastructure described in this study, it aims to make a prototype that includes a microprocessor, wireless communication capability, and gyro sensor so that patients can perform physical therapy movements while playing games. Additionally, in this study, the presented prototype is compared in terms of cost with the high-budget products preferred in the market. With this study, we aimed to raise awareness that producing such innovative technologies may be less costly than transferring them from outside.

1. INTRODUCTION

With Industry 4.0, the technology is progressing quickly. With the automated systems, physical effort needed works are getting easier for humans. However, it causes them not to move during the day, and benefit from the sun, and fresh air less. Due to these disadvantages, humans lose their physical resistance and can faced with muscle diseases easily. It is also possible to encounter physical damage that cannot be compensated in unexpected accidents and some issues came from innate or traffic events. According to a guide about the global strategy for improving musculoskeletal health; approximately 1.71 billion people globally live with musculoskeletal conditions, affecting people of all ages. This report also shows us that high-income countries have the highest number of affected individuals (441 million) [1].

Additionally, physical disorders can be seen because of birth defects. "Birth defect" is a medically accurate term to describe structural changes to a person's body that happen during fetal development. About 3% of children born in the United States (US) have a major birth defect; birth defects account for about 20% of all infant deaths [2]. Every four and a half minutes, a baby in the US is born with a birth defect. This equals 1 out of every 33 babies born or 120,000 babies each year [3]. These statistics show us how common birth defects are. The humans are born with birth defects will probably need some physical support equipment or physical therapies.

Some jobs like dentistry, software engineering, and hairdressing, besides some issues that come from innate, accident, or chronic diseases, or arising from intensive computer use in daily life may cause physical disorders.

For patients with limited mobility due to many different reasons, it may be necessary to be treated in physical therapy centers to restore the lost movement capabilities. Physical therapy and rehabilitation processes are treatments that give results over a long period and require patience and stability. Treatments can be painful and challenging at times, depending on the place and severity of the condition.

This study presents a design that will help patients who need physical therapy for wrist disorders to perform painful and sometimes boring rehabilitation treatments more easily and funny. In traditional treatments for wrist disorders, the physical therapy specialist teaches the patients flexion, extension, radial-ulnar deviation and wants them to make these exercises in sets. The specialists sometimes use some toys like play dough, stress balls, and hand bows to simulate the daily movement requirements. During these treatments, the patients need only a table and a towel, which is shown in Figure 1.

Figure 1. Traditional treatment choices for wrist disorders

These types of traditional treatments sometimes come boring to the patients and they don't prefer to complete all treatment periods. At this point, we prepared a system to encourage patients with wrist function disorder to perform physical therapy movements. They wear a lightweight box on their hand surface and fasten it with velcro straps. After that, they can make their treatment while playing a game. The electronic infrastructure in the box can take the hand movement angles via Bluetooth and gives the movement to the game objects. The patient and the specialist can view the improvement of the patient from the reports. This feature will be planned for the last version of this study.

In this paper, we studied to take the data from a wire connection and gave the movement to the game objects with the data of the users' wrist movement angles. We used an Arduino Uno, which includes an Atmega 328P microprocessor it, an MPU6050 IMU 3-axis gyro sensor, and cables for communication. The angle data was collected from the users while they were doing the physical therapy exercises with 3D games. This data was read by a gyro sensor with a developed script file. By transferring the movement data to the game platform, Unity, we gave directions to the game object. We designed a lightweight box to locate the circuit on user's hand. We developed a 3D game, which allows users collecting gold while driving a car, and a car selection with collected gold. We didn't use any commercial equipment or games for developing this prototype. We are still studying this prototype to provide it with a wireless connection, and improving its reports.

It will be possible to get more efficient results by improving this prototype in terms of game technologies, motion sensitivity, and reporting features. This design offers patients to be able to perform the necessary movements at home. It is also suitable for clinics because it can be cleaned easily and it can fit many patients' hands. This product will be suitable for both adult and pediatric patients.

This kind of technologies are getting popular in health treatments. Unfortunately, most of the physical therapy centers cannot afford this kind of trend technologies' budgets. In this study, we propose a prototype that has a big price difference with professional products. It is evaluated that by supporting the mass production of similar prototypes, cost-effective and functional products that compete with the global market can be developed. It aims to raise awareness on the possibility of a domestic product alternative to centers and patients currently using or planning to use computer game-based treatment tools which are imported with high budgets.

2. OVERVIEW

Commercial products that are especially preferred for hand and wrist physical therapy and rehabilitation processes were studied. Then, we searched for a literature review and academic studies related to our study. You can find the details below.

2.1. Commercial Products and Academic Literature Review Related to Smart Tools Suggested For Hand and Wrist Disorders' Physical Therapy

There are many commercial products that provide treatments with gaming options.

"Rapael Smart Glove" is a wearable technology product. It has bending sensor, 9-axis motion and position sensor with 3 acceleration channels, 3 magnetic field channels, 3 angular velocity channels. With Wi-Fi connection, it sends the wrist movement angles to the computer. It uses 32-bit microcontrollers and low power consumption which makes the device lightweight, 132 g. After each exercise, the patients can see the performance report and share the results with the doctor [4].

"Hocoma/Armeo@Spring" is for neurological disorders such as multiple sclerosis (MS), spinal cord injuries, cerebral palsy, or subsequent brain damage. It has mechanical arm support, and relevant performance feedback [5].

"Armeo Senso" has a tool for the hand and 3 motion sensors on the wrist, elbow, and chest. It is appropriate for use at home with remote control, following the initial training provided by a therapist [5].

There are some academic literature that suggests treatments with gaming options in Türkiye.

Fidan U. et al. studied on "Design and Implementation of Measurement and Exercise System with Kinect Sensor for Neurological Rehabilitation" [6]. They used Kinect device for taking patients' movement data and sent these data to Unity 3D gaming motor. By this study, they were offering a sustainable solution to the patients who were suffering from stroke, parkinson's and cerebral palsy.

Erdogan H. et al. studied on "Game Design for Physical Therapy and Rehabilitation Using Kinect" [7]. They used Kinect device for taking patients' movement data and sent these data to Unity. They offered patients or users the opportunity to exercise without getting bored. They prepared one main game called "Maze" and the user can reach other 3 game choices through the main game.

Ozcan H. and his friends studied on "A Leap Motion Based Mobile Game Design for Developing Hand and Wrist Movement in Children" [8]. They used Leap Motion device for taking patients' movement data and sent these data to the computer and a game infrastructure. Unfortunately, they did not mention about the technology or tool that they used for developing games. They offered the children a motivated way to do the physical therapy they needed.

In all the researches that we reviewed during this study,

1. They offer a sustainable and funny way to do the mandatory physical therapies especially for neurological issues, stroke, parkinson's and cerebral palsy.
2. They claim that they provide more effective and successful treatment conclusions by the support of gaming.
3. They prefer to use commercial products for taking the patients' movement data. Most preferred commercial products are Nintendo's Wii remote [9], Sony's EyeToy

[10], Microsoft's Kinect [6, 7] and Ultrahaptics's Leap Motion [8].

4. They generally provide game options which were prepared with Unity game application.

2.2. Comparison

Below you can find a table where we compared those products and studies:

TABLE 1
COMPARISON OF TOOLS AND STUDIES

	Treatment Area	Mechanic Support	3D Game Support	Budget/ Subscription
Design and Implementation of Measurement and Exercise System with Kinect Sensor for Neurological Rehabilitation	Hand, hand wrist, arm	X	✓	Half-commercial, using Kinect device.
Game Design for Physical Therapy and Rehabilitation Using Kinect	Hand, hand wrist, arm	X	✓	Half-commercial, using Kinect device.
A Leap Motion Based Mobile Game Design for Developing Hand and Wrist Movement in Children	Hand, hand wrist, arm	X	✓	Half-commercial, using Leap Motion device.
Rapael Smart Glove	Hand, hand wrist	X	✓	£17,230 / £175 per month [11]
Armeo@Spring	Hand wrist, arm, shoulder	✓	✓	N/A
Armeo@Senso	Hand, hand wrist, arm	X	✓	N/A

To summarize, the results show us that there are some choices about using new generation technologies in wrist/hand physical therapy treatment. But they are limited or have high prices. They are generally commercial or half-commercial with using a commercial device's capabilities. This conclusion directed us to develop a low-cost and effective solution.

3. OUR DESIGN

3.1. Methodology

During the research and study, we noticed that physical therapy and rehabilitation treatments produce productive results only if the patients make the exercises regularly. This project started with the idea of making physical therapy and rehabilitation fun while entertaining the patients and improving them. Due to the needs and applications that vary according to the region where physical therapy will be applied, this study has developed against wrist disorders caused by any reason.

In the literature reviews, Sutanto and his friends shows us that a gaming physical therapy solution supported with a commercial device like Kinect, Leap Motion or Wii,etc. isn't a cost-effective choice [12]. We tried various development alternatives for a cost efficient solution with this idea. We have an awareness after these researches, we should develop not only the games but also the communication infrastructure to be able to provide the patients or users a sustainable and cost-effective solution.

The project needs a multidisciplinary study. For this reason, it is possible to itemize the components of the project, each of which touches on a separate discipline;

- Material research suitable for modeling and manufacturing,
- Determine the reference values of healthy people and implement them in the system,
- Electronic and communication infrastructure,
- 3D game design and implementation.

Figure 2 shows us that the design of electronic and communication infrastructure, 3D game development, and implementation. These titles will be explained in detailed in next subtitles since other components like modeling and manufacturing and health subtitles constitute a study subject belonging to a separate discipline.

Figure 2. The process steps examined in this study.

3.1.1. Electronic and Communication Infrastructure

This section includes the infrastructure components and functions that will collect the movement angles of the hand and wrist on the material to be positioned on the hand and transmit these data to the computer.

First of all, since the study aims to include hand and wrist movements, the circuit that plans to be put on the hand's surface should consist;

- Sensors to consistently detect motion angles,
- A microprocessor to collect this data,
- A serial port adapter for data communication,
- A Bluetooth connection adapter is suitable for communication from the serial port to provide wireless usage,
- Lightweight, not preventing movement, and having instantaneous data transmission.

Many researches and trials have been carried out within the scope of these requirements. First, we studied an Arduino Uno

microprocessor, a three-angle MPU6050 gyro sensor, a cable with USB A and USB B inputs, yellow, gray, and red male-male jumper cables, and a breadboard on which all these would locate. The wired connection has been used to make it faster.

The circuit that prepared for this study is shown in Figure 3. We continue to improve this study for making wireless connection for the next versions.

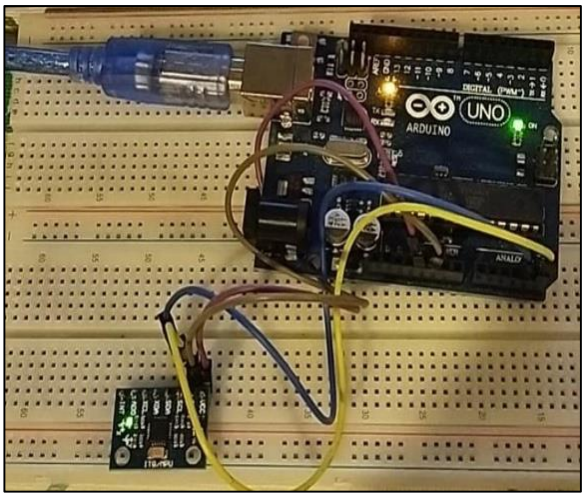

Figure 3. Circuit Elements

A *.ino file was created using the Arduino editor to read the angle values given to the breadboard with the use of the three-angle gyro sensor. In the Arduino code file;

- The MPU6050 IMU has both 3-Axis accelerometer and 3-Axis gyroscope integrated on a single chip,
- The gyroscope measures rotational velocity or rate of change of the angular position over time, along the X, Y and Z axis,
- The outputs of the gyroscope are in degrees per second, so in order to get the angular position we just need to integrate the angular velocity,
- To implement this, we used MPU6050_tockn.h and Wire.h libraries of the gyro sensor,
- The code block consists of two methods, setup, and loop,
- In the setup method; the serial communication channel opened, the port read rate was assigned as 9600 baud rate, and the assigned port was COM4. The MPU 6050 is automatically calibrated via the calcGyroOffsets function,
- In the loop method; It reads the three-angle data of the gyro sensor as X, Y, and Z angles from the serial port every 100 ms and writes it to the screen by putting comma between them,
- Because this study aims improvement of the patients' hand wrist movements, we don't need to use accelerometer data. For the further development, this capability can be integrated easily and provide a treatment alternative for the patients' arm disorders.

After the program is loaded on the Arduino card and opened at a 9600 baud rate, the angular values of the gyro sensor are read and written to the screen every 100 ms. You can find the detailed connection schema (Figure 4) and circuit design (Figure 5) below:

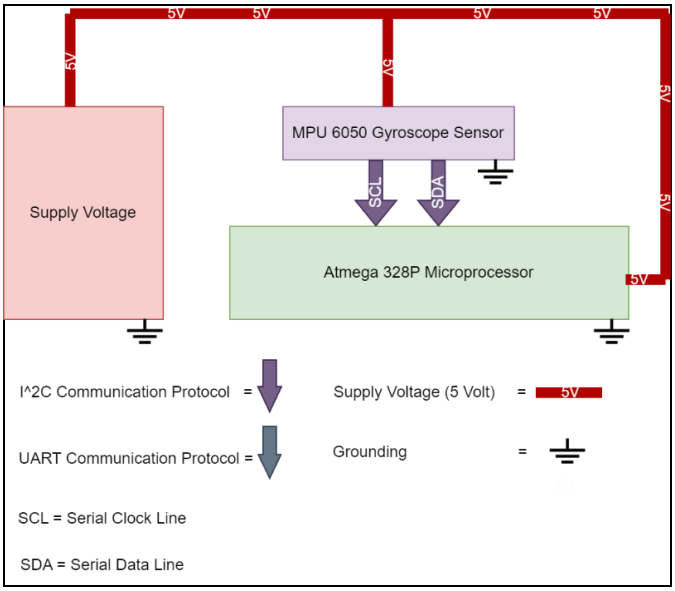

Figure 4. The circuit connection schema.

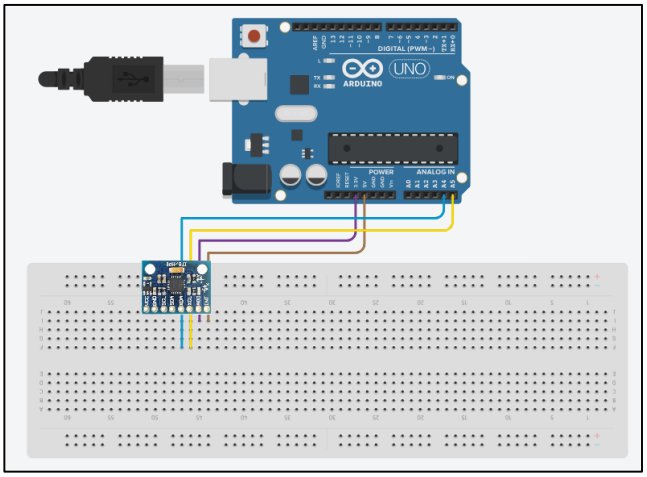

Figure 5. The circuit design.

These components are easily reachable and cost-effective items as shown in Table 2. Even we are still studying to improve this device to make it more comfort and user-friendly, we will keep the main components of this circuit. So there won't be more changes about the required budget for the next version.

TABLE 2
THE PREDICTED COSTS REQUIRED IN THIS STUDY

	The Item Used In The Circuit Design	Price (€)
1.	Arduino Uno Microprocessor	~32 € [13]
2.	MPU 6050 3 axis gyro sensor	~3 € [14]
3.	Breadboard (83.5mm x 54.5mm x 8.5mm)	~2 € [15]
4.	Cables (M-M Jumper, 200mm)	~1€ [16]
Total		~38€

3.1.2. 3D Game Development and Implementation

There are many alternative platforms for game development. Platforms such as Unity, Unreal Engine, Marmalade, and Buildbox are among the most preferred. According to Staiano and Flynn, using the videogames for balance, rehabilitation, and illness management could considered useful and funny [17]. According to Elor, et al., insights from the interviews, that they made around 130 interviews with therapists/physical therapists from mostly

California and New York, suggest that virtual reality offers great potential to improve physical therapists' skills and expand their scope of practice in rehabilitation, and health care through telemedicine[18]. Patients are more willing to complete the treatment. In our study, we decided to develop a game and use Unity since it is the most preferred platform, has many assets and source documents provided by the community, provides non-commercial opportunities, and has technical support forums used by a wide variety of audiences.

We used Windows 10 Enterprise operating system. As with many development platforms, the configurations you need to make during development may change depending on the version you use in Unity. The last consistent version at that time was 2021.2.3f1, and it has been preferred for development.

It is also possible to customize the development stages required for the game within itself. To develop a successful game, you need to create a consistent scenario of the game, design and draw the characters to use, gain the movement abilities of the characters both as drawing and code, create the game scene, design, and implement the game objects to be in this scene, give sound, light, and visual effects, etc. Many stages needed to be completed. In this study, since our aim is not to develop a game in a professional sense, free templates that are already offered at some resources were used. It is possible to access quite a lot of characters and environment design libraries through the asset store, which can also be accessed from the Unity editor, especially for character designs, and you can easily download these designs from the Package Manager and import them into the game.

First, we tried to develop an augmented-reality-supported animation-based game alternative shown in Figure 6. It was similar to a dart game. However, it didn't work synchronously with the circuit.

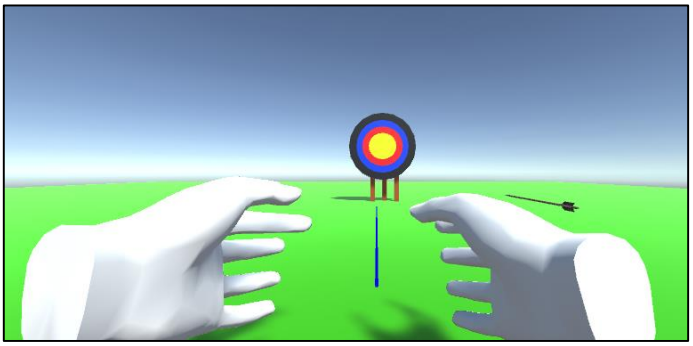

Figure 6. The developed augmented-reality-supported game trial

So we decided to develop a 3D game with serial port communication. A gold collection game with an interactive car with wrist movements has been prepared to treat wrist disorders.

The game starts with an object selection, a standard car option. When the user lowers his wrist while it is parallel to the ground, the car game object will move in the forward direction, by moving his wrist to the right and left, the car game object will change direction in the same way. With the gold collected in this way, the user will be able to choose other car options among four options. In this study, the basic functions and configurations that support physical therapy movements for wrist movements related to the developed 3D computer game will be emphasized. Visual details will not be entered.

During the preparation of the game, Arcade Free Racing Car, Kajaman Roads, Joystick Pack, and Gold Coins assets were downloaded from the asset store and imported into the project.

The most critical step of the game is to read the data coming from the serial port in a meaningful way in the game environment. For this task, Unity and Visual Studio work together. There are many programmatic activities in the game like controls, conditions, transitions between scenes, etc. For many steps, Unity needs scripts written in Visual Studio. For consistent data read from the serial port, System and System.IO.Ports libraries must be used in Visual Studio. To do this, the Player Settings screen opens via File-> Build Settings->Player Settings. There is an "Other Settings" title. The configuration must be set like Figure 7. Below the "Configuration" part, "Scripting Backend" should be selected "IL2CPP", and "Api Compatibility Level" should be selected ".NET Framework". The other settings are the same. Only in this way, the System.IO.Ports library can be activated on the Visual Studio platform.

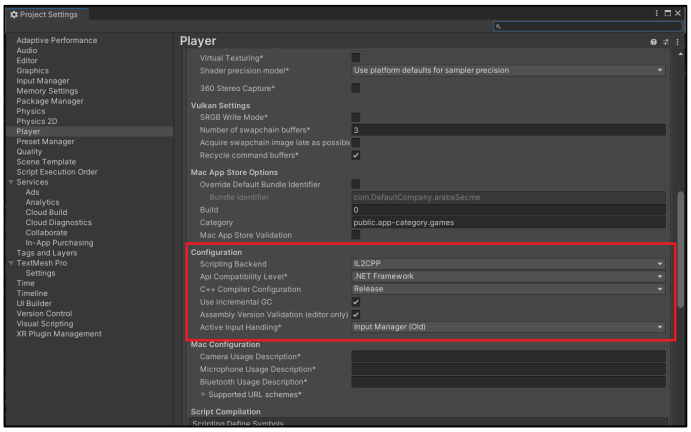

Figure 7. Player Settings Configuration Editor

Prefab allows you to save the current properties of a completed game object, use it later, change it, and automatically make changes at once at all the points you use prefab. Like working with templates. We can list prefabs in the Project tab in the Unity Editor. We can move the prefabs, listed in the Project tab, to the scene or hierarchy part by drag and drop.

There are different road, landscape, and car options in the selected asset packages. There is also a prefab in the car asset package where the colliders of the wheels are defined. Collider is a feature that allows us to use the physical features of the game object with the Rigidbody feature, together with the Unity physics engine capability. With this feature, game objects can pass through each other, gain mobility, etc. A collider unspecified prefab was chosen to provide more comfortable control. This asset consists of four wheels and a body. The body includes a Rigidbody property, and the wheel collider property is assigned to each wheel. With these essential configurations and the script to be created, we can give the wheels rotation and other movements.

The canvas component is used to show stable objects on the game screen. We used canvas to show a joystick, the amount of collected gold, and buttons for turning the main menu and exiting the game. To simulate the progress of the car, we desire to add a joystick to the game screen. The downloaded asset for the joystick should be imported into the project as in the previous objects. All these stable views should be sub-objects of the canvas.

The gold game object that should be in the game scene is also imported into the project. On the Inspector tab, the tab where the properties of the game objects are listed, the tag of the gold game object is defined as "gold". By the definition of all game objects will make the code and object management more controlled. Since the gold object will be created and deleted regularly in this game, it will be called by the code with the related game object tag. The components used in the game scene are seen in Figure 8.

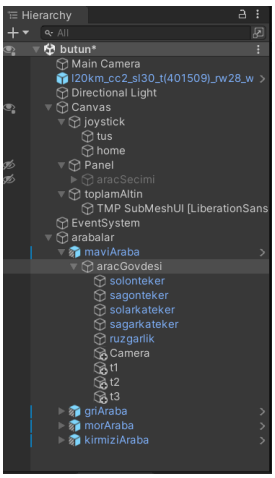

Figure 8. Main Scene Game Objects List in the 3D Game

The primary function defined in the game performs by the script file assigned to the car. Due to the car selection capability in the game, similar scripts have been defined in other car game objects. It can be seen in Figure 9 where Rigidbody, Box Collider, and Scripts are defined on the car body.

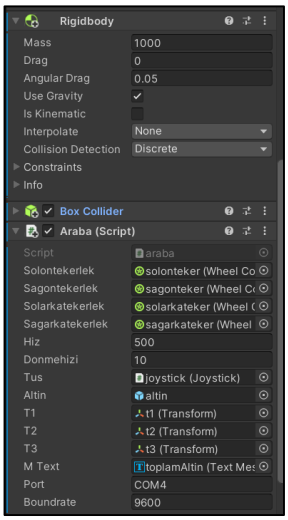

Figure 9. Car Game Object Configurations in Inspector Tab

Scripts can also be created by choosing a script file under the project folder view, Project tab, or by selecting the “Adding a New Script” choice in the Inspector tab, where the relevant object properties are listed. Double-clicking on the relevant file will switch to the Visual Studio platform. Coding is done using the C# programming language. The class is opened with two standard methods’ templates, “Start” and “Update”. In the Start() method, it is necessary to define the opening of the serial port, which will be done once. Since the codes related to reading data will be a recursive process, it should be written into the Update() method.

Libraries and variables related to reading data from the serial port should be defined in the "araba" script file. Another important point here is that the SerialPort(string port name, int baud rate) method should be entered with the values as SerialPort(“COM4”, 9600) that are compatible with the code written in Arduino. The flow charts for reading data from the serial port can be seen in Figure 10 and Figure 11.

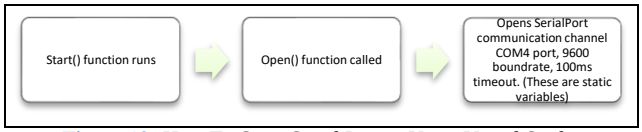

Figure 10. How To Open Serial Port in Unity-Visual Studio

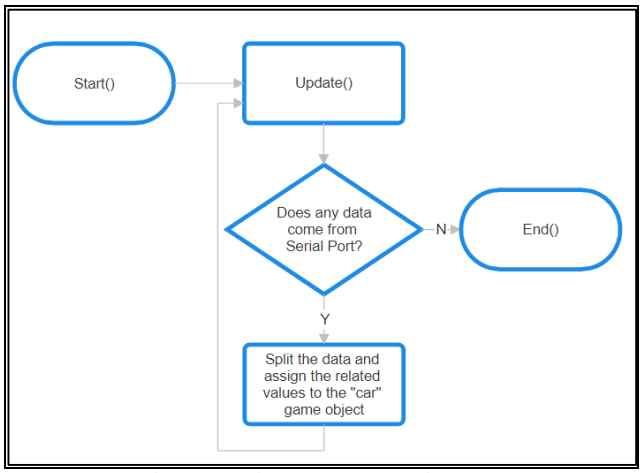

Figure 11. The flow chart of the receiving data from Serial Port process

With the car game object moving with the data from the three-angle gyro sensor, the user will make flexion, extension, and radial-ulnar deviation movements to treat wrist disorders while playing the gold collecting game. The car will move forward with flexion movement, back with extension movement, and right-left with radial-ulnar deviation which can be seen in Figure 12.

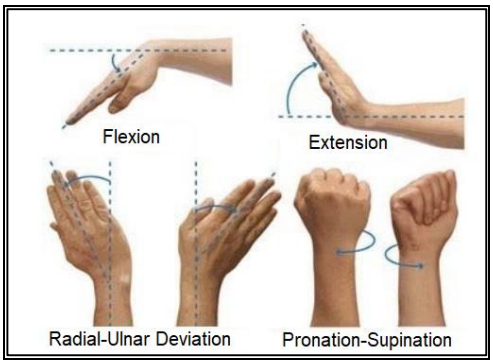

Figure 12. Physical Therapy Movements For Wrist Function Disorders [19]

The players start with the screen seen in Figure 13-a.

Figure 13-a. Start screen for the 3D Game

Figure 13-b. The main game screen of 3D Game

This study has a game view as seen in Figure 13-b. There is a car game object that can be moved by the user's wrist movements. By this way, the user can gain gold and can change the car game object choice. To switch the screens or change the car choice, the user has to use mouse control.

Figure 14. Car options screen.

After the users collected some gold, they can select the other car options, which can be seen in Figure 14.

4. CONCLUSION

There are many people that experienced various physical disorders. As the reviews show us, the number of people who needs physical therapy treatments is increasing day by day [1]. Also, we can see the results that the patients and the physical therapists have preferred game-based treatments or telehealth since Covid-19 according to Staiano and Flynn [17], and Elor, et al. [18]. The addition of game-based components to the tool enhances the interaction and enjoyment of physical treatment. Patients are more likely to remain motivated and involved throughout their rehabilitation process by having games in therapy sessions. Games offer patients a fascinating and engaging setting that diverts them from potential discomfort and boredom. This improves adherence to prescribed activities and makes therapy fun [20].

There is great potential for improving the rehabilitation process with the development of a device built with electronic infrastructure for Bluetooth communication with a computer and the ability to let patients play games while receiving physical therapy for wrist disorders. This technology improves patient engagement, motivation, and compliance while incorporating interactive games into therapeutic activities, resulting in more efficient and fun wrist rehabilitation. Besides these positive sides, unfortunately, these new-generation solutions require a high budget. The physical therapy clinics which decided to use this kind of tool have to pay purchasing budgets and monthly game renting prices. This study aims to show that the budget required to manufacture this tool is not as much as what clinics pay to own these technologies. Production and presentation of original, interesting game choices are essential.

In this study, we showed the current game-based treatment choices and the request for these new treatment methods. We compared their capabilities and budgets. After that, we described our development of a tool that provides physical therapists and wrist disorder patients with an enjoyable, effective, and affordable alternative to treatment. In this version of the study, we used communication with wire. By integrating electronic infrastructure, Bluetooth technology enables easy communication between the tool and a computer. Since real-time data transmission and remote monitoring are made possible by this connectivity, healthcare providers are better able to monitor the progress of their patients and promptly alter their treatment plans. The tool's flexibility and utility will be increased by the wireless and adaptable interface that Bluetooth connectivity offers [21]. As Karagedik et al. showed us in their study, there are different items available to make a connection both Bluetooth and wireless connections [22]. They are also showing these technologies performance measurement in their study. We have the awareness of the wireless usage effect so we are continuing the improvement of the tool. We are planning to develop more game choices, detailed reports for patients and therapists, and compact design for our study's further versions.

By developing these new-generation technologies inside the country, we won't have to spend more money for providing these capabilities from abroad. In this way, the clinics, the physical therapists, and the patients can reach these types of technologies more easily and it will be easier and cheaper to take technical support also it won't need high budgets as today to subscribe to the game offers. Thus, improvement and advancement in new technologies will motivate new developers and investors.

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