AN OPERATOR-ASSISTED ROBOTIC ARM IMPLEMENTATION VIA LEAP MOTIONTM CONTROLLER

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ABSTRACT

It is obvious that the medical, military and industry are the sectors which mostly benefit from the technological developments. Innovations and improvements about robotic technology find place in these listed sectors directly or indirectly. For example, in a medical application; touches of the robotic fingers can be sensed by human through electrodes which are located into the brain. In military field, vehicles with robotic arm can do searching/destruction activities in dangerous areas. On the other hand, in industrial field robotic arm technology is used in manufactural activities frequently. In this practical application, it is purposed that sensing of motions and carrying over to the robotic arm without auxiliary instrument apart from the Leap Motion™ Controller (LMC). In this way, an application that imitates human arm and hand motions has been developed. This study has specific features which can be used for various purposes in medical, military and industrial fields. Furthermore, it contributes an innovative approach to operator-assisted robotic arm technology.

Keywords: Operator-assisted**,** Robotic arm, Leap Motion™ Controller, Innovation.

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INTRODUCTION

Contrary to popular belief, birth of the robotic technology is not limited to the recent past. First idea and samples started with Abū l-ʿIzz ibn Ismāʿīl ibn ar-Razāz al-Jazarī's designs in AD 1200 (Nadarajan, 2005).

In 15th Century, mechanical knight which was designed by Leonardo Da Vinci can be shown the first sample of the humanoid robot (Rosheim, 1997).

In the recent past, Theater play called Rossum's Universal Robots (R.U.R.) which had been written by Czech novelist Karel Čapek in 1920 was important inspiration for development of robotic technology. It may be the evidence of why we still use the word of robot which means "the servant" in Czech.

In "I Robot" which had been written by Isaac Asimov in 1950, he came up with the basic rules of the robotics. In Early 1960's, first industrial robot design was carried out. At the same time that was one of the most important developments about the robotic technology. Today, developments of the robotic technology keep up in three different fields such as industrial, mobile and micro-nano robotics.

The main purposes in industrial robot technology, carrying out the manufactural activities as fast as possible and eliminating the man-made manufacturing errors. Therefore, designers kept in forefront the robotic arm technology for industrial robot applications. First generation of the industrial robots had limited memory and processing capability. Moreover they could only work in static environment. Second generation industrial robots were added adaptive feature. In other words, they could adapt themselves against the varying of the environmental conditions. Today, the third generation industrial robots have artificial intelligence and the ability of analyzing (Petrina, 2011; Garcia et al., 2007).

Mobile robot technology shows developments mostly in space programs and military applications. High complexity and cost limit the mobile robot usage except a few fields such as space programs and military. Robotic arm is the important factor for mobile robots as well. In space programs, collecting the specimens from the planets via robotic arm vehicles or using robotic arm pallets for searching/destruction activities in dangerous areas can be given as the striking examples for usage of robotic arm.

This is not wrong to say that micro-nano robotic technology shows itself in medical field generally. Robotic arm usage is indispensable in this field as well. Nowadays risky and sensitive surgeries can be made by surgeons who use robotic arm. Robotic arm usage adds sensitivity and accessibility to the surgeon. On the other hand, produced micro-robots can carried out micro-surgeries through travelling into the human body (Fig. 1).

Fig. 1: A micro-medical robot

In analyses, it is seen that robotic arm commonly is used in main fields such as industrial, mobile and micro-nano. In this study operator-assisted robotic arm technology is deliberated specifically.

Operator assisted robotic arm could be characterized as a hybrid approach which uses the advantages of the robotic technology and human talents. On the one hand operator assisted robotic arm application uses human's heuristic and mental talents, on the other hand it uses robotic characteristics such as sensitivity, power etc. Therefore these features provide an effective application possibility.

Conventionally, operator assisted robotic arm consists of some complex devices and wired sensitive equipment attached to the human arm. This situation obstructs operator's mobility and sensitive movements.

In this study, considering the mentioned conditions and obstructions, operator assisted robotic arm control has been carried out through only arm and hand gestures by using no other extra hardware or equipment except LMC. Typically, this application has the specifications that can be used in industrial, medical and military fields. Consequently it can be said that this study contributes an innovative approach to the operator assisted robotic arm technology.

In following sections; hand gesture recognition and LMC are explained. Hand gesturing is the one of the important part of this study. For this reason typical studies in the literature are examined. On the other hand details of LMC which was used in this study are given as well. In methodology section, used method and components are explained. In next section, it is examined that if the application works as desired or not. And in the final section results are evaluated and future studies to be carried out are explained.

HAND GESTURE RECOGNITION AND LEAP MOTION CONTROLLER

We use hand gestures and signs consciously or unconsciously in our daily communications with other people. Sometimes this contributes our oral communication or may be the first communication tool when we try to talk with a person whose mother tongue is different from us. On the other hand hearing-impairers use hand gestures directly to communicate with each other and with the community. Hands that have very complex joint and muscle structure anatomically, can do various gestures and signs by using many combinations. Hand gestures that have certain meanings may resemble with each other. Recognition approach of hand gestures includes the studies to sense gestures and signs accurately (Khan and Ibraheem, 2012; Dan and Mohod, 2014; Chen, Z. H. et al., 2014). There are many methods for recognition of hand gesturing but these can be examined in three basic categories. These are; data glove based, visual based and colored glove based methods (Dan and Mohod, 2014).

In data glove based method, hand gestures are worked to recognize by a sensing glove which is worn to hand (Kumar et al., 2012). Although it has high accuracy; cost, additional hardware requirement and non-ergonomic design for hand mobility are the disadvantages of the data glove method.

In visual based method, operator does not wear additional equipment or device to his hand. Hand gestures are captured via cameras (Garg et al., 2009). It has simpler design than data glove method.

Colored glove based method is a hybrid method which is combination of the data glove and visual based method. Hand gestures are captured via colored glove (Iwai et al., 1996). But it includes the disadvantages of the data glove based method.

Leap Motion™ is a commercial product was introduced in 2012. It has ability to capture hand gestures through infrared camera and infrared leds (Fig. 2).

Fig. 2: Layer structure of the Leap Motion™

Light that is radiated from infrared leds in 850nm wave length reflects from hand and fingers, then it is captured by infrared camera. Technically it has angle of view from 25mm to 600mm and up to 150 degree. In addition, it has 200fps (frame per second) capturing speed and 0.01mm movement sensitivity theoretically (Silva et al., 2013). 3-Dimensional angle of view pattern of the Leap Motion™ controller is shown in below Fig. 3.

(Weichert et al., 2013) who made an experimental study based on real-time performance analysis of the LMC say that they acquired 0.7mm movement sensitivity in practical although it is expressed as 0.01mm theoretically.

(Marin et al., 2014) determined the fingers that are in region of view but hide or curled, cannot be identified by LMC. Moreover, they determined the fingers that are perpendicular with camera region of view cannot be identified as well. Again in same study it is mentioned that bracelet, jewelry etc. may be sensed as finger. This also effects the accuracy of LMC significantly.

It has been benefited from experiences, knowledge and warnings of previous studies for the next phases of the study.

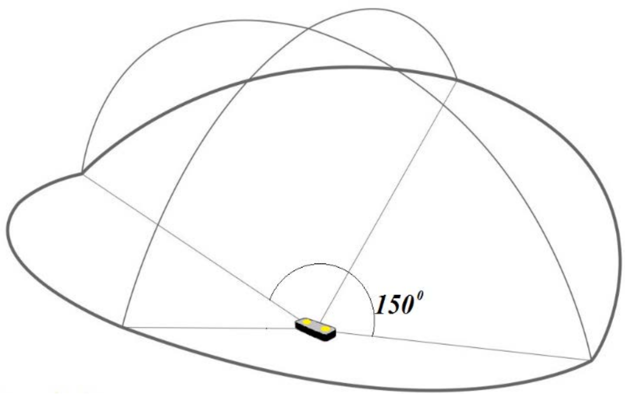

Fig. 3: 3-Dimensional angle of view pattern of the Leap Motion™ controller

METHODOLOGY

Required block diagram of the system components for the operator assisted robotic arm is shown in Fig. 4. Generally, acquired information from LMC is linked to Arduino UNO® platform through codes which are written in MATLAB®. In next stage, information is transferred to robotic arm via actuators (servos) which are connected to Arduino UNO®. In last stage, process is carried out by movement of robotic arm.

Fig. 4: Block diagram of the system components

LMC can capture many information about hand gestures very quickly such as angular position of fingers, finger types, extended finger number, palm position, distance of the fingers to the palm normal etc. Information is captured as instant frames. In addition, it allows to develop various applications because of its Software Development Kit (SDK).

In first stage of application, communication between computer and LMC was carried out. MATLAB® was preferred as communication and coding platform because of its real time performance and ability to connect with many other platforms. Communication between MATLAB® and LMC was carried out by using Mex-functions. Details of this process can be explained as;

Mex-functions converts C++ file to binary Mex-file by compiling that MATLAB® can understand. To create Mex-file, Matleap file set was used. Matleap file set was obtained from GitHub® which is a free software sharing and storing platform for developers. Matleap includes m-file, header and C++ files. Firstly, Visual C++ was assigned as MATLAB® C++ compiler. Then Mex-file was obtained by compiling *built.m* file which is in Matleap file.

On the other hand, to provide the communication between MATLAB® and Arduino® Uno, support packages within Mathworks® were downloaded and installed in MATLAB®. In this way, programming of Arduino® Uno or communicating with the Arduino® Uno can be possible through MATLAB®.

After communication is carried out between LMC-MATLAB® and MATLAB®- Arduino® Uno, determining the hand gesture modes for the robotic arm was the second stage.

In application, 6-DOF robotic arm with gripper end-effector was used shown in Fig. 5.

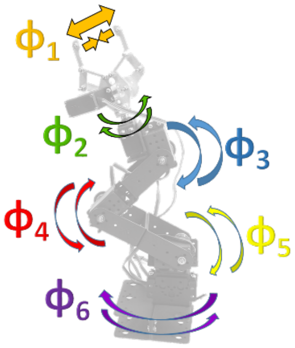

Fig. 5: 6-DOF robotic arm with gripper end-effector

Relation between robotic arm movement and hand gestures were determined as shown in Fig. 6. Robotic arm has the capability to move in five axis via determined ten basic hand gestures.

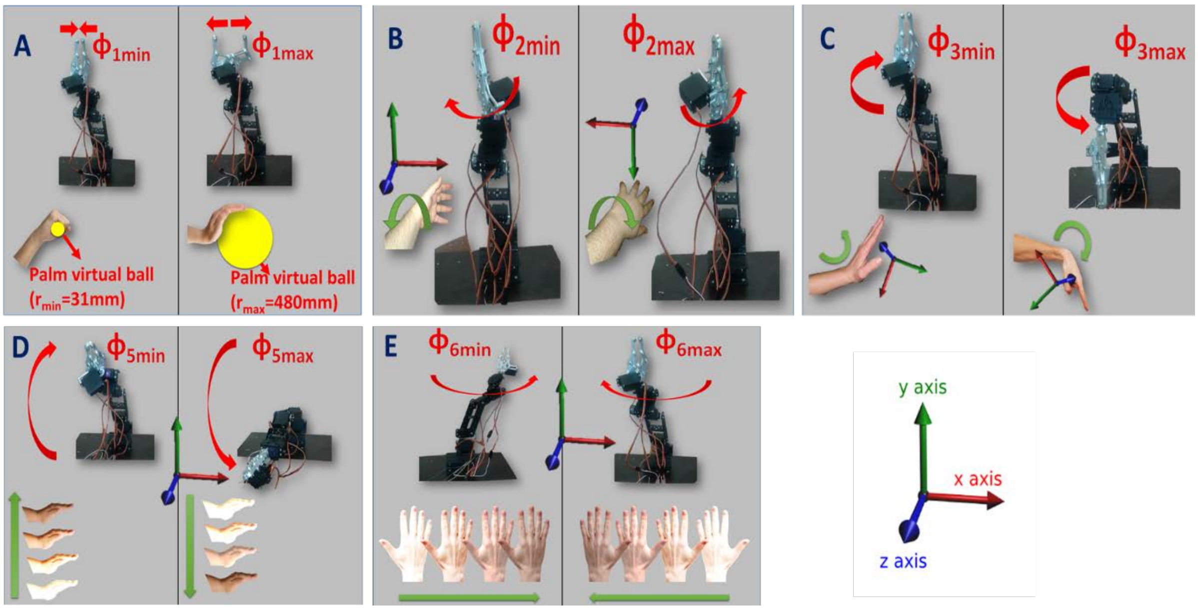

Fig. 6: Determined hand gestures for robotic arm

Openness control of the gripper which is the end-effector of robotic arm is made by varying the angle (ϕ1) of servo 1 as seen in Fig. 6A. Openness of gripper is related with a palm virtual ball radius. If palm is opened, gripper also opens as if a bigger virtual ball is in the palm. Because radius of the virtual ball increases. If hand becomes a fist, gripper closes as if a smaller virtual ball is in the palm. Because radius of the virtual ball decreases. In analysis with LMC, minimum and maximum radius values of the palm virtual ball were determined as in Table 1.

Table 1: Relations between the axis angles of robotic arm/ hand positions according to the hand gestures.

Hand Gesture Parameters	ϕ[min^0-max^0]	Min_{axis}~ Max_{axis} (mm)
A- Palm virtual ball radius	ϕ_1 [0^0-85^0]	31 ~ 480
B- Palm normal right-left change	ϕ_2 [20^0-160^0]	-0.9_x ~ 0.9_x
C- Palm normal forward-backward change	ϕ_3 [20^0-160^0]	-0.8_y~ 0.8_y
D-Palm up-down change	ϕ_5 [60^0-170^0]	31_y ~ 480_y
E- Palm right-left change	ϕ_6 [60^0-120^0]	-190_x ~ 190_x

Fig. 6B. shows the changing (ϕ2) angle of the servo 2 through the changing of wrist rotation. Fig. 6C. shows the changing (ϕ3) angle of the servo 3 through changing of the palm normal position from forward to backward. Fig. 6D. shows the changing (ϕ5) angle of the servo 5 through changing of the palm from up to down in y-axis. And finally, Fig. 6E. shows the changing (ϕ6) angle of the servo 6 through changing of the palm from right to left in x-axis. All of the determined changes of the servo angles through changes of the hand gesture are shown in Table 1.

Angle of the servos are between (0-π). By analyzing each of servo, intervals were determined as shown in second column of Table 1. By using second and third column, conversion line equations for each servo were acquired as shown in equation (1). All equations and conversion line graphs can be seen in Fig. 7a. to Fig. 7e. respectively for servo1, servo2, servo3, servo5, servo6.

$$\frac{x-x_a}{x_b-x_a} = \frac{y-y_a}{y_b-y_a} \tag{1}$$

In equation (1), x_a is abscissa of the first point, x_b is the abscissa of the second point, y_a is the ordinate of the first point and y_b is the ordinate of the second point.

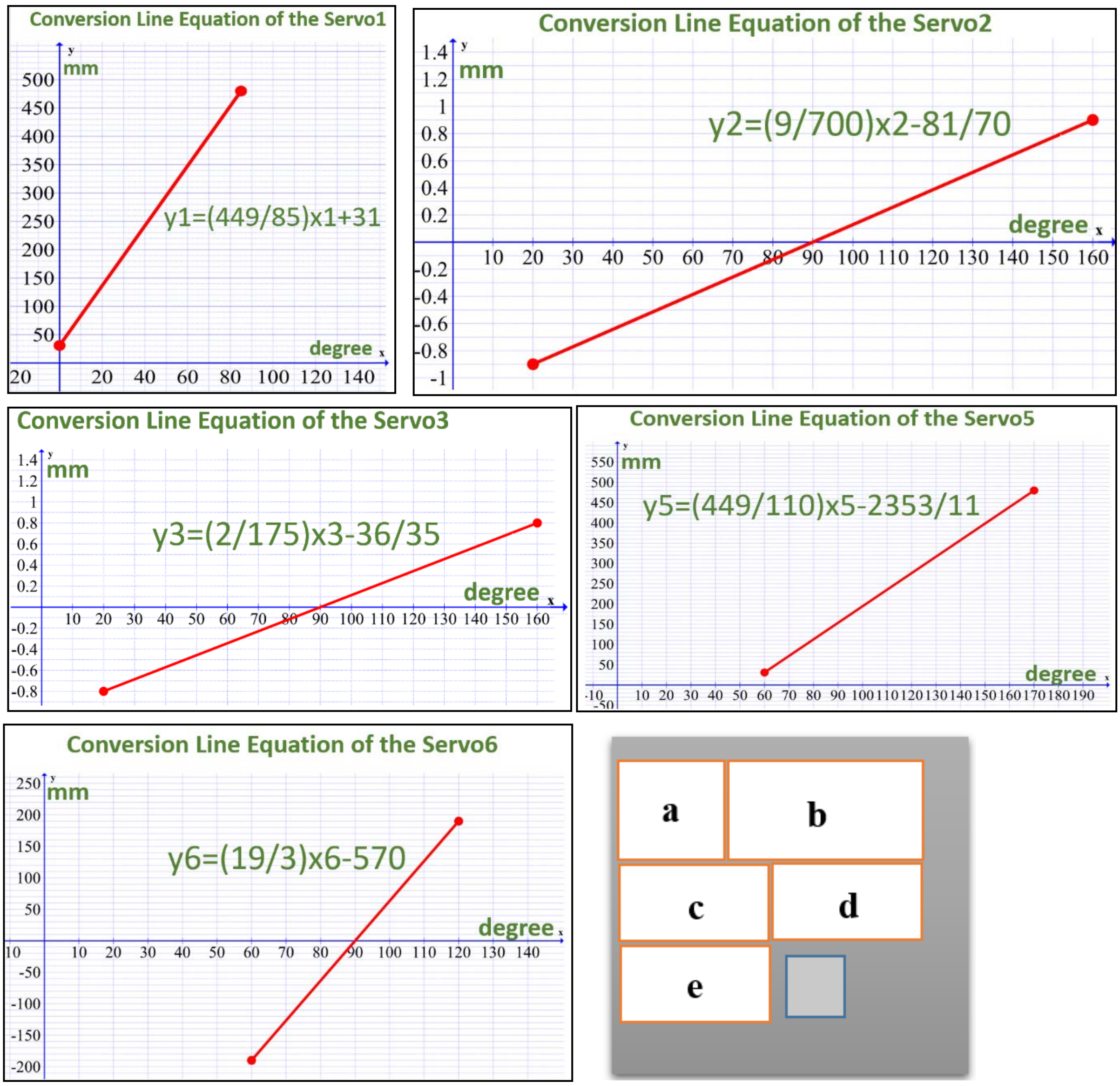

Fig. 7: Conversion line equations and graphs for each servo

After obtaining conversion line equations, codes were written in MATLAB® environment by using simplified algorithm shown in Fig. 8. As seen in algorithm, primarily instant hand gesture frames which are captured via LMC are analyzed, next position information about each hand gesture is obtained by using program functions separately. Then, angle values which should be sent to each of servo are calculated by using conversion line equations. Finally, calculated values are sent to servos. This process continues until certain time ends.

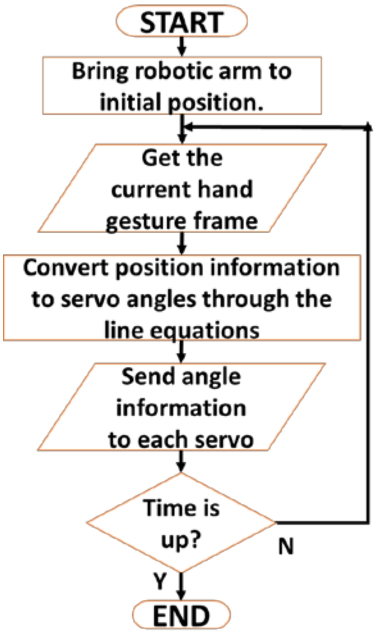

Fig. 8: Simplified algorithm of the system

EXPERIMENTAL RESULTS

Performance of the application was examined via a simple scenario. In scenario, a target area was located at the left side of the robotic arm and the right side of the robotic arm a toy car was put on a paper cup. Purpose of the scenario was, taking the toy car from the paper cup and put it to located target area. Target area and object were chosen small for testing operation sensitivity of the robotic arm. Control of the robotic arm was carried out through operator's hand gestures. The scenario process is shown step by step in Fig. 9. , Fig. 10. , Fig. 11. and Fig 12. respectively.

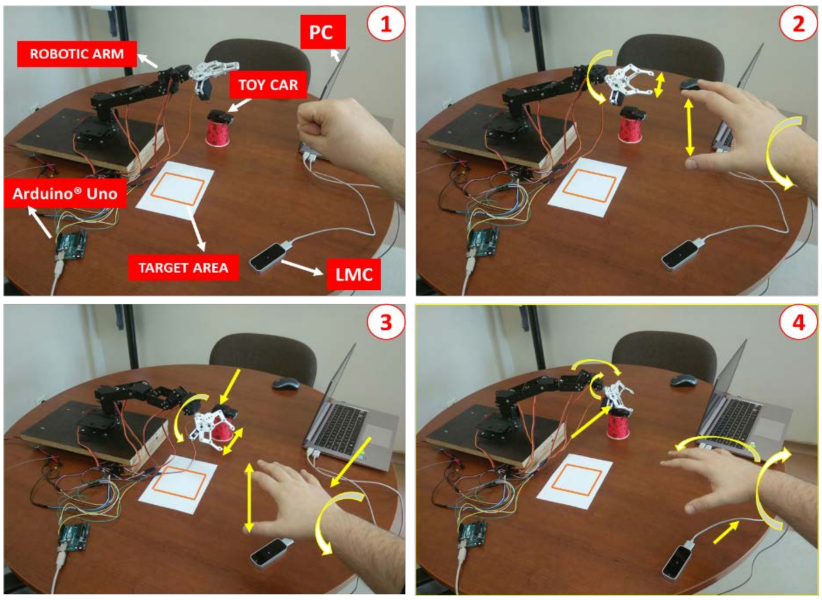

Fig. 9: 1 to 4 frames of the process.

In Fig. 9(1). devices and equipments are intruduced. Fig. 9(2). is the second frame of the process. You can see the yellow-white arrows which denote the robotic arm and hand position changings according to the previous frame. In following frames, it is benefitted from these colored arrows to show similar position changings.

As can be seen, in second frame, robotic arm is started to open grippers and turned the wrist counterclockwise (ccw) a little. If operator's hand gestures considered, it can be seen that operator's hand gesture changings look alike with the robotic arm changings. In third frame, operator extends his fingers a little bit more, turns his wrist ccw much more and starts his hand down. In response to this, robotic arm also opens gripper much more, turns wrist ccw much more and starts to move down. In forth frame, operator bends his wrist forward, moves hand to the right and turns his wrist to clockwise. Thus , robotic arm also gets close to the toy car, turns gripper to clockwise and bends gripper forward.

Second four frames of the process shown in Fig. 10. Fifth frame in Fig. 10. shows last positioning of the holding phase. Operator makes fine adjustments to hold the toy car firmly. Robotic arm copies the movements in same way.

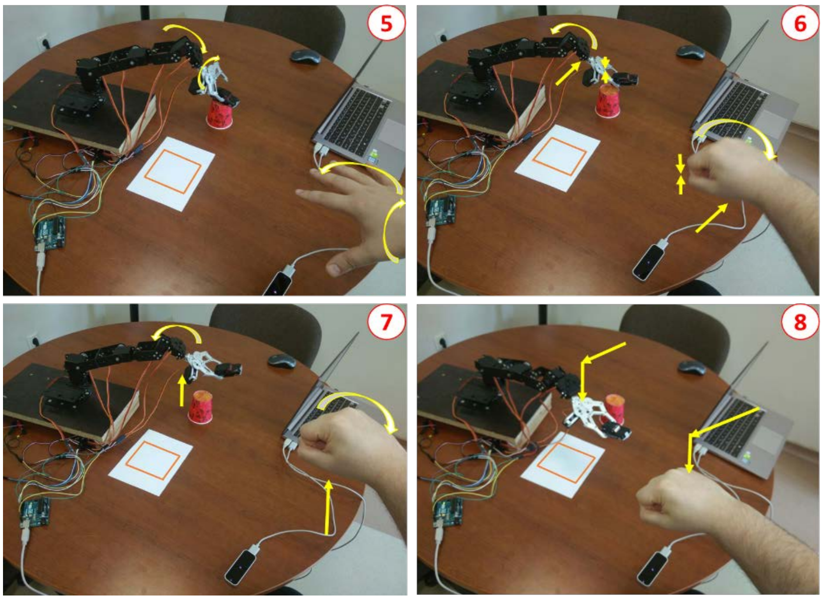

Fig. 10: 5 to 8 frames of the process.

Holding action of the operator and robotic arm can be seen in sixth frame. To close gripper of the robotic arm, operator bends his fingers and makes hand the fist. Thus gripper gets close and holds the toy car. In the seventh frame operator bends his wrist backward and hold his fist up. In the seventh frame, operator bends his wrist backward and holds his fist to up. As a result of this, gripper of robotic arm moves to up by holding the toy car. In eighth frame, to reach the target area, operator takes his fist to left and down. Robotic arm also moves left and down like operator.

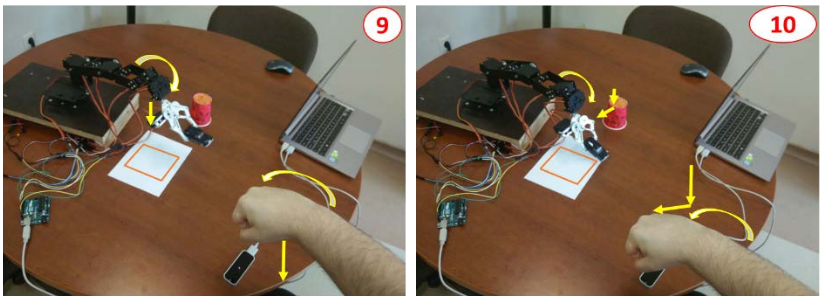

Fig. 11: 9th and 10th frames of the process.

In ninth frame, operator gets his fist lower and bends his wrist forward. In this way, robotic arm starts to approach to the target area. Approaching phase also goes on in tenth frame. Operator bends his wrist thoroughly and takes his fist to a little right and down. In a result of this, gripper of robotic arm approaches thoroughly to the target area.

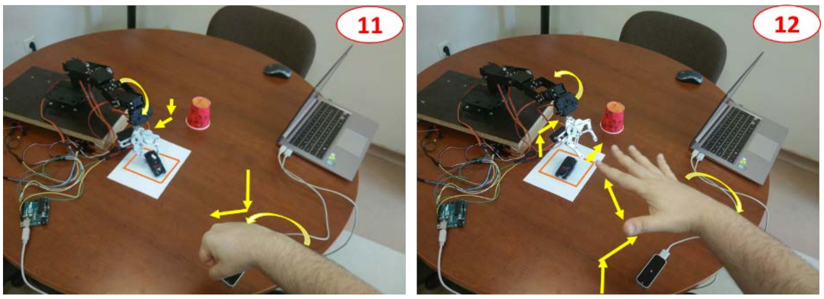

Fig. 12: 11th and 12th frames of the process.

In eleventh frame last step of the holding phase can be seen. Toy car is ready to be released through operator's last adjustments on target area. In last frame, operator releases toy car by extending his fingers, then lifts up his hand. When he extends his fingers, gripper opens and toy car drops from the gripper. Then robotic arm lifts up its gripper. Finally process ends.

EVALUATION AND FUTURE WORK

In scenario, it was purposed that a toy car is transferred from one place to another by operator assisted robotic arm. Consequently, purpose has carried out successfully. Maneuverability of the robotic arm and other factors were worked to determine via the scenario for this study. Experiences that have obtained at the end of this experimental study can be listed as below;

- The time of movement of the robotic arm via operator's movement, in other words response time of the system is quite enough. Operator couldn't be able to sense the delay.
- General resolution of movements are good level.
- Measurements may be wrong because position analysis is getting hard when fingers bends. As a result, random opening and closing movement of the gripper may occur.
- Light level of the environment may affect sensing and performance of the movement.

At the future works, it will be focused at solutions of the disadvantages of the LMC. Related studies about different fields will be carried out by developments of the existing algorithms.

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