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Proposal for Natural Human-Robot Interaction through the Use of Robotic Arms

Giovanni Leal-Cárdenas, Germán Medina-Niño, Fernando De la Rosa
Systems and Computing Engineering Department
Universidad de los Andes
Bogotá, Colombia
{eg.leal2132, gd.medina2889, fde}@uniandes.edu.co

Abstract—**The study of the ways in which humans interact with robots is a multidisciplinary field with multiple contributions from electronics, robotics, human-computer interaction, ergonomics and even social sciences. The robotics industry is mainly focused on the development of conventional technologies that improve efficiency and reduce the amount of repetitive work. To achieve this, enterprises must train their technical staff to accompany the robot when performing tasks, during configuration and technical programming for proper operation. Taking the latter into account, the development and creation of unconventional interfaces for interaction between humans and robots is critical, because they allow for a natural control over a robot to generate wide acceptance and massive use in the performance of a wide range of possible tasks. This paper presents the challenges in the design, implementation and testing of a hand-based interface to control two robotic arms and the benefits of this technology that is between robotics and human interaction.**

Keywords-Robotic arm, Human-Robot Interaction, gesture-based commands, hand-based interface.

I. Introduction

Currently, the use, implementation and programming of robots in the small business and domestic environments have been associated to an unfavorable cost-efficiency ratio. This factor is regarded as the main obstacle against the popularization and promotion of the advantages of robots among the general public. Taking into account machines that can be controlled using gestures or that enable a natural interaction in order to perform and repeat tasks of daily life, without the intervention of a professional or the requirement of technical knowledge can be the differentiating factor that allows the massive entry of robots to small and medium businesses as well as domestic environments. Other proposed research directions include the use of the gestures as guidelines for autonomous devices but, in this case, the perception of the environment and planning is delegated to a human [1].

This paper presents the process of design, implementation, testing, and benefits of a hand-based interface that enables controlling two robotic arms. All test iterations were designed with the aim of improving the precision of the system and reducing the perception of discomfort that any user may manifest.

II. Problem of Interest

The robotics industry is preparing itself for a new business opportunity made possible by new affordable technologies, the domestic market. However, the fact that electronic agents cannot be used universally prevents the industry from promoting and selling them to the average consumer. Fortunately, the challenge of producing a robot that adapts to an untested environment is no longer an issue; for example, the Roomba robot vacuum cleaner manufactured by the American company iRobot [2], has been often compared to a pet due to the low level maintenance that it requires. This example also shows the unawareness of users regarding the pieces of equipment they acquire, making it the most remarkable success story in the industry by sales and being the sole example in this market.

A proposition has been made to simply offer the public nonspecific-use robots at margin prices in order to see what the consumer would do with them. At first glance, this looks like a move from a desperate industry trying to get a market share without the importance of solving a real problem, in other words, a capitalist move for a capitalist society. However, it is a deeper well taught step. After seeing the evolution of the Makerbot Replicator 3D-printer, that was initially conceived without a target market and, as shown in an architectural publication [3], created for the sole purpose of designing structures but ended up having unintended uses, it is evident that the eye of the consumer is the one that has the real potential to exploit the capabilities of such a product. The latter could be looked at as an opportunity which confronts companies to revise one of the biggest challenges of the industry, Human-Robot Interaction (HRI). If the average consumer has to find a way to use an advanced piece of electronics in his/her daily live, the interaction between them must be seamless to facilitate its use.

The implementation of new interfaces for interaction between humans and robots proposes several unique challenges to the systems being developed. The problem addressed in this paper is to develop an unconventional interface to control two robotic arms in order to enable the user to perform tasks near the arm's workspace or from a remote workspace because of security reasons.

The developed system must adhere to certain restrictions besides working properly and differentiating itself. The first constraint is economic in nature and is one of the necessary requirements to build a project that differentiates itself from those that are currently on the market, therefore, the budget of the whole device should not exceed US$500. The robotic arm OWI provides the second limitation. The budgeted hardware moves using DC motors, which are operated by pulses of current in one direction for each degree of freedom. These motors, unlike servo or stepper motors, have no way

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to know the arm's position. For this reason, the system is command-based.

III. RELATED WORK

Regarding the natural interface, the proposed project focuses on the ease of configuration and the intuitive implementation of such systems (without the need for writing code). Danish company Universal Robot [4] and Rethink Robotics robots [5] have proposed approaches to this premise. These two companies focus their efforts on the ability of the robotic arms to maintain a state of neutral gravity. The operator can guide the system and point out what locations should be reached sequentially, without learning about its functioning, so it is an interesting contribution to the line of assembly technology. The mentioned technologies describe a promising future and provide improvements for the use of robotic arms in medium-sized industries; nevertheless, they do not consider the cost-benefit limitation nor the implementation of an implicitly natural interaction.

The Leap Motion device has been used in several other HRI projects. For instance, the Pomodoro is a platform that integrates the Leap Motion to control a mobile robot with the goal of rehabilitating children with reduced hand mobility in a didactic manner [6]. This work exemplifies the range of applications that are possible by using a natural interface between a human and a robot. It also highlights the importance of studying the factors that improve this experience and make it viable for the general public. Another sensor that has been a disruptive technology in commercial and research fields is the Microsoft Kinect [7], where the human body is meant to be the controller. This sensor provides a high level of precision that boosts its capabilities as an input device in fields as virtual reality, augmented reality and, clearly, HRI.

IV. PROPOSED NATURAL INTERFACE

The following section describes the materials, concepts and architecture used to build the system of two robotic arms controlled through a natural interface, with the capabilities of remote control via WEB protocol.

A. Components

The movement of the hands and fingers of the user is captured, in real time at a frequency of 120 fps, through only one Leap Motion device [8]. Then, a computer processes this information. If the user generates a gesture or places a hand over a limit, it triggers a command and sends it to one of the two Arduino that serve as controllers of both robotic arms (each Arduino related to a specific arm). Each Arduino is attached to an Adafruit Motor-Shield [9] that sends electrical signals to an Owi robotic arm that can be moved according to the user's movements (Fig. 1).

B. Hand position tracking

A software component was developed to track the user's hand position, gestures and if it is the right or the left one, on the Processing platform that uses the Java language.

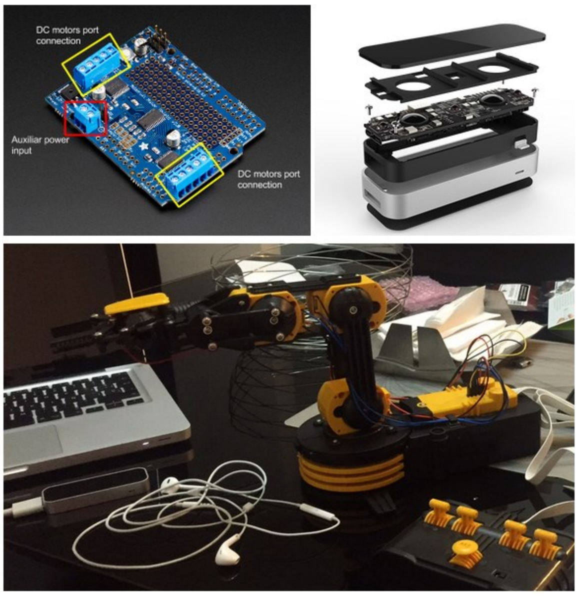

Figure 1. (Top left) Adafruit Motor-Shield. (Top right) Explosion view of the Leap Motion peripheral. (Bottom) Assembled OWI Robotic Arm.

The Leap motion interface provides real time position in the three conventional axes as well as the other needed aforementioned information (Fig. 2). This information is analyzed whether or not it activates a trigger that sends a command to a robotic arm depending on the hand that is being used. The triggers are conditional statements defined if a hand trespasses a limit.

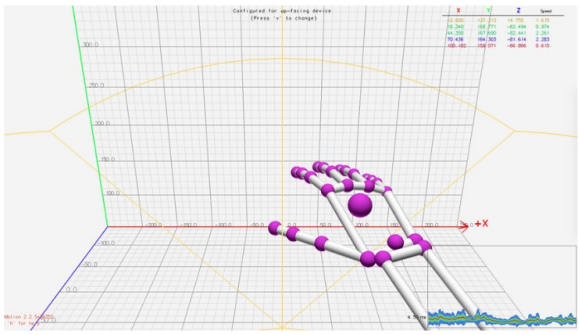

Figure 2. Real time position visualizer provided by the Leap Motion API.

The Leap Motion input interface enables the interaction between the user and the robotic arms by capturing the motions and gestures made by the user's hands. The developed software receives the information of the motions and gestures in real-time and then processes it according to the commands presented in the function below (Fig. 3). These commands depend on the hand being used (right or left, which the Leap Motion can detect on its own) as well as on the position of the hand over the X, Y, and Z axis, defining (0, 0, 0) as the center of the space. Additionally, hand gestures made by the user are taken into account. In the case that any of these triggers is detected, the corresponding command is sent to the Arduino board, which is responsible for sending electrical signals through the Adafruit Motor-Shield to move a robotic arm according to the user's motions and/or gestures. All of these factors determine the first letter of the command (R for right or L for Left) and a number corresponding to a selected ASCII character.

$$command = \begin{cases} left\ hand \begin{cases} L111\ \ if\ \ circle\ gesture\ is\ detected \\ L105\ \ if\ \ fist\ is\ closed \\ L100\ \ if\ \ x > 120 \\ L97\ \ if\ \ x < 30 \\ L119\ \ if\ \ y > 160 \\ L115\ \ if\ \ y < 90 \\ L103\ \ if\ \ z > 95 \\ L116\ \ if\ z < 115 \end{cases} \\ right\ hand \begin{cases} R111\ \ if\ \ circle\ gesture\ is\ detected \\ R105\ \ if\ \ fist\ is\ closed \\ R100\ \ if\ \ x > 120 \\ R97\ \ if\ \ x < 30 \\ R119\ \ if\ \ y > 160 \\ R115\ \ if\ \ y < 90 \\ R103\ \ if\ \ z > 95 \\ R116\ \ if\ z < 115 \end{cases} \end{cases}$$

Figure 3. Commands result of the processing of the information retrieved by the Leap Motion interface.

C. *System architecture*

Next, the overall system architecture developed and the integration of its various components, both software and hardware, are described. The two developed architectures that facilitate user interaction with the robotic arms are also explained. These architectures allow the user to naturally interact with the robotic arms, either locally or remotely.

- *Local Architecture*

The local architecture configuration allows the user to perform tasks and have physical access to the robotic arms. The physical components of Fig. 4 are needed for this configuration.

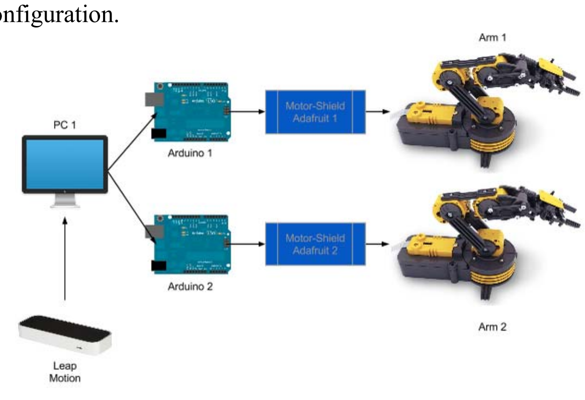

Figure 4. Hardware architecture for controlling both arms, operated locally.

The integration of two robotic arms with only one Leap Motion interface takes place and the user can control the robots through motions and gestures provided by his/her hands. The necessary adjustments were made to recognize each hand with the Leap Motion interface; this means that the Leap motion recognizes the movements of both hands and these are processed properly so that the arms move in an equivalent way. This architecture may be simplified to allow control of a single robotic arm with one of the user's hands.

- *Remote Architecture*

A remote communication platform for handling the robotic arms was developed, therefore, the user can interact with the robotic arms from any place in the world through an Internet connection. The development of this platform consists of a Client-Server architecture that uses a UDP communication protocol, which allows for fast communication due to the small size of the data packets (Fig. 5).

In the first instance, the connection between the client and the server is achieved, where the user enters the IP address of the server and the IP address of the client is also configured on the server side. This software is responsible for capturing information received by the interface, and building datagrams or data packets that will be sent to the server software where the arms are located through the preset connection. The server software receives the datagrams or data packets sent by the client software and then processes and sends this information to the Arduino Uno which also processes it thus enabling the arms to follow the movements executed by the user from the client software.

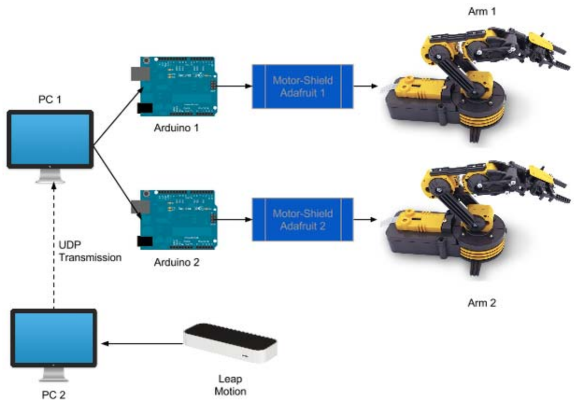

Figure 5. Hardware architecture for controlling both arms, operated remotely.

Under this architecture, a feedback with two cameras was necessary to provide the user with sufficient visual information. One camera is situated on top of the place giving a bird's eye view and the second camera is placed parallel to the arms compensating for the perception of depth. Together, these two cameras provide sufficient feedback to the user for a correct orientation as was tested in the third iteration described in the following section.

V. Methodology

The project was developed through incremental iterations, where solutions were provided to each one by adding new functionalities in the next one. The testing first iteration uses only one control arm in mirror and natural configurations. In the mirror configuration the user and the robotic arm are located one in front of the other, which created difficulties for the user related to location and guidance with respect to the arm (Fig. 6 Top). For this reason, a natural configuration is proposed where the robotic arm and the user are side by side and the robotic arm follows the motion of the user's hand (either the right one or the left one) (Fig. 6 Bottom). Ten users were selected and each one executed two tasks. The first one entailed picking up a pill and placing it in a cup; this was designed to test the level of precision of the gripper part of the robotic arm. The second task involved testing large continuous displacement of the arm in order to test how tedious it was to maintain a certain position of the hand over a prolonged period of time.

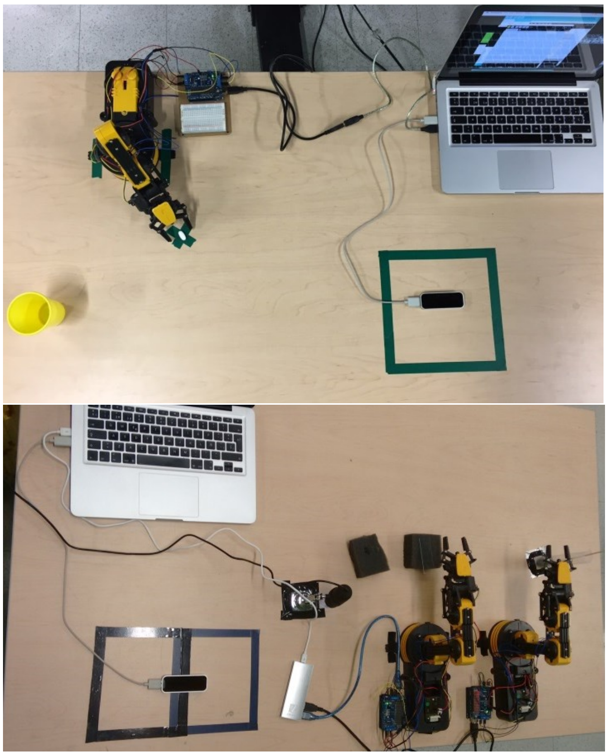

Figure 6. Arrangement of elements for the first iteration. (Top) Mirror configuration. (Bottom) Natural configuration.

In the second iteration, tasks with two arms are performed in both natural and mirror configurations, where the purpose is to evaluate the use of both arms simultaneously. Each user's hand controls a different robotic arm, so both robotic arms are able to move simultaneously (Fig. 7). The proposed task involved relocating different objects of laboratory equipment and interacting with them. The implementation of the task was posed as a sequential process thus aiming for a better interaction so that users felt that they were doing something interesting and productive.

In the third and final iteration, the task to be performed is the same one as in the second iteration but it was conceived to analyze the behavioral aspects of the tele-operated control of the arms (Fig. 8). Tests were designed so that the user may view the arms through a camera located frontally to the in front of them but the performance was significantly poorly compared to that using the natural configuration. One change regarding the setup of the robots is the camera placed over the system designed to give a bird-eye view and another one to portrait another angle. Another change is the setup where the user is able to see through the two aforementioned cameras as shown in the Fig. 10.

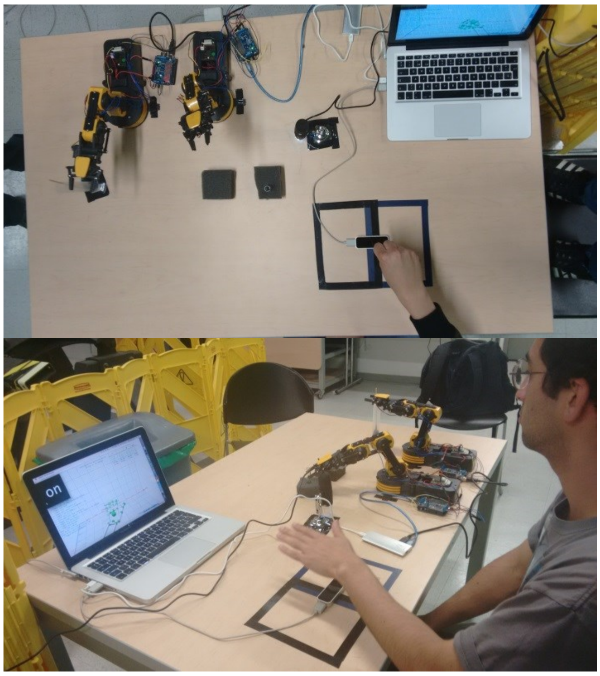

Figure 7. Arrangement of elements for the second iteration. (Top) Mirror configuration. (Bottom) Natural configuration.

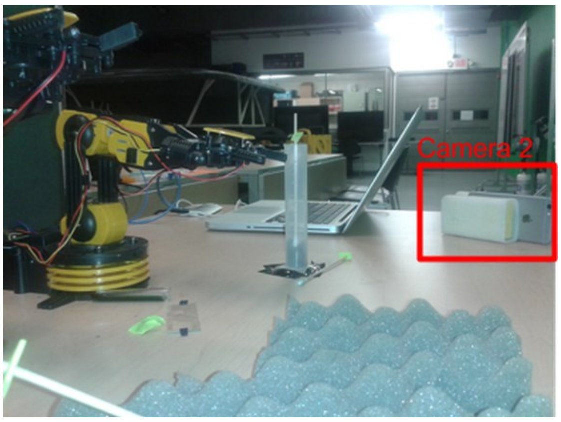

Figure 8. Experimental workspace: Arrangement of elements for the third iteration with a Web camera at the roof (bird's eye view) and a cell phone (camera 2) at one side of the workspace (natural configuration).

Subsequently, the time that a user needed to complete the proposed task is consolidated and classified for further analysis. Finally, it is noted that the technological limitations are an important factor when acquiring practical results, because the movement of the robotic arms using DC motors hinders some of the interaction with users. However, this behavior could be more natural if the robotic arms were composed of servomotors, which provide greater feedback from the movement.

VI. RESULTS

In the execution of the first task of the first iteration, users showed great interest in the developed system and made an effort to perform the exercises in the best way possible. Note that this is directly related to the complexity and usefulness perception that the user has about the task.

As shown in Fig. 9, the execution times dramatically lowered (40-65%) when users perform more tasks and become more familiar with the system. This learning curve tends to imply that processes are executed to be natural and easy to associate after trial and error. The time differences between the natural and mirror configurations always favored the natural one because the perception of depth played an important role in the performance of the tasks. Nevertheless, the second iteration was conceived considering the two configurations and it confirms the affirmation from the results of the first iteration.

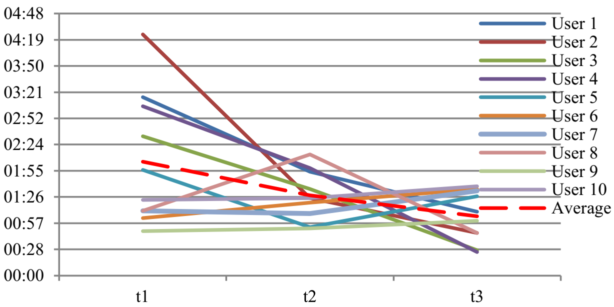

Figure 9. Time graph of Task 1 (Natural configuration) in the first iteration, repeated tree times and displaying a clear learning curve.

The second task of the first iteration is tedious and repetitive for users. They complained due to lack of real application of the procedures they were asked to execute. However, it was possible to identify the problem that was expected to be found considering the posed constraints. Unable to replicate the movements of the arm, due to technical limitations, users have trouble handling tasks requiring movement in different spatial axes simultaneously. This is noted and will be considered in future work, due to the impact that it represents in an application-level system in a real environment.

The results of the first iteration were assertive and the events that were foreseen to happen in the planning stages of the tests were identified. User perception was generally positive (Table I) and their recommendations are with respect to hardware, features and applications of the system, not the interface. Possible errors associated with the used tools such as times and measurements are negligible considering the magnitude of the average times.

TABLE I. RESULTS FROM USERS IN THE FIRST ITERATION (NATURAL CONFIGURATION)

User	User perception	Interaction with the system
1	Satisfactory	Normal
2	Satisfactory	Normal
3	Satisfactory	Hard
4	Satisfactory	Normal
5	Satisfactory	Normal
6	Unsatisfactory	Normal
7	Satisfactory	Normal
8	Satisfactory	Easy
9	Satisfactory	Normal
10	Satisfactory	Normal
Average	Satisfactory	Normal

In the second iteration the process was more focused and motivated because users were facing a task that had an actual application, the users felt they were doing something productive.

The same test of the second iteration was performed in the third one, where users complete a set of tasks handling laboratory instruments, but this time these tasks are performed remotely. In this case, the setup includes two workspaces: the user workspace where users perform tasks remotely (Fig. 10) and the experimental workspace where the robotic arms and the elements to be manipulated are located (Fig. 8).

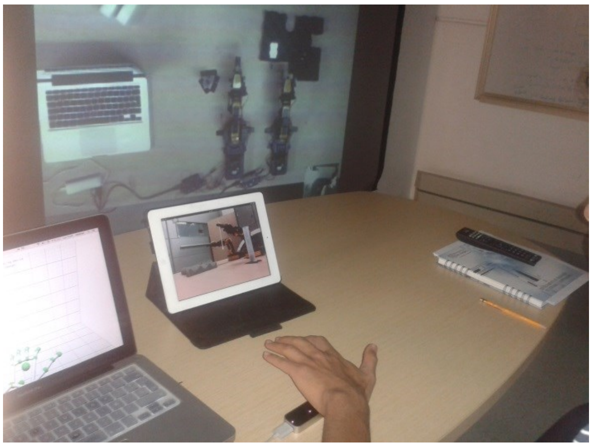

Figure 10. User workspace: User through the process in remote configuration with feedback from two cameras.

The tests results of iteration 3, where the user is in a remote workspace with the feedback of only one camera, compared to the results of iteration 2, where the user shares the workspace with the robotic arms, show that it was difficult for users to perform the task completely because they lacked the depth information needed to manipulate the robots and the elements in the experimental workspace (Table II). Regarding communication quality, there were minimal delays between the user interaction, the Leap Motion interface and the robotic arms because of the implementation of the UDP protocol; however, there were problems regarding the transmission of the video because of the use of commercial video streaming providers. At the end of the tasks, the users learned to work and compensate for video delays but needed two perspectives from two cameras.

In order to achieve the proposed goals, with the tests performed on the system, two cameras were integrated with different viewing angles over the tele-operated system. Thereby, the second camera located on the same level as the robotic arms resulted in tests being executed and completed without complications and without any instructions from external sources. These conditions let users reach the goals of the tasks in a moderate time and by themselves.

TABLE II. ELAPSED TIME WHILE TESTING FOR ITERATION 2, ITERATION 3 WITH ONE CAMERA*, AND ITERATION 3 WITH TWO CAMERAS**.

User	Iteration 2	Iteration 3*	Iteration 3**
1	8 min 3 sec	17 min 29 sec	11 min 42 sec
2	9 min 00 sec	10 min 32 sec	7 min 3 sec
3	6 min 32 sec	14 min 0 sec	9 min 23 sec
4	11 min 44 sec	14 min 57 sec	10 min 1 sec
5	5 min 25 sec	14 min 29 sec	7 min 5 sec
6	6 min 56 sec	13 min 27 sec	6 min 35 sec
7	3 min 39 sec	13 min 58 sec	9 min 46 sec
8	4 min 2 sec	21 min 46 sec	10 min 39 sec
9	6 min 38 sec	14 min 27 sec	7 min 4 sec
10	6 min 53 sec	18 min 6 sec	8 min 52 sec
Average	6 min 53 sec	15 min 19 sec	8 min 49 sec

In the improved workspace of the robotic arms, the system has one camera at the roof and other camera at arms level, for an easy and better view of the system area. Through this distribution, the system provides the user with a wide field of vision. Moreover, the room where the user controlled the arms through the Leap Motion is equipped with a projector that displays the working area of the arms in real time, so that the user received feedback of the current state of the system. At the same time, the second camera shows the user a view of the system from the same height as the arms thus providing the user with greater detail of the arms' movements. This configuration allowed validating the progress made by the implementation of a tele-operated control and signaled the importance of multiple views for humans to perceive depth. Therefore, the latter was defined as an important requirement in HRI.

VII. CONCLUSIONS AND FUTURE WORK

A natural human robot interaction system has been implemented and tested in an experimental environment with good performance. A user can interact and control two robotic arms by using his/her hands in the same workspace or he/she can tele-operate the robotic arms remotely. Using new technologies to control prototypes can be a trial and error cyclic process but the results with untrained users are valuable and make the whole project worthy of follow-up work and continuous monitoring.

The different iterations accompanied by user feedback made clear that this kind of technologies, as they are known, only take place in local industries and small businesses. However, the developed prototype shows how small must be the investment for a technology that could offer the ability to train people without the assistance of a technical professional in a couple of years, and that can contribute to manual labor in common environments such as production chains. In this work, the two most important factors for the proper control, precision and well performance of users in the proposed robotic tasks were: first, the use of their hands to control, and to interact with the robotic arms; and second, to provide a visual feedback composed of at least two views (cameras) to gain a good depth perception of the experimental workspace. The results from this work allow to think that ways of natural interactions will have good results in the Human-Robot Interaction field.

The authors are convinced that these technologies, such as the Leap Motion device, provide developers and the robot industry with a disruptive way to approach the HRI field due to their low investment value and good level of precision.

Regarding the future work related to the project, the extent and evolution can be accomplished by implementing common robotics technologies. The implementation of servomotors is certain to generate a positive impact on the system interaction with the user, because this technology provides greater control and degrees of freedom of movement, thus allowing replication of the movement of the hands and wrist of the user. The developed system provides facilities when scaling new features and technologies, because a non-layered software architecture was implemented which avoids dependencies on hardware and software, therefore allowing better fluency in future implementations of the system.

REFERENCES

[1] J. Burke, R. Murphy, E. Rogers, V. Lumelsky, and J. Scholtz, "Final report for the DARPA/NSF interdisciplinary study on human-robot interaction," IEEE Trans. on Systems, Man and Cybernetics, Part C (Applications and Reviews), vol. 34, no. 2, May 2004, pp. 103–112.

[2] Nytimes.com, Review: The Roomba 880 from iRobot, 2014. [Online]. Available: http://www.nytimes.com/2014/01/23/technology/personaltech/review-the-roomba-880-from-irobot.html?_r=0. Accessed on: June 1, 2015.

[3] M. Stokes, 3D Printing for Architects with MakerBot, Birmingham, UK, Packt Publishing, 2013.

[4] Universal Robots, Collaborative Industrial Robotic Arms Universal robots. [Online]. Available: http://www.universal-robots.com/en/. Accessed on: June 1, 2015.

[5] Rethink Robotics, Rethink Robotics | Advanced Robotics Technology | Collaborative Robots. [Online]. Available: http://www.rethinkrobotics.com/. Accessed on: June 1, 2015.

[6] S. F. dos Reis Alves, A. J. Uribe-Quevedo, I. Nunes da Silva, H. Ferasoli Filho, "Pomodoro, a Mobile Robot Platform for Hand Motion Exercising", in 5th IEEE RAS & EMBS Int. Conference on Biomedical Robotics and Biomechatronics (BioRob), 2014.

[7] Microsoft, "The kinect effect: How the world is using kinect," 2013. [Online]. Available: http://www.xbox.com/enGB/Kinect/Kinect-Effect. Accessed on: June 1, 2015.

[8] Leap Motion | Mac & PC Motion Controller for Games, Design, & More. [Online]. Available: http://www.leapmotion.com. Accessed on: March 2, 2015.

[9] Motor/Stepper/Servo Shield for Arduino v2 Kit. Adafruit.com. [Online]. Available: http://www.adafruit.com/product/1438. Accessed on: June 1, 2015.