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Pomodoro, a Mobile Robot Platform for Hand Motion Exercising

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***Abstract*— According to the *World Report on Disability*, currently 93 million children experience some kind of moderate or severe disability. Several systems including motion capture, serious games, exoskeletons and robotics have been researched and developed for assisting them on recovering basic functionality and daily activities, thus, improving mobility and providing a better quality of life. The popularization of these tools is a challenging task due to the required technical knowledge and the high acquisition costs, yet, the field of didactic robots is growing as an alternative that can be used in education, research, entertainment and other scenarios. This project proposes the development of the *Pomodoro* mobile robot as a device for encouraging hand motion exercise through flexion/extension and ulnar/radial deviation movements, for teleoperating the system in users experiencing reduced hand mobility. The system is composed of a low cost non-holonomic robot controlled with an embedded smartphone for on-site interactions through speech, image recognition and touch controls, along with a complimentary hand motion tracking subsystem for teleoperating the system using both real and virtual system, while recording position and orientation data for further assessment.**

I. INTRODUCTION

Moderate or severe Mobility disabilities negatively affect how people perform tasks on a daily basis, thus, reducing their quality of life. According to the World Health Organization (*who*) [1], around 93 million children are suffering some sort of disability. To aid them, assistive technologies involving robotics [2] and virtual reality [3] are becoming widely used as means for improving motion recovery, physical training and therapy. However, even though *e-health* trends are widespreading, the field of Human-Robot Interaction poses challenges due to the need of expensive hardware, large workspaces and advanced technical knowledge for adapting them to different scenarios [4]. These challenges are more notorious in cognitive sciences, where researchers may benefit from robotics and virtual reality, but are not motivated to adopt them due to the huge expertise and knowledge gap. To reduce the distance between researchers and technology, current advances in robotics platforms and virtual reality have focused on abstracting the hardware of the robot by providing high-level programming languages and computer generated environments for more immerse and realistic interactions. The development of these systems is helping to overcome the challenges of integrating image, video or speech processing methods in assistive systems that aid therapy processes for children that suffer from motion disabilities. These systems must provide an interaction mean that allows the user to perform the required sequences of motion while playing with the device, which provides training and entertainment at the same time [5].

Among the current trends in user interfaces (UIs), there are the three dimensional UIs, also known as 3DUIs, which allow the user to interact through natural movements or gestures [6]. Some 3DUI devices have used inertial sensors, and became popular due to the improvements of videogame controllers, such as the Wiimote [7]. The current research on 3DUI focuses on non-invasive or minimum-invasive devices, some being based on image processing such as the Kinect [6], on stereo vision such as the LeapMotion [8], on ECG signals such as the EPOC EMOTIV [9], and myography sensores such as the MYO [10]. These devices are being subject of study for various areas, since their affordability, available SDKs and prospects interest researchers and enterprises [6].

In the physical therapy area, devices like the Kinect, Wiimote and even the Leap Motion are being used as interfaces for rehabilitation games, as they increase the sense of immersion and interaction, allowing to overcome obstacles such as the lack of interest, the difficulty for exercising, the lack of quantifiable measurements of motion, and the lack of motivation [11][12][13].

In the robotics area, the cost of didactic kits is decreasing, which encourage their adoption for aiding the development of motor and analytical skills. These robot kits are complementing educational syllabus through elementary and high school [14][15][16].

This project presents the proposal of the Pomodoro mobile robot system, whose goal is to encourage users suffering from reduced mobility to engage in therapy by taking advantage of their proxemics space [17]. The system is composed of a non-holonomic platform and a smartphone with a virtual system, both controlled through hand motion tracking offering an interactive solution for performing motions. Thus, while the user is distracted teleoperating the Pomodoro, the motion data is captured for later assessment with a healthcare professional.

II. SYSTEM DEVELOPMENT

The proposed system's main goal is to encourage the motion of the upper and lower members whether for devel-

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oping motor coordination, for rehabilitation, or simply for entertainment. To this end, the interaction with a mobile robot is accomplished by hand gestures, since users often used hands to interact with the environment [18]. Since the cost of acquiring and maintaining a mobile robot is still expensive, the system was designed with a complimentary 3D virtual environment, which does not requires the physical robot, but allows connectivity with the real robot if available. Therefore, two main scenarios of interaction are possible: one where the user teleoperates the virtual Pomodoro robot through and open and a maze scenario; and the other where the child teleoperates and follows the robot within his or her proxemics space, as presented in Fig. 1.

Additionally, there are two modes for interacting with the robot. The "manual mode" allows the user to control the wheels speeds with his or her gestures, and focuses on hand motions that allow exercising the hand's muscles and ligaments by requiring the user to maintain the same gesture accordingly to recommendations by a healthcare specialist. The "automatic mode" allows the user to inform where the robot should go within a chessboard-like environment, which results in gestures with shorter maintaining spam that are useful for preventing musculoskeletal disorders[19]

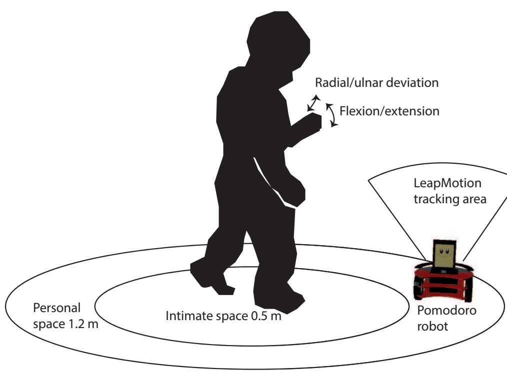

Fig. 1. Proxemics diagram of interaction.

A. Materials

For hand recognition, the Leap Motion gesture tracking device was chosen, as it tracks finger and palm position and orientation using stereo vision, provided by its two high speed infrared cameras. The detection and accuracy depends on the amount of light and the position of the fingers facing the tracker, the device can detect the position and orientation of the center of user's palms (*pitch*, *roll* and *yaw*) in 3D space, thus allowing the system to translate hand gestures into suitablecommands for the robot to execute.

The robot is designed for allowing interactions through a smartphone and hand tracking subsystems, that allows achieving a low-cost system of small size that avoids the need of large operational spaces, a mechanical structure composed by flat pieces for easy replication, rounded and safe shapes to prevent any harm on the user, light structure for easy manipulation, friendly appearance, explicit or implicit verbal or non-verbal communications with the user, and embedded processing for portability with remote access.

The remote control software was created using Processing 2 [20], which provides an extension of Java language and a simple integrated development environment to create interactive programs with 2D and 3D output. Furthermore, Processing 2 is open source and multi-platform, thus the remote control software is both affordable and flexible, since there is no cost to configure the software environment and users can modify the software to meet their requirements.

B. Hand Tracking

The human hand is composed of 22 Degrees of Freedom (DOF) that offer the ability of performing several grasps, for executing different tasks and interactions with the environment and other people [21]. The human hand tracking problem have been addressed from several solutions involving haptics [22], such as gloves involving optical fiber sensors [23], conductive fabrics [24], strain gauges [25], and even exoskeleton mechanisms [26]. These solutions require the user to wear some sort of glove-like device, which poses challenges in which the user may not be able to properly wear them or sustain their weight due to his condition. This issue can be addressed by using current trends in 3DUI where non-invasive devices allow motion capture from image processing algorithms. From analysing three probable solutions for the proposed system, Microsoft's Kinect was rejected due to its size and need for wired power supply, web cameras were also rejected as their tracking capabilities depend on camera resolution and the effectiveness of the algorithms to obtain as much 3D information from a 2D image. Finally, the Leap Motion device was chosen as the appropriate solution given its tracking comparabilities from three infrared sensors, power supply over USB and portable size.

As part of providing more scenarios for using the Pomodoro robot, the Leap Motion user interface is used for providing means to teleoperate the platform using JavaScript and websockets. The goal is to allow a remote user to interact with the robot in scenarios were he or she does not have access to the device. This interaction is configured as presented in Fig. 2.

The Leap Motion is capable of recognizing both hand and fingers, however its tracking prone to errors when the hand and/or fingers are occluded, or when there is no line-of-sight between the aligned fingers and the sensor (e.g. a perpendicular palm position to sensor) [27]. The interaction is configured accordingly to finger detection and motion. Pomodoros eyes are configured to respond to the detection and motion of the index finger motion as presented in Fig. 2. The robot's movements are controlled by the position and orientation of the user's hands.

C. System Architecture

As mentioned on Section II, the proposed system provides means for controlling both real and virtual robots through

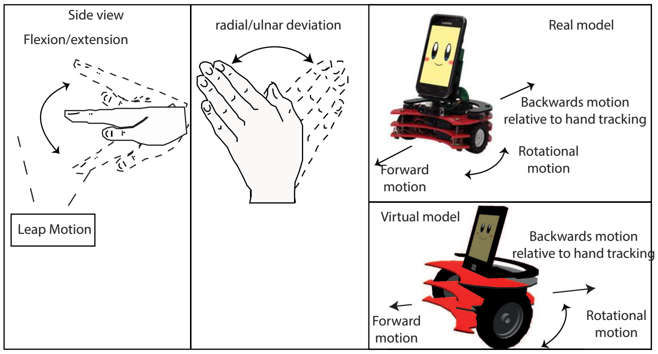

Fig. 2. System overview.

hand gestures. The information flow starts with the user performing the predefined gestures, presented on Section II-B. These gestures are recognized by the Leap Motion device, which can be connected to either the computer or the mobile robot with open source electronics, such as the Raspberry Pi, and converted into position $p = (x, y, z)$ and orientation $\omega = (\alpha_{\text{roll}}, \alpha_{\text{pitch}}, \alpha_{\text{yaw}})$. The gesture recognition then translates p and ω into user commands ("*go straight ahead*", "*go back*", "*turn to the right*", etc.) for the controller. Finally, the controller activate both the real and virtual robots according to the selected mode. For the real robot, these activation commands are given as its wheels speeds; for the virtual robot, they are given as the model's transformation matrix. In addition, the software takes advantage of the smartphone's touch screen and voice synthesis to draw the user attention whether by changing its "face" or by reproducing predefined phrases.

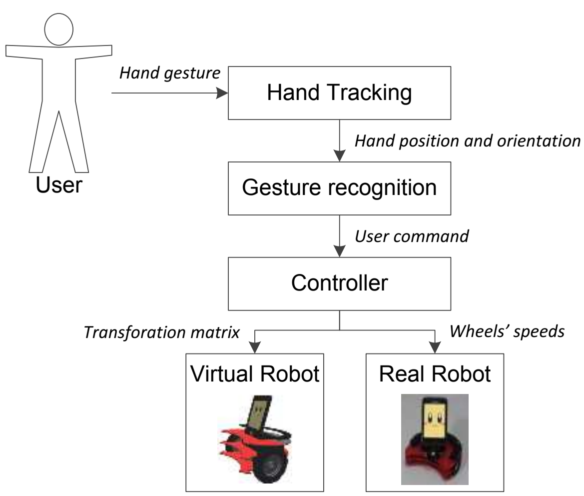

Fig. 3. System architecture.

A more detailed system architecture, which refers to the used hardware, is presented in Fig. 4, where two modules can be seen, one integrating the hardware for activating the motors and sensor readings along with the smartphone whose role is to control the robot. A supervisory subsystem is implemented for monitoring the eight infrared reflective sensors used to prevent falls, a infrared distance sensor for obstacle detection, motor actuators for the wheels and for the smartphone levelling mechanism. It is worth noting that the supervisory system is not fully autonomous, it receives commands from the smartphone through a Bluetooth connection.

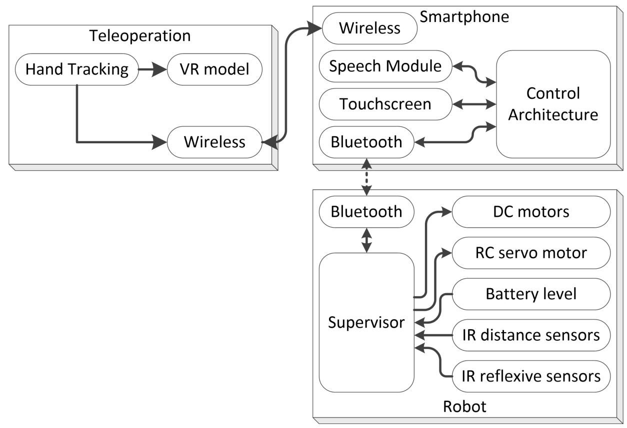

Fig. 4. Hardware architecture.

D. Kinematic Control

To move the Pomodoro robot within the chessboard environment, a controller capable of guiding it on the two-dimensional plane is required. Pomodoro adopts a differential drive system, whose kinematics model is well known and thoroughly discussed in [28], and can be described as axis and rotation speeds in the global frame as $(\dot{x_c}, \dot{y_c}, \dot{\theta})$.

The kinematic model allowed developing a controller that enables the robot to move from an arbitrary position C on the workspace to a goal given by the point $M = (x_M, y_M)$. Knowing the orientation of the robot and the coordinates of C and M, it is possible to determine the distance error d_e and angular error θ_e, determined using Eq. (3).

$$\Delta_x = x_M - x_C \tag{1}$$

$$\Delta_y = y_M - y_C \tag{2}$$

$$d_e = \sqrt{\Delta_x^2 + \Delta_y^2} \tag{3}$$

$$\theta_e = -\theta + 2 \arctan \frac{\Delta_y}{\sqrt{\Delta_x^2 + \Delta_y^2} + \Delta_x} \tag{4}$$

Considering that the robot has a maximum linear velocity v_max and is able to slow down with an acceleration a, it is possible to determine both the speed at with which the robot must move to reach the goal, as the distance d_a with which he should begin to decelerate. The distance d_a is given by Eq. (5) as follows:

$$d_a = -\frac{v_{\max}^2}{2a}, a < 0 \tag{5}$$

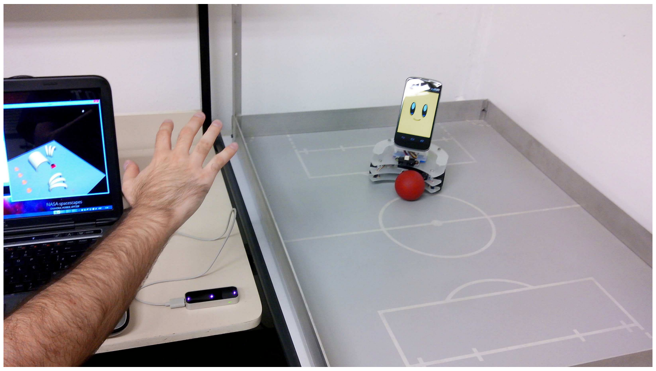

Fig. 5. Real environment for a simple soccer game.

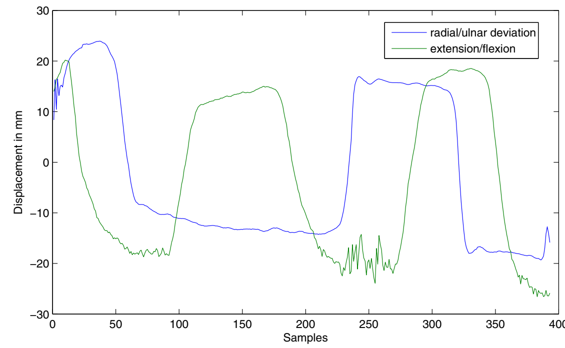

Fig. 6. Flexion/extension and ulnar/radial deviations motion capture.

To determine a control (v_c, ω_c) that stabilizes the errors d_e and θ_e to zero, the control law described by Eq. (5) - (6) is used.

$$v_c = \begin{cases} v_{\max}, & d_e > d_a, |\theta_e| < k_1 \\ v_{\max} * \frac{d_e}{d_a}, & d_e \leq d_a, |\theta_e| < k_1 \\ 0, & |\theta_e| > k_1 \end{cases} \tag{6}$$

$$\omega_c = k_2 \cdot \theta_e \tag{7}$$

where k_1 is the minimal angle error accepted for the robot to move linearly and k_2 is the angular speed gain. With this control, the robot moves only when the error θ_e is less than k_1, which prevents the robot from moving more than the necessary to achieve its goal.

III. Results

The onsite and teleoperation modules were developed using the open-source programming language Processing, whose capabilities are sufficient for developing the intended application. Processing have been widely used in several scenarios regarding robotics as its platform is available for everyone. It offers compatibility and flexible features that makes it a suitable tool for the affordable solution proposed in this project.

A. Open Space

To verify the proposed system controlling the real Pomodoro robot, a simple, single-player soccer game. The objective is to guide the robot to the red ball and thereafter to the given goal, as shown by Fig. 5, so that the user can develop his or her dexterity while maintaining a gesture for some time. This test was also performed to configure the controller constants and to determine whether the delays associated with the data acquisition, processing and transmission to the robot would interfere with the robot's manoeuvrability.

The controller configuration was satisfactory, as it allows the robot to perform smooth curves in slow speeds, which is ideal for a small robot such as Pomodoro. Also, although the Bluetooth connection to the robot imposes a 20ms delay, it does not deteriorates the robot control in slow speeds.

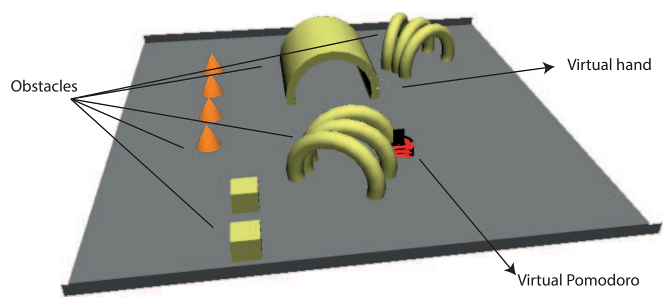

Fig. 7. Virtual environment for navigacion and Pomodoro control

B. Virtual Space

The virtual test was developed using the CAD models from the Pomodoro, these were imported intro Processing using the saito OpenGL library along with the LeapMotionP5 library. The interactions for moving the Pomodoro forward, sideways and its rotation were programmed accordingly to the detection of the user's palm. Ranges of motion were configured relative to the origin of the LeapMotion's coordinate system. Motion captured from performing flexion/extension and ulnar/radial deviations are presented in Fig. 6.

The hand inputs were mapped onto the virtual Pomodoro so the user could control the robot while the data was being saved for further analysis and assessment from the healthcare specialist. For the virtual navigation an obstacle-based circuit was developed and imported, so the user requires to perform hand flexion/extension and ulnar/radial deviation in order to succesfully navigate through the path. The visual feedback provided to the user is composed of the circuit, the Pomodoro and the tracked hand as presented in Fig. 7

IV. Conclusion

Robotics applications usually rely on traditional computer interfaces to control or program a mobile robot. To allow disabled children to use such applications, off-the-shelf AT must be used to adapt them to the children needs. However, if the inclusion of children with disabilities is considered while designing an application, then the resulting product could be easier to use than an adapted product.

Based on that idea, this project proposes a teaching environment that considered the inclusion of children with motor disabilities during the project's conceptual stage. Therefore, the resulting application provides different means for controlling the mobile robot, which does not rely on a single interface, such as the computer keyboard or mouse. Other goal of the proposed inclusive environment is being low-cost and flexible, which led to the adoption of entry-level PC or smartphone as the computational base, and the employment of Leap Motion gesture recognition. This may ease the replication of this environment on schools or hospitals, since it can make use of available infrastructure.

On future works, the voice interaction will be considered to motivate children while they perform their exercises. Also, to improve the robot controller, the harmonic potential field navigation technique will be implemented.

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