Remotely Operated Robots with Application to Landmines Removal in Egypt

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***Abstract*—Landmine detection and removal is a challenging field. In demining operations, the phase of Area Reduction is very important and has a significant impact on its cost. Manual demining operations are dangerous, exhaustive and costive in time and money. It is important to produce assistive mechanisms like mobile robots to cope with the landmine fields' environment. This paper presents the requirements and design constraints of such a robot with its mathematical modeling, simulation and control. The limits of contact pressure of robot tires with ground for different mine types are investigated to protect the robot and prevent the activation of imbedded landmines. A prototype of a mobile platform with a robot arm is developed and manufactured using cheap components.**

Keywords:- Robot - Mechatronics – Demining-Fuzzy logic.

I. INTRODUCTION

Automated or semi-automated solutions for landmine problem instead of manual methods have a good potential and minimize danger and cost. In a previous publication [1], a literature survey is presented about Egypt landmine problem history, facts, constraints, and demining techniques. This paper is organized in four main sections. Section 2 discusses the requirements and constraints of demining robots and investigates a method for sensor selection. In section 3, a mathematical model is developed using the so called Virtual Robot Approach (VRA) developed by the first Author of this paper in addition to its simulation results. This approach was used for missile-Camera modeling as a virtual robot [2]. Section 4 experimentally tests the developed mobile robot. The embedded system programming is used to develop the control strategy of such a robot. The paper ends with a conclusion and future work. More details may be found in reference [3].

II. ROBOT REQUIREMENTS AND CONSTRAINTS

A. Proposed Robot Main Requirements

The general requirements of a demining robot may be summarized in the following items [4]:

1- **Design:** The robot can safely crossover various ground conditions and its mechanical structure should be simple, flexible and highly reliable and equipped with a self recover mechanism.
2- **Power**: The robot must have a reasonable sustained power supply.
3- **Components:** Robot components must be available in the local market such as bicycle components of low weight and cost and uses simple practical technology. They should resist water, sand, temperature and humidity.
4- **Control modes and navigation:** Robot should have efficient surface locomotion to be adapted to unstructured environment. Robot navigation should assure balance between maneuverability, stability, speed, and ability to overcome obstacles. Efficient navigation techniques need sensors' based localization and man/machine interface including portable control station. Using more than one operational mode such as Tele-operated, semi-autonomous and autonomous, keeps operator safe.
5- **Sensors**: Robot should employ multi sensors system.
6- **Interaction with mines:** Robot and Ground contact Pressure should not exceed certain threshold. Robot should withstand explosive blast without suffering major damage, and its high technology parts must be well protected.
7- **Maintenance**: Robot must be easy maintained in terms of service and repair with indigenous users and minimum cost [5].

The main requirements demining robots are given in Table I. Humanitarian demining robots may be classified as [6]: Tele-operated machines, Multifunctional Tele-operated robots, Demining Service Robots, Unmanned Aerial Vehicles & Airships, New Robotic Systems (Warm, Lizard), Multi-Robot System, and Hybrid Robots.

TABLE I: ROBOT MAIN REQUIREMENTS

#	Title	Description
Req.1	Sensors selection	Based on the survey about sensors and evaluating the linguistics with fuzzy grading
Req.2	Track / Low pressure tires	A Mobile robot can navigate on rough terrain with low contact area pressure.
Req.3	Arms of extreme reach	It has the capability to scan the ground surface. (almost horizontal)
Req.4	Wireless remote control from PC	Robot operator must be away from the robot
Req.5	Movable wireless Camera	In order to deliver quiet view of the robot surroundings to the user of the Laptop
Req.6	GUI, motion Patterns	Give the user graphical user interface (GUI) to command the robot through it.
Req.7	Test scenarios	Prepare test scenarios in order to verify that the robot will meet the required command.

B. Landmine Activation Pressure Analysis

The landmine activation pressure is one of the most important factors in designing a demining robot. Based on the information available about the Landmines [7, 8], the activation pressure may be calculated for each landmine type as given in Table II. The minimum contact pressure is 1.9 kPa for B-2, V-2 (AT) mine type used in Egypt, which is the main design parameter of the demining robot.

TABLE II: LANDMINES ACTIVATION PRESSURE

Country	Mine Type	Dimensions	Activation load (kg)	Activation Pressure= F/A
U.K	MK5 (AT)	Diam:20.3cm	114.45 kg	34.6 kPa
U.K	MK7 (AT)	Diam:32.5cm	150-275 kg	17.7 kPa
Germany	Rieglmine43 (AT)	Length: 80cm Width: 9.5 cm	180-360 kg	23.2 kPa
Germany	S mines (AP)	Diam: 10.2 cm	3 - 5.5 kg	3.5 kPa
Germany	Tellermine 35, 42, 43 (AT)	Diam: 31.8 cm	90-180 kg	11.1 kPa
Italy	B-2,V-3(AT)	Diam: 27.3 cm	115/9.8kg	1.9 kPa
Egypt	M71 (AT)	Diam: 30.5 cm	120-400kg	16 kPa
Egypt	T79 (AP)	Diam: 9 cm	12.5 kg	19.2 kPa
Extremes for AP		Diam: 7 cm	3 kg	7.6 kPa
		Diam: 15 cm	20 kg	11 kPa

C. Available Sensors Information Analysis & Selection

Sensors selection for mine detection is important in demining robot design process. Two methods based on data processing with fuzzy logic concepts are presented for this selection process as given in [9, 10].

In Table III, the fuzzy grading applies a fuzzy logic values (grade S_1) to replace the linguistic value assigned for each linguistic variable: Maturity, Cost, Speed, and Effectiveness are calculated using the Formula [9]:

$$S_1 = \sum grade$$

In Table IV, the fuzzy grading applies a fuzzy logic values (grade S_2) to replace the linguistic value assigned for each linguistic variable: kind of terrain, speed, false alarms rate, cost and complexity, maximum depth, kind of mines are calculated using the Formula [10]:

$$S_2 = 2 N_y + N_b - N_r$$

where N_y , N_b, and N_r are respectively an indicative number for (very good occurrences or yellow), (good occurrences or blue), and (bad occurrences or red).

The aggregation (T) of the two fuzzy grades (S_1 & S_2) of sensors is calculated based on the Formula [3]:

$$T=17 S_1 + 10 S_2$$

Table V gives five sensors with the highest score.

TABLE III: FUZZY GRADING KEY

Fuzzy Grade	Maturity Linguistic value	Fuzzy Grade	Cost Linguistic value
6	OK	6	Low
5	In Use	5	Low to medium
4	In Use, In devel.	4	Medium
3	In devel	3	Medium to high
2	R&D Prototype	2	High
1	R&D	1	Very High
Fuzzy Grade	**Speed Linguistic value**	**Fuzzy Grade**	**Effectiveness Linguistic value**
4	Medium to high	6	Very High
3	Medium	5	High
2	Low to medium	4	High(in wet soil)
1	Very low	3	Medium to high
		2	Medium
		1	Low
		2	Unknown

TABLE IV: FUZZY GRADING KEY

Terrain	Speed	Alarms rate	Cost & complexity	Eval. of criteria	Color	Fuzzy Grade
All	High	Low	Low	v. good	yellow	2
Dry soil	X	X	X	Good	blue	1
X	Low	High	High	Bad	red	-1
other	Other	Other	other	Other	white	0
Depth	**Kind of mine**	**Con's**	**Pro's**	**Eval. of criteria**	**Color**	**Fuzzy Grade**
Deep	All	X	V. reliable	v. good	yellow	2
Changeable	Metallic	X	Reliable	Good	blue	1
X	X	Heavy	X	Bad	red	-1
other	other	Other	other	other	white	0

.

TABLE V: AGGREGATION AND SENSORS SELECTION

Class: Sub class	From S_1 /10	From S_2 /17	Aggregation $17S_1+10S_2$		Remarks
Chemical Sniffers: Alive,dogs	10	16	330	best 1	Selected
Magnetometers: Fluxgate	8	17	306	best 2	Selected
Magnetometers: Proton prec.	8	17	306	best 3	Selected
GPR: GPR	9	15	303	best 4	Selected
Induction coil: Metal Detector	9	14	293	best 5	Selected
Manual Prodding	7	17	289	best 6	--
Brute force: Mechanical	7	12	239	best 7	--

III. MATHEMATICAL MODELING AND SIMULATION

The main issue of a mobile robot arm is how to coordinate the mobility of its platform and the manipulability of its arm (Fig. 1). Most work in this issue, assumes that the platform transports its arm to a proper location in which the arm performs alone the desired task. This makes the robot control and planning problems much easier. However, it will be more flexible if both subsystems (platform & arm) can work simultaneously. The virtual robot Approach VRA is used to obtain the kinematic models of the mobile robot arm [2, 3].

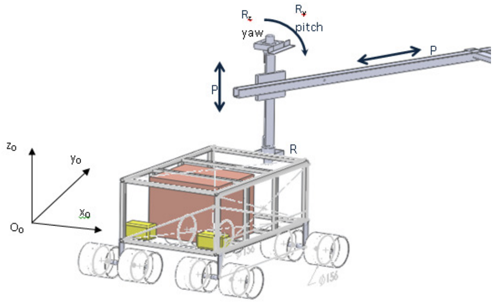


Fig.1 Robot: Solidworks model

The equivalent Virtual Robot, representing the two subsystems (platform or carriage & arm) is developed in two levels of complexity: (A) Spatial platform of type PPPRRR where (P) for prismatic and (R) for revolute and (B) Planar platform of type PPR with virtual links as give after. The kinematic models of both levels are obtained

A. Spatial Platform Virtual Robot (PPPRRR)

Using Denavit-Hartenberg (D-H) notation, the Homogeneous Transformation Matrix is given by [11]:

$$T_{0,7}=\begin{bmatrix} t_{11} & t_{12} & t_{13} & t_{14} \\ t_{21} & t_{22} & t_{23} & t_{24} \\ t_{31} & t_{32} & t_{33} & t_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$=\begin{bmatrix} \text{-s5*c6} & \text{s5*s6} & \text{-c5} & \text{-s5*L6*c6+q1} \\ \text{c4*c5*c6+s4*s6} & \text{-c4*c5*s6+s4*c6} & \text{-c4*s5} & \text{K1*c5+K4+q2} \\ \text{s4*c5*c6-c4*s6} & \text{-s4*c5*s6-c4*c6} & \text{-s4*s5} & \text{K3*c5-K2+q3} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where ci =Cos (qi) and si =Sin (qi) for i = 4, 5, 6 and K1= L6*(c4*c6); K2=L6*(c4*s6); K3= L6*(s4*c6); K4=L6*(s4*s6); G1=(cϕ*c5 + sϕ*c4*s5);

Using the yaw ϕ, pitch, θ and roll ψ angles for orientation, the Direct Kinematic Position Model DKPM and the platform Jacobean matrix are given by:

$$\begin{bmatrix} X_1 & X_2 & X_3 & X_4 & X_5 & X_6 \end{bmatrix}^t = \begin{bmatrix} t_{14} & t_{24} & t_{34} & \phi & \theta & \psi \end{bmatrix}^t \quad (2)$$

$$\left.\begin{aligned} \theta &= a\tan2(\sin\theta,\cos\theta) : \sin\theta = -t_{31}, \cos\theta = \pm\sqrt{1-\sin^2\theta} \\ \phi &= a\tan2(\sin\phi,\cos\phi) : \cos\phi = t_{11}/\cos\theta, \sin\phi = t_{21}/\cos\theta \\ \psi &= a\tan2(\sin\psi,\cos\psi) : \sin\psi = t_{32}/\cos\theta, \cos\psi = t_{33}/\cos\theta \end{aligned}\right\} (3)$$

$$J=\begin{bmatrix} 1 & 0 & 0 & 0 & -L6*c5*c6 & s5*L6*s6 \\ 0 & 1 & 0 & -K3*c5+K2 & -K1*s5 & K3-K2*c5 \\ 0 & 0 & 1 & K1*c5+K4 & -K3*s5 & -K1-K4*c5 \\ 0 & 0 & 0 & c\phi*\tan\theta & c4-s4*s\phi*\tan\theta & -\tan\theta*G1-s4*s5 \\ 0 & 0 & 0 & -s\phi & -c\phi*s4 & s\phi*c5-c\phi*c4*s5 \\ 0 & 0 & 0 & c\phi/c\theta & -s\phi/c\theta*s4 & -G1/c\theta \end{bmatrix}$$

The Tool Center Point Direct Kinematic Velocity Model (TCP_DKVM) is given by:

$$TCP\_DKVM = \dot{X}_{mx1} = J_{mxn}\dot{q}_{nx1}$$

***B. Planar Platform Virtual Robot* (PPR)**

$$TCP\_DKPM = \begin{bmatrix} X \\ Y \\ Z \\ \phi \end{bmatrix} = \begin{bmatrix} q_1 + L_3 * c_3 \\ q_2 + L_3 * s_3 \\ 0 \\ a\tan2(s_3, c_3) \end{bmatrix} \quad (4)$$

The Platform Jacobean matrix is given by:

$$J = \begin{bmatrix} 1 & 0 & \text{-}L_3 * s_3 \\ 0 & 1 & L_3 * c_3 \\ 0 & 0 & 1 \end{bmatrix} \quad (5)$$

The TCP_DKVM is given by:

$$TCP\_DKVM = \dot{X}_{mx1} = J_{mxn}\dot{q}_{nx1}$$

$$TCP\_DKVM = \begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} \dot{q}_1 - L_3 * \dot{q}_3 * s_3 \\ \dot{q}_2 + L_3 * \dot{q}_3 * c_3 \\ 0 \\ \dot{q}_3 \end{bmatrix} \quad (6)$$

Note: $\theta = 0,\ \psi = 0, \dot{\theta} = 0,\ \dot{\psi} = 0$

C. Arm of Type RPP

The arm TCP_DKPM, Jacobean matrix and DKVM are given by:

$$TCP\_DKPM = \begin{bmatrix} X \\ Y \\ Z \\ \phi \end{bmatrix} = \begin{bmatrix} q_3 * c_1 \\ q_3 * s_1 \\ q_2 \\ a\tan2(s_1, c_1) \end{bmatrix} \quad (7)$$

$$J = \begin{bmatrix} -q_3 * s_1 & 0 & c_1 \\ q_3 * c_1 & 0 & s_1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix} \quad (8)$$

$$TCP\_DKVM = \begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} \dot{q}_3 * c_1 - \dot{q}_1 * q_3 * s_1 \\ \dot{q}_3 * s_1 - \dot{q}_1 * q_3 * c_1 \\ \dot{q}_2 \\ \dot{q}_1 \end{bmatrix} \quad (9)$$

Note: $\theta = 0,\ \psi = 0, \dot{\theta} = 0,\ \dot{\psi} = 0$

D. Assembled Carriage –Arm (PPR-RPP)

$$TCP\_DKPM = \begin{bmatrix} X \\ Y \\ Z \\ \phi \end{bmatrix} = \begin{bmatrix} q_1 + q_6 * c_{34} + L_3 * c_3 \\ q_2 + q_6 * s_{34} + L_3 * s_3 \\ q_5 \\ a\tan2(s_{34}, c_{34}) \end{bmatrix} \quad (10)$$

$$J = \begin{bmatrix} 1 & 0 & \text{-}q_6 * s_{34} \text{-} L_3 * s_3 & \text{-}q_6 * s_{34} & 0 & c_{34} \\ 0 & 1 & q_6 * c_{34} + L_3 * c_3 & q_6 * c_{34} & 0 & s_{34} \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \end{bmatrix}$$

$$\begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} \dot{q}_1 - \dot{q}_3*(q_6*s_{34}+L_3*s_3)+\dot{q}_6*c_{34}-\dot{q}_4*q_6*s_{34} \\ \dot{q}_2 + \dot{q}_3*(q_6*c_{34}+L_3*c_3)+\dot{q}_6*s_{34}+\dot{q}_4*q_6*c_{34} \\ \dot{q}_5 \\ \dot{q}_3 + \dot{q}_4 \end{bmatrix} \quad (11)$$

Note: $\theta = 0,\ \psi = 0, \dot{\theta} = 0,\ \dot{\psi} = 0$

E. Assembled Carriage-Arm-Camera (PPR-PRRR)

$$TCP\_DKPM = \begin{bmatrix} X \\ Y \\ Z \\ \phi \\ \theta \\ \ \end{bmatrix} = \begin{bmatrix} q_1 + L_3 * c_3 \\ q_2 + L_3 * s_3 \\ L_4 + q_4 \\ a\tan2(s_{35}, c_{35}) \\ a\tan2(s_6, c_6) \\ \ \end{bmatrix} \quad (12)$$

$$J = \begin{bmatrix} 1 & 0 & -L_3 * s_3 & 0 & 0 & 0 \\ 0 & 1 & L_3 * c_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$TCP\_DKVM = \begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \\ \dot{\phi} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \dot{q}_1 - \dot{q}_3 * L_3 * s_3 \\ \dot{q}_2 + \dot{q}_3 * L_3 * c_3 \\ \dot{q}_4 \\ \dot{q}_3 + \dot{q}_5 \\ \dot{q}_6 \end{bmatrix} \quad (13)$$

Note: $\psi = 0, \dot{\psi} = 0$

F. Simulation examples: Robot Trajectories

Using a third part toolbox [12], a number of robot trajectories are animated as presented In Fig. 3 and Fig, 3. In addition, a Simulink model is presented in Fig.4.

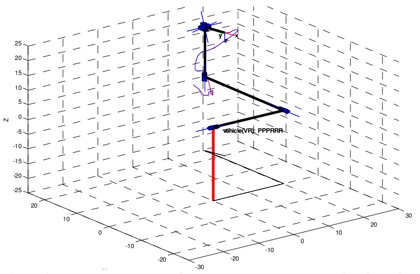


Fig.2: Virtual Robot Representation (PPPRRR) track sin-sin in 3D

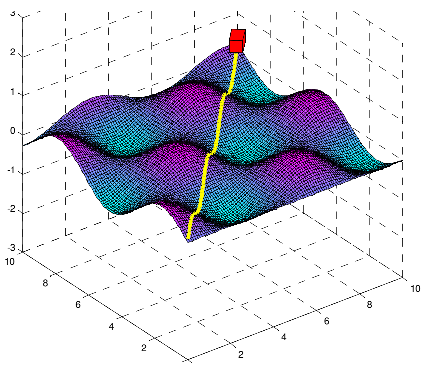


Fig.3: Virtual Robot Representation (PPPRRR) track path on terrain

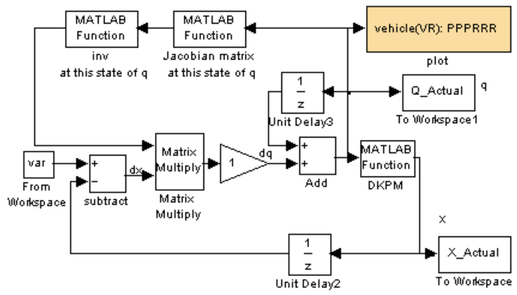


Fig.4: Virtual Robot (PPPRRR) SIMULINK model tracking paths

Recalling that DKVM for any robot arm is given by [11]

$$\dot{X}_{mx1} = J_{mxn}\dot{q}_{nx1}$$

Multiplying the above equation by J^t produces

$$J^t_{nxm}\dot{X}_{mx1} = \left[J^t J\right]_{nxn}\dot{q}_{nx1}$$

$$\dot{q}_{nx1} = \left[J^t J\right]^{-1}_{nxn} J^t_{nxm}\dot{X}_{mx1} \quad (14)$$

This relation defines the so-called inverse kinematic velocity model. The Direct and Inverse Kinematics Acceleration Models (DKAM and IKAM) are given by:

$$\ddot{X}_{mx1} = J_{mxn}\ddot{q}_{nx1} + \dot{J}_{mxn}\dot{q}_{nx1}$$

$$\ddot{X}_{mx1} = J(q)\ddot{q} + H(q)\dot{q}\dot{q} \quad (15)$$

$$\ddot{q} = J^{-1}(q)[\ddot{X}_{mx1} - H(q)\dot{q}\dot{q}] \quad \textit{if} \quad J \textit{ is} \quad \textit{square}$$

$$\ddot{q} = G(q)[\ddot{X}_{mx1} - H(q)\dot{q}\dot{q}] \quad (16)$$

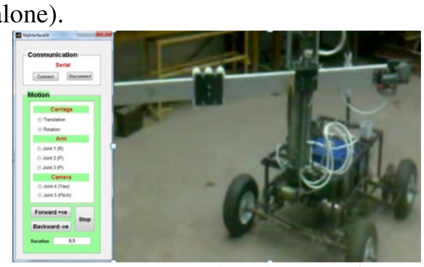
IV. System Control & Experimental Work

The developed system shown in Fig. 5 is a mobile robot with an arm and a camera and its GUI controls. The used mechanical hardware consists of:

(1) a carriage with two actuators one for each side,

(2) an arm of type RPP with its R joint around the z axis (yaw) and one of its P joints is in the z direction and the 2^{nd} P joint is in the horizontal direction, and

(3) a camera of type RPRR with its 1^{st} revolute joint around the z axis (yaw: for the arm and the camera) and its P joint is in the z direction (for the arm and the camera) and its 2^{nd} R joint around the z axis (yaw: for the camera alone) and another R joint around the y axis (pitch: for the camera alone).



(a) GUI (b) Robot: Manufactured

Fig.5: Matlab GUI and the Robot (Carriage Arm) hardware

A. Mechanical Hardware Specs

The carriage chassis (Fig. 6) is manufactured using square welded pipes of (20 mm x20 mm). The chassis dimensions are (500mm x 800mm x300 mm). The wheels axis is 1" pipes suspended by an L section of (30 mm x30 mm). Each suspension is individually adjusted in the XYZ space. For each side, 2 sprocket-chain sets are used to increase the torque and decrease the rotational velocity delivered from the motors to the wheels for constant Power = T*ω. The 1^{st} sprocket-chain set is adjusted by a couple of sprockets tensioned with springs while the 2^{nd} one is adjusted by a couple of table plates which align the chain parts with the sprocket before matching. The base of the arm is fixed on the carriage front and pulled to its back to minimize the arm vibration.

B. Electronic Hardware and Control Algorithm

The user commands the robot though the GUI controls. Referring to Fig.7, a command is transferred through the serial port (USB2seria)l to the Control Unit1 which is a microcontroller ATMEGA32 circuit developed to transform the command (serial) to the RF transmitter 4-channels (parallel).

Fig.6 Mechanical hardware: sprocket chain, wheel, track

As the RF receiver 4-channels (fixed on the robot carriage) receive a command, it will be delivered to the Control Unit2: ATMEGA32 circuit developed to command the actuators and to collect information from the sensors. Simply, it selects the actuator and the movement direction. The driving circuits (high power) are five H-Bridges to drive the DC motors: two for the carriage sides and three for the arm and ULN2003 circuit to drive the stepper motors (two for the camera).

The control strategy is described in Fig.8. The RF-4 channels are used to select which motor actuates through a menu, where 2 channels are used to make interrupt to select certain motor and/or reset. The remaining two channels are used to decide the direction. Figure 8 shows the pin utilization of the microcontroller: ATMEGA32 in the Control Unit2 (Main Brain). Interrupts pins (16, 17) are used to select the motor form the menu shown before. The directions are decided from the pins (14, 15). Each DC motor has two pins one for each direction (+ve &–ve).

While each stepper motor has four pins where the sequence is applied. Also each limit switch has a single pin when pressed in gives low 0v (active low). The ultrasonic and metal detector signals are input in pins (20, 21). When the sensors set are in the operating mode the green led lights and when metal detector detect metal the red led lights and the alarm is raised. In Fig.9, this microcontroller: ATMEGA32 is the main brain of the robot.

C. Test Scenarios

In Fig.10 and Fig.11, four test scenarios are done to ensure correctness of the control algorithm by using:

1. Computer and the test board (led show the response when command the microcontroller through the RF set.
2. Motors driving circuits without motors (just see the leds and sense the heat from power transistors).
3. Motors similar to those already used in the robot.
4. Actual robots at no load and at load.

D. Repeatability Tests

Repeatability test 1: In Carriage translation, 20 commands are given to the robot to translate (Forward & Backward) to test the repeatability (Fig.12). Note: beside translations 20 times little rotation occurred counter clockwise $\tan^{-1}(36/90) = 21.79$ deg. This means on the average each translation trip suffers: 1.1 deg.

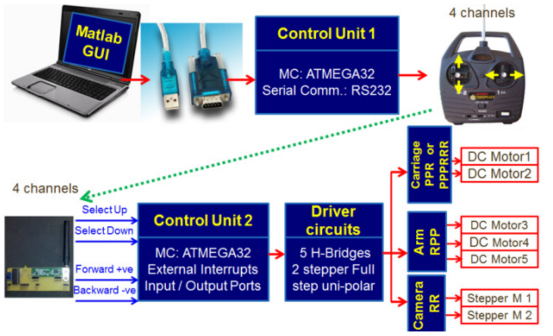


Fig.7: System Architecture

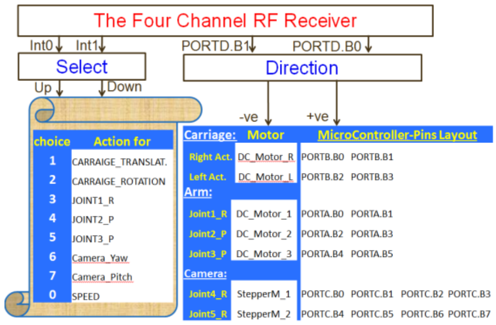


Fig.8: Control Strategy

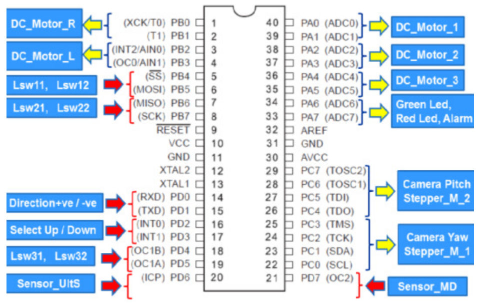


Fig.9: Main Brain, Microcontroller pins utilization ATMEGA32

Fig.10: Circuits, Test scenario 1, Test scenario 2

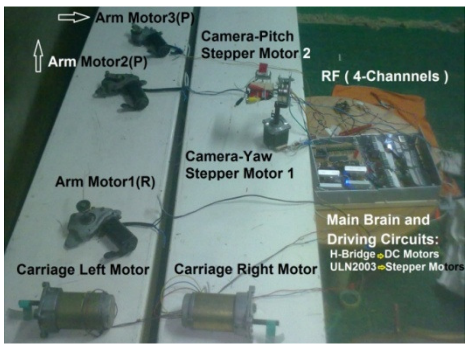
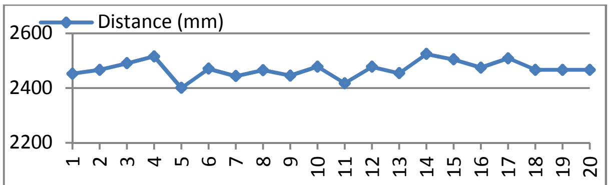


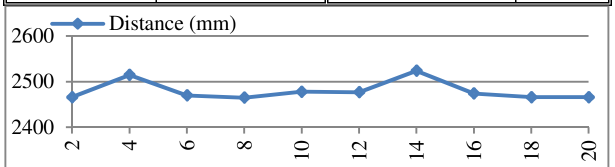
Fig.11: Test scenario 3

Repeatability test 2: In arm 3rd Joint (P), 20 commands are given to the robot to move the prismatic joint (Forward and Backward) to test the repeatability (Fig. 13).



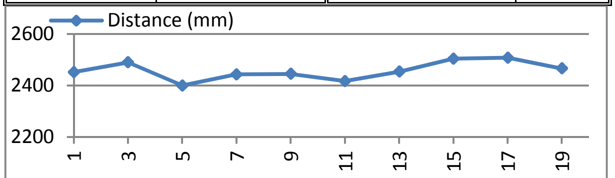
(a) Forward and Backward

Avg. Distance	2469 mm	Extreme +ve Error	2.23%
Avg. Speed	493.8 mm/s	Extreme -ve Error	-2.79%



(b) Forward only

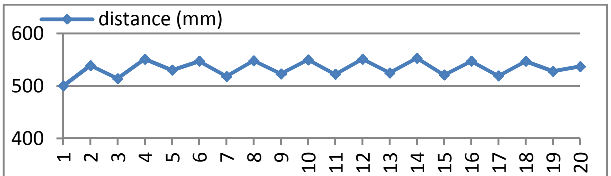
Avg. Distance	2480.1 mm	Extreme +ve Error	1.77%
Avg. Speed	49496.02 mm/s	Extreme -ve Error	-0.61%



(c) Backward only

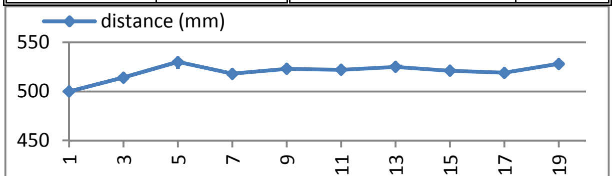
Avg. Distance	2457.9 mm	Extreme +ve Error	2.04%
Avg. Speed	941.58 mm/s	Extreme -ve Error	-2.36%

Fig.12: Repeatability Carriage Translation



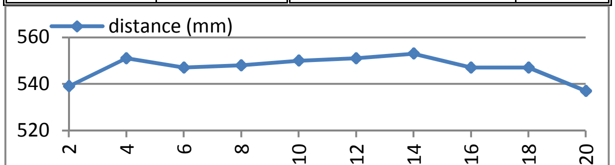
(a) Forward and Backward

Avg. Distance	533.5 mm	Extreme +ve Error	3.66%
Avg. Speed	106.7 mm/s	Extreme -ve Error	-6.28%



(b) Forward only

Avg. Distance	520 mm	Extreme +ve Error	1.92%
Avg. Speed	104 mm/s	Extreme -ve Error	-3.85%



(c) Backward only

Avg. Distance	547 mm	Extreme +ve Error	1.10%
Avg. Speed	109.4 mm/s	Extreme -ve Error	-1.83%

Fig.13: Repeatability Arm Joint3 (P) Translation

V. Conclusion and Future Work

Manual demining operations are very dangerous, exhaustive and costive (time and money). It is very important to produce assistive mechanisms like Robots to cope with the landmine fields' environment. One of the required design constraints of a robot is its contact pressure with the ground in order not to activate the imbedded landmines. In addition, the demining robot must be equipped with Multi-Sensors system to detect the imbedded landmines when scanning the infected areas. The developed prototype is only to ensure the possibility to manufacture and to remotely control a complete mobile robot from scratch in order to work in very rough terrain. Things still needed such as:

1. Enhance the tracks in order to fit in their position while moving and turning.
2. Minimize the weight of the robotic system.
3. The system hardware/software architecture enrichment is needed to do more tasks.
4. Develop better control strategies and complete scenarios for control situation.
5. Extend the wireless communication reach through utilizing varieties of communication system like: Zigbee module (> 100m) ,WiFi (> 500m)
6. Research in advanced sensors to reach deeper depth.
7. Tasks distribution between Multi-Robot systems in demining is needed.

VI. Acknowledgment

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VII. References

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