Controlling a Robot Arm Using Exoskeleton for Land-Mines Disposal

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***Abstract*- Robotics, Virtual Reality, Exoskeleton and Human Machine Interface are fields of growing interest and applications every day. Robotic systems have enormous potential to reduce human exposure to dangerous situations and/or increase human presence in remote locations. Most of industrial robots are usually controlled by a computer or micro controllers to perform systematic sequence of actions stored in its memory. Navigation of autonomous robots involves following trajectories generated by automatic motion planners. For non-autonomous systems, the robot's trajectories are provided by the operator, either trajectories that are pre-set or fed in an on-line fashion, such as teleoperation. Teleoperation is widely used for the direct control of non-autonomous robots from a remote location. The objective of this paper is to facilitate the controlling process by using human-machine interface techniques instead of predefined limited actions in its memory; this is done in order to be able to control the robot arm remotely to discover the World Wide II mines that are still in the western desert of Egypt.**

Keywords: *Robotics, Exoskeleton, Teleoperation, Modeling, Simulation, Mines Disposal, Human Machine Interface.*

I. INTRODUCTION

This paper describes solution to an important problem arising in robotic applications: teleoperation. To achieve this mission, the motion of the user's arm is accurately measured and converted to a trajectory command for the robot; we measure the angles of each joint of the human arm to know the potential position of the user's palm relative to the user's body and use a sensing glove to measure finger flexure. All gathered data is used as input to the computer to transform the signals to a sequence of actions. We use a digital camera fixed beside the robot arm and display unit to make the user see the area surrounding the robot to be able to control its actions remotely and correctly.

A new technique of controlling a robot arm is proposed to solve the problems of land-mines, “More than 100 million land mines are buried in over 80 countries around the world, according to the International Campaign to Ban Land Mines, headquartered in Washington, D.C. It estimates that removing them at the present rate will take more than 500 years and US$ 33 billion. Mines kill or injure an average of 70 people every day.” [1].

We have designed and implemented the exoskeleton system, integrated the robot arm with a chained vehicle to make it mobile robot, and proposed a new technique for controlling this mobile robot by converting a human vector to a robot vector. This system is called *“CRAUVR”*.

The accuracy of this system has reached the extent of moving an egg from one place to another more than 32 times without scratching or dropping it even once. But why do we choose an egg to test the robot accuracy that is used for land mines disposal? Because the egg has the same nature of the iron mine that are exposed to the rain and to the hot desert weather for more than 50 years; these mines became very sensitive to either any extra squeezing by robot gripper, or sudden falling due to improper holding, both will lead to sudden explosion to a mine or scratch to the held egg.

We are applying the three rules of robotics: [2]

1) *A robot may not injure a human being or, through inaction, allow a human being to come to harm.*
2) *A robot must obey orders given to it by human beings except where such orders would conflict with the First Law.*
3) *A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.*

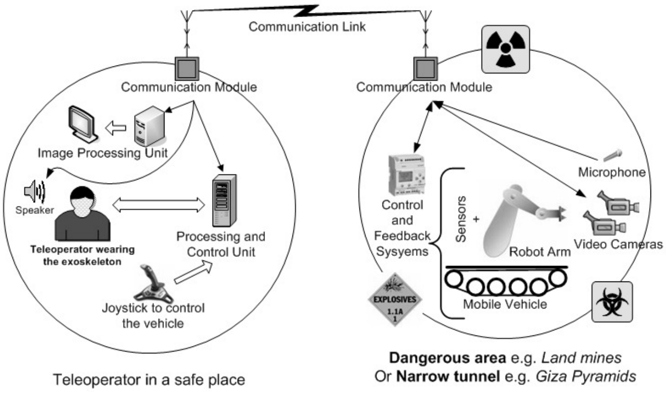


Figure 1. CRAUVR System Architecture.

CRAUVR architecture is introduced in Fig. 1. We can divide the CRAUVR system into two parts from location perspective, safe zone and dangerous area. There is a communication module in each part. Each part of the system will be discussed in detail in this paper.

In Section 2, the general CRAUVR robot design is introduced and the most important parts of its subcomponents. In Section 3, the introduction of a human vector to a robot vector and the relation between them are explained. In Section 4, the conversion technique from human vector to robot vector is explained. The self protection technique is introduced. The conclusions are given in Section 5. In Section 6, the CRAUVR simulator used is introduced.

1-4244-1366-4/07/$25.00 ©2007 IEEE

II. CRAUVR ROBOT DESIGN

The system consists of three subsystems

1) *Exoskeleton system*: to measure angles of each joint of the human arm.
2) *Controlling the vehicle movement: to* control the vehicle that holds the robot arm.
3) *Vision system:* to transmit the video from the mobile camera to 5DT Head Mounted Display (HMD).

The components of the three systems are shown in Fig. 2, 3, and 4.

III. INTRODUCING THE HUMAN VECTOR AND THE ROBOT VECTOR

The human arm is 3 pieces (back arm, fore arm and wrist) which is shown in Fig. 5 and the robot arm is 4 pieces (back arm, fore arm, base arm and gripper) which is shown in Fig. 6, the difference in the components of the human arm and the robot arm makes the mapping process more complicated as we have to know which angles we have to get its values and which vectors we have to calculate their values to reach an efficient mapping by using the ratio of the direction and ratio of the magnitude of the human to control the robot arm.

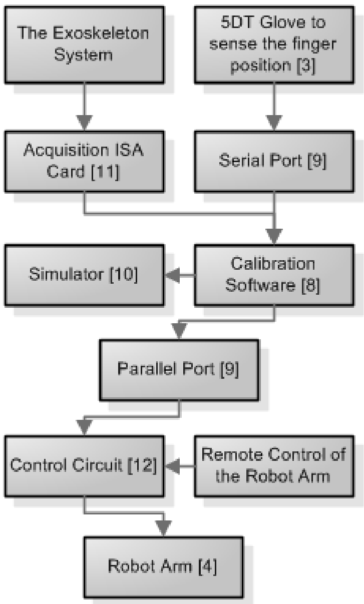


Figure 2. Exoskeleton system to measure angles of each joint of the human arm.

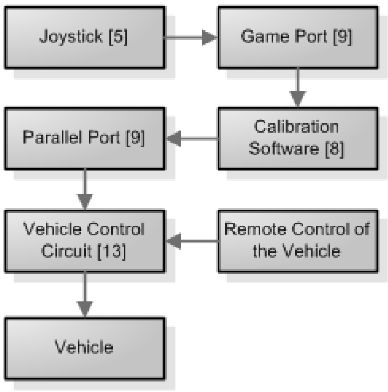


Figure 3. Controlling the vehicle movement to control the vehicle that hold the robot arm.

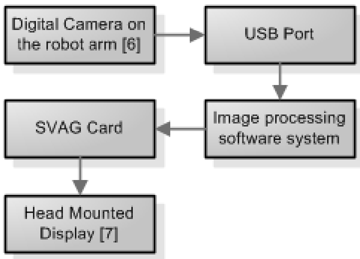
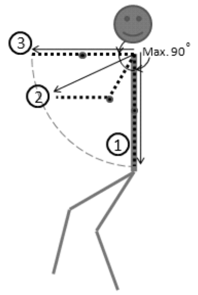


Figure 4. Vision system to transmit the video from the mobile camera to 5DT Head Mounted Display.



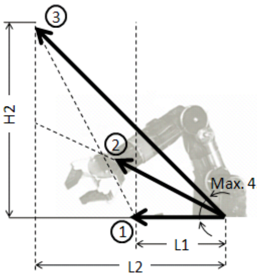


Figure 5. Human arm vector. Figure 6. Robot arm vector.

All the steps of mapping the movement of robot arm to the human arm are shown in Fig. 7.

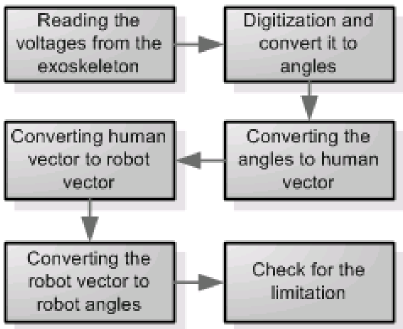


Figure 7. Steps for control the robot arm.

IV. CONVERSION FROM HUMAN VECTOR TO ROBOT VECTOR

Measuring the following angles of human arm: (e, s, r) and the length of the fore arm (*A*) and the back arm of human arm (*B*) -as shown in Fig. 8- are well known constants; treating the problem using very simple geometric laws (cosine law):

$$Lh = \sqrt{A^2 + B^2 - 2 \times A \times B \times \cos(e)} \tag{1}$$

Now the value of the vector L is calculated but we have to determine its direction; using also cosine law

$$\hat{m} = cos^{-1}\left(\frac{L^2 + A^2 - B^2}{2 \times L \times A}\right) \tag{2}$$

$$\widehat{mh} = \hat{m} + \hat{s} \tag{3}$$

The conversion technique is to map each state of hand to its similar one of the robot arm. The human arm vector has a magnitude Lh and direction $\widehat{mh}$. The robot arm vector has a magnitude Lr and direction $\widehat{mr}$. The relation between them is (4), (5) where $L1$ $L2$ and $H2$ are constants depending on the robot arm; Lh_max is the maximum length of the human arm.

$$\widehat{mr} = \frac{\widehat{mh}}{2},\ where\ mh \in [0°, 90°] \tag{4}$$

$$Lr = \left(\frac{Lh}{Lh\_max}\right) \times \sqrt{(mr \times H2)^2 + \left(\left(\frac{mr}{45°}\right) \times (L2 - L1) + L1\right)^2} \tag{5}$$

As we mentioned before, we will measure the angles of each joint of the human arm to calculate the potential length of the vector between the user's palm referenced to the human body and its direction, then map this vector length and direction to that of the robot arm.

V. SELF PROTECTION TECHNIQUE

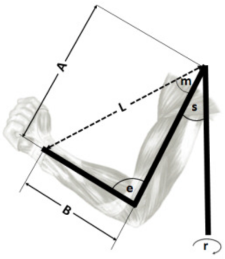


Figure 8. Human arm angles.

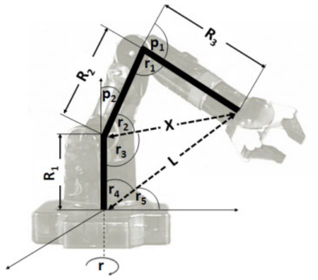


Figure 9. Robot arm angles.

CRAUVR applies the third law of robotics; *“A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.”*, it protects its own existence as long as such protection does not conflict with the order given by the exoskeleton system. There are four cases for the CRAUVR where it autostops itself violating the order given to it. These cases or states depend on the angles of P1, and P2. First case ($P1 < 90°\ and\ P2 < 90°$) shown in Fig. 10, Second case ($P1 < 90°\ and\ P2 > 90°$) shown in Fig. 11, Third case ($P1 > 90°\ and\ P2 < 90°$) shown in Fig. 12, and Fourth case ($P1 > 90°\ and\ P2 > 90°$) shown in Fig. 13.

$$X = \sqrt{R2^2 + R3^2 - 2 \times R2 \times R3 \times cos(r1)} \tag{6}$$

$$r2 = \cos^{-1}\left(\frac{X^2 + R2^2 - R3^2}{2 \times R2 \times X}\right) \tag{7}$$

$$r3 = 180° - r6 - P2 \tag{8}$$

$$L = \sqrt{R1^2 + X^2 - 2 \times R1 \times X \times \cos(r3)} \tag{9}$$

$$r4 = \cos^{-1}\left(\frac{R1^2 + L^2 - X^2}{2 \times R1 \times L}\right) \tag{10}$$

At the first case:

$$mr = 90° - r4 \tag{11}$$

If $(|Lr \times \cos(mr)| < |R2 \times \cos(r2 + r3 - 180°)|)$ then Stop.

At the second case:

$$mr = r4 - 90° \tag{12}$$

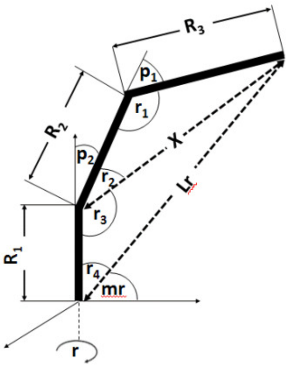


Figure 10. First case (P1<90° and P2 <90°)

If $(|Lr \times \cos(mr)| < |R2 \times \cos(90° - r2 - r3)|)$ then Stop.

At the third case:

$$mr = 90° - r4 \tag{13}$$

If $(|Lr \times \cos(mr)| < |R2 \times \cos(r2 + r3 - 90°)|)$ then Stop.

At the forth case:

$$mr = 270° - r4 \tag{14}$$

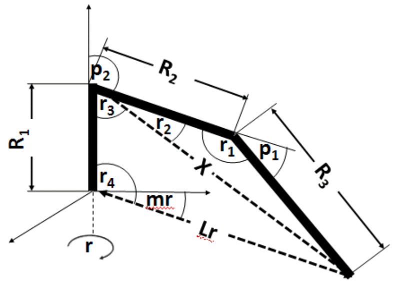


Figure 11. Second case (P1<90° and P2 >90°)

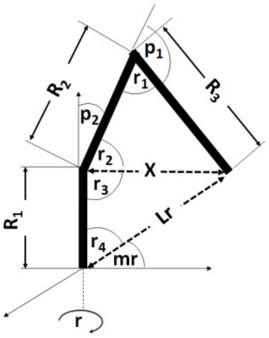


Figure 12. Third case (P1>90° and P2 <90°)

If $(|Lr \times \cos(mr)| < |R2 \times \cos(90° - r2 + r3)|)$ then Stop.

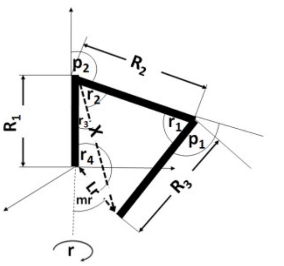


Figure 13. Fourth case (P1>90° and P2 >90°)

VI. SIMULATOR

There was a simulator for the CRAUVR robot arm, this simulator has two functionalities; it helps measureing the accurate angles and distances of the remote CRAUVER arm, to monitor the robot movement while training the users without connecting the robot to it, as shown in Fig. 14.

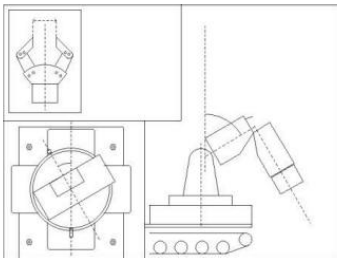


Figure 14. Snap shot of CRAUVR simulator

VII. RESULTS AND COMPARISONS WITH OTHER RELEVANT SYSTEM

The design achieves high performance in terms of efficiency and accuracy. The accuracy of this system reached to a limit to move an egg from its place to another for more than 32 times with neither scratching it nor dropping the egg even once.

There are many systems that are doing the same functionality like

1) *Master Control*: Researchers at the Korea Institute of Science and Technology, in Seoul, created an exoskeleton master arm that can control a humanoid robot's arms [2].
2) *Hand Exerciser:* An arm exoskeleton developed by a group at the University of Salford, in Manchester, England, helps users in rehabilitation exercises [2].

TABLE I
CRAUVR WITH COMPARISON WITH OTHER SYSTEM

	Robot Arm	Mobile Robot	Number of Arms of the exoskeleton	Vision System
CRAUVR	√	√	1	√
Master Control	√	X	2	X
Hand Exerciser	X	X	1	X

VIII. CONCLUSIONS

Robotic systems have an enormous potential to reduce human exposure in dangerous situations. A reliable and cheep robot and exoskeleton model is designed to handle land-mines disposal. The design achieves high performance in terms of efficiency and accuracy. The accuracy of this system reached to a limit to move an egg from its place to another for more than 32 times with neither scratching it nor dropping the egg even once. The design can be expanded to include Using wireless control system to provide better control on the robot. CRAUVR helps in many applications; a sample of them is as follows: *Military*: Removing mines from the Western desert of Egypt (Our main target), or any other place with being far enough for safety. *Medical*: Open surgery between a doctor on his hospital and a patient in a faraway place; even in a submarine in the middle of an ocean. *Tourism*: Exploring the Egyptian pyramids or any pharonic mystery that is unreachable because of large size equipments that is used for this purpose. The CRAUVR exoskeleton is shown in Fig. 15, and the CRAUVR robot is shown in Fig. 16.

Figure 15. CRAUVR exoskeleton

Figure 16. CRAUVR robot

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