TVF-1: Experimental Model of an EOD Robot

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***Abstract*—Robots have been and are an extremely useful alternative for replacing human staff for the execution of high-risk missions in difficult and dangerous environments. The construction and use of EOD robots in such missions is an evolving field. This paper presents a model of an EOD robot named TVF-1, a model designed to emphasize the functional characteristics of the typical architecture of an EOD robot.**

***Index Terms*—robot, EOD, manipulation, disruption.**

I. Introduction

On the way to a deeper and more diversified knowledge, mankind is constantly concerned with the creation of the means and tools to be used to enhance its own capabilities.

The development of military robots has grown exponentially, and many military organizations today use robots to replace human staff in dangerous missions. The use of robots in this area comes as adaptability to the changes that occurred in the conduct of military actions (asymmetric war, terrorist actions). It can be considered that the widespread use of robotic systems in the military field will represent the next wave in the evolution of military technology [1].

Reality shows that in areas where military conflicts are underway or have occurred there is a wide variety of UXO (Unexploded Ordnance) and IED (Improvised Explosive Device). Annually a growing number of military and civilian personnel fall victim to these explosive devices. Between 2011 and 2016, Action on Armed Violence recorded over 109,000 deaths and injuries from IEDs and of these, 81% were civilians [2].

Removing the danger posed by the presence of these explosive devices is a very high risk mission when carried out by human staff.

Research efforts have been primarily geared towards meeting the requirements for replacing human staff for the execution of high-risk missions in difficult environments [3].

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II. The General Architecture of an EOD Robot

The intervention of the specialized forces for the neutralization of explosive devices involves complex missions including: detection, identification, location-based assessment, safe deployment or neutralization, recovery and destruction of improvised explosive devices or munitions.

The EOD robot is a complex mechatronic device with a degree of autonomy that allows navigation in different operating environments, being able to execute a class of useful tasks throughout its mission. Although the concept of an explosive ordnance disposal robot is not an old subject, many commercial samples have been manufactured [4].

From the analysis of the missions [3-7] that an EOD robot has to accomplish, it is remarkable: the possibility of moving in different types of field, the safe handling of objects, the possibility of remote control, master-slave control, and the capacity for destruction by disruption of targets.

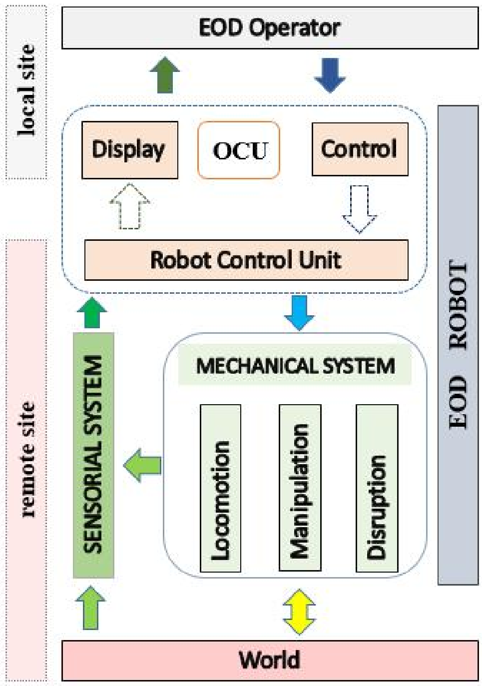

Figure 1. The general architecture of an EOD robot

The analysis of the general and specific functions of an EOD robot has led to the determination of a robot's general architecture, consisting of the following main systems:

- *Mechanical System*: Locomotion Subsystem, Manipulation Subsystem and Disruption Subsystem;
- *Command and Control System*: Operator Control Unit, Robot Control Unit, Data Transmission Subsystem, Drive and Power Subsystem;

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- *Sensorial System*: External Sensorial Subsystem and Internal Sensorial Subsystem.

The robotic system interacts with the environment through the mechanical structure. This ensures movement, positioning and orientation of the final effector. The links are of the type of direct links when the control and control system transmits mechanical system commands and inverse links when information is provided by the sensing system to the control and control system.

For disruption subsystem the robot will be armed with the appropriate tools and disruptor device. The operator will guide the robot to the target device. After using the robot camera, the operator will decide upon best placement of the disruptor before initiating it.

Control of mobile robots based on remote operation requires a robust system with an intuitive, flexible and efficient interface.

The idea of autonomous EOD robot activity is not under consideration in this paper.

III. The Experimental EOD Robot - TV1

The experimental EOD robot - TV1 was made in the Military Technical Academy and was the subject of a diploma paper [5] that was designed to highlight the functionality of the main components within a robot designed for EOD missions (Figure 2).

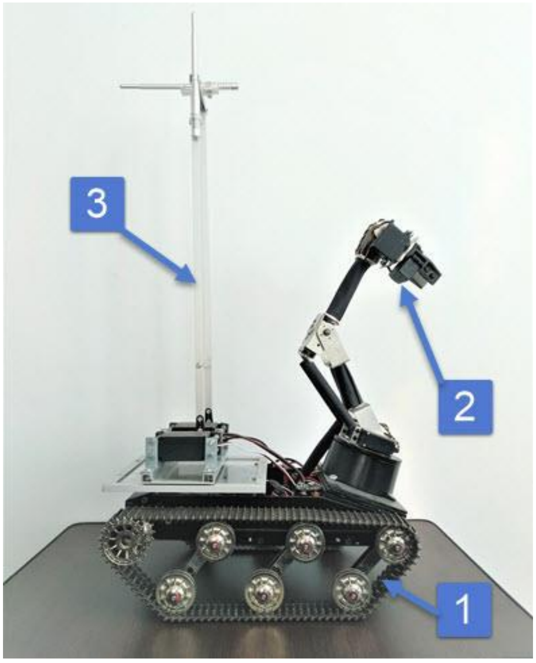

Figure 2. The experimental EOD robot - TV1 (1 – Locomotion Subsystem, 2 – Manipulation Subsystem, 3 – Disruption Subsystem)

A. Locomotion Subsystem

As a result of the analysis we can conclude that the tracking system is preferred by most EOD robots because it has the following functional characteristics: it allows to obtain a simple kinematics with firm rectilinear motion and a wide variation of the bending radius from zero to infinity; the drive is simple; the average pressure on the ground has low values; increased ability to tackle obstacles and increased resistance to ground action.

The mechanism by the locomotion robot mechanism EOD TV1 (Fig. 3) is a unit having two planes of symmetry track fixed to the frame T'REX Tank Chassis based product DAGUROBOT TANK, China.

Figure 3. T'REX Tank Chassis [8]

The main features of the all-terrain chassis are: anodized aluminum body, the gears, tracks, suspension struts and wheels are die cast zinc; 70 mm clearance, dimensions: 355 × 175 × 130 mm and 3.7 kg weight [8].

The T'Rex Tank Chassis is equipped with two independently driven 12V gear-motors with a typical current rating of 4A (No Load at 1.3A & Stall Current at 11A with a 5000 mAh LiPo Battery). Each motor drives one tank tread that offers three lower wheels that help improve traction and reduce shock to the main body and controller. Additionally, all six lower wheels have independent suspension to help improve traction and absorb shock and

B. Manipulation Subsystem

The EOD missions meet a variety of objects of different sizes and shapes and therefore, the function of gripping oriented task must be carried out with maximum handling capacity planning and the optimal disturbance rejection. It should also be borne in mind that the manipulation of objects in the EOD missions should involve high precision movements of the gripping mechanism and high accuracy in positioning.

The manipulator arm is responsible for precisely locating the end effector to the desired position.

The SES Lynxmotion Robotic Arm (Figure 4) delivers fast, accurate, and repeatable movement and is a robot developed by Lynxmotion, USA and designed for educational projects.

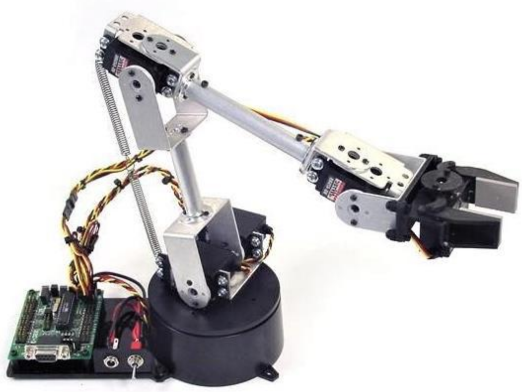

Figure 4. The SES Lynxmotion Robotic Arm [9]

The mechanical part of the robotic arm consists of black anodized aluminum brackets, aluminum tubing and hubs, custom injection molded components, and precision laser-cut Lexan components.

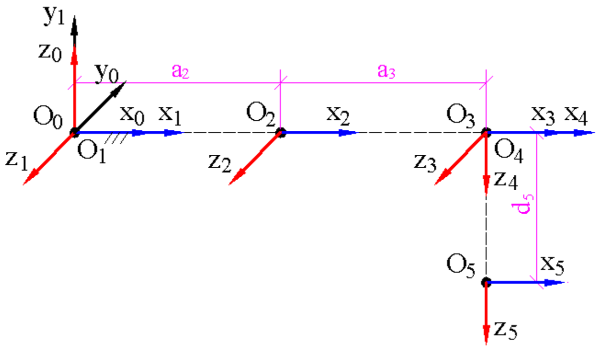

Figure 5. Coordinate reference frames for the SES Lynxmotion Robotic Arm [5]

The chosen configuration of robotic arm is the 5-DOF, a vertical articulated robot with five revolute joints in a R⊥R||R||R⊥R configuration (Fig. 4).

For an arm to perform specific tasks, the location of the end effector relative to the base is established first. This technique is called the kinematic analysis problem. In robotics, the kinematic descriptions of manipulators and their assigned tasks are utilized to set up the fundamental equations for dynamics and control. The Denavit and Hartenberg notation in Table I gives a standard methodology to write the kinematic equations of a manipulator [10].

TABLE I. D-H PARAMETERS THE SES LYNXMOTION ROBOTIC ARM

Link	$\theta_i = q_i$ [rad]	d_i [mm]	a_i [mm]	α_i [rad]
1	θ_1	0	0	$\pi/2$
2	θ_2	0	**153**	0
3	θ_3	0	**153**	0
4	θ_4	0	0	$\pi/2$
5	θ_5	**85**	0	0

For the actuation of the robotic arm it is used Hitec digital servos (HS-645 133 oz.-in. torque and HS-475 76 oz.-in. torque) to control the base, the shoulder, the elbow, the wrist and the grip.

C. Disruption Subsystem

The neutralization subsystem must meet the disruption requirements imposed by the variety of improvised explosive slides and unexploded ordnance in EOD missions.

In general, the EOD robots use explosive devices which propel the blast jets using colloidal particulate (disruptors). They are made up of a pipe made of an anticorrosive material, provided with a chamber that is filled with the disrupter (water, antifreeze, sand, balls, bolts) and with a recess where there is a pyrotechnic electric cartridge to propel the cargo.

The presence of this subsystem leads to a series of security measures for the fire-giving procedure for the propellant liquid neutralization means.

The TVF-1 EOD robot has an explosive neutralizing device subsystem consisting of a manipulator and a disrupter. The manipulator for positioning the disruption subsystem in the workspace has a length of 520 millimeters. It is powered by two TURNIGY TGY-58166M actuators acting on the kinematic element. The disruptor can be mounted in different positions (manually) to benefit from the optimal orientation with respect to the target object and to simplify the construction of the manipulator.

D. Sensorial Subsystem

In accordance with the unpredictable changes in the environment, a mobile robot needs the following categories of information: the general description of the work environment, the physic and chemical characteristics of the objects with which it interacts, and the position, the orientation and the state of the robot's internal systems.

The robot's sensorial subsystem includes the internal sensing subsystem (proprioceptive sensors) that provides information about the robot's internal state (configuration, temperature, current, etc.) and the external sensor system (exteroceptive sensors) that provides information about the state of the environment relative to the robot.

EOD robots operate in a dynamic environment where rapid changes can occur in any direction of their field of action and therefore generally require: video sensors, audio sensors (microphones and speakers), space position sensors (GPS) sensors for the detection of chemicals, or explosives.

E. Command and Control System

The analysis of existing systems has led to a teleoperation solution. A teleoperation system is based on master-slave architecture; with the master system located in a safe area (local site), and the slave system located in the remote site. Both systems require communication and data processing systems due to the distance between them. In the master system, the human operator acts on the operator control unit (OCU)) and is guided by informational feedback (provided by the slave) to execute the remote manipulation task.

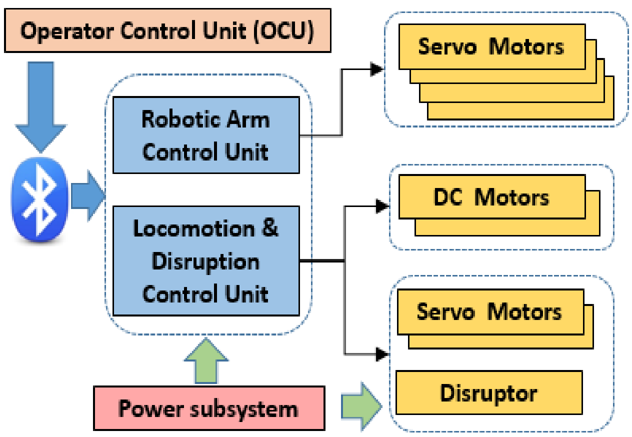

Figure 6. The TV-1 Robot Command and Control Diagram

The TV-1 Robot Command and Control System is based on the following features:

- two Arduino UNO open-source development board: one for manipulator control and one for control of the

locomotive subsystem and the disruption subsystem;
- two Bluetooth Mate Gold modules (as data transmission subsystem);
- a device with an Android (as OCU);
- two applications that allow you to control, command the robot;
- a power system.

The implementation of the command and control system is based on the use of two open source Arduino UNO development board. Arduino UNO consists of a small platform (6.8 cm / 5.3 cm) built around a signal processor that is able to retrieve data from the environment by a series of sensors and to perform actions on the environment by means of DC motors, servo motors and other types of mechanical devices. The connection of these elements that act on the environment with the development board is achieved through analog and digital ports.

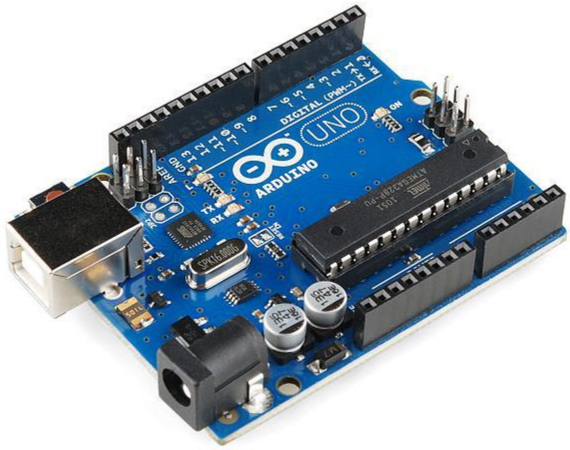

Figure 7. The Arduino UNO development board

To ensure data transfer between the device with an Android system and Arduino UNO controllers, we have attached a Bluetooth Mate Gold module (Fig. 8) to the Arduino UNO development board. The Bluetooth module has the following specifications: Bluetooth Class 1 modem, data transmission distance: 100 meters, power supply 3.3 - 6 V, capable of transfer rates between 2400-115200 bps and an antenna included on the board.

Figure 8. The Bluetooth Mate Gold module

The large number of mechanical elements to be operated, used in the construction of the experimental model, requires the use of two development boards Arduino UNO. Each drive element uses a digital pin in this case and the open-source board has only 14 digital pins. Thus, it has been chosen to construct two different circuits grouping the subsystems of the experimental model according to the number of pins used.

The first command and control circuit consists of seven servo motors of the manipulation subsystem, the Bluetooth module, the Arduino UNO development board, and the power system. The hardware connections are shown in Fig. 9.

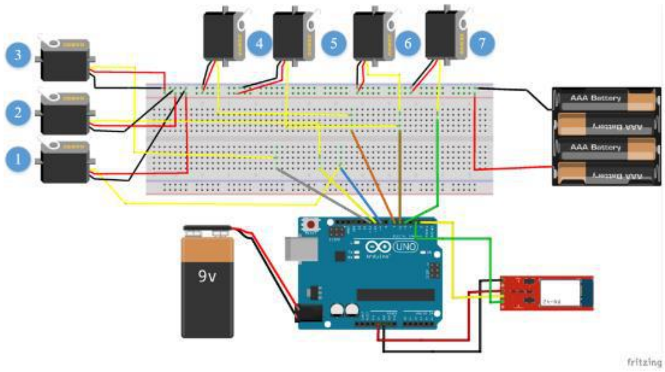

Figure 9. The robot command and control system for manipulation subsystem [5]

The second circuit (Fig. 10) is made up of the Bluetooth module used, Arduino plate, the two actuators of the manipulator for positioning the composition in Cartesian space disruption system, the power supply system and two DC motors of the locomotion system.

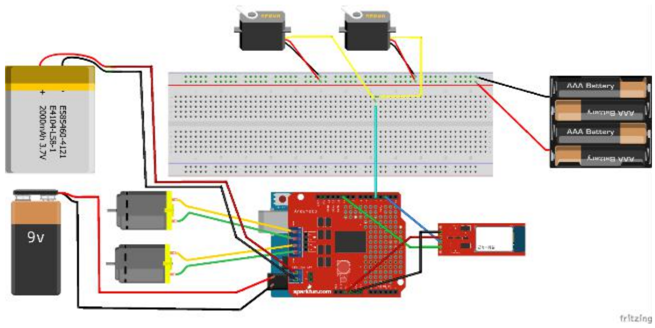

Figure 10. The robot command and control system for locomotion and disruption subsystem [5]

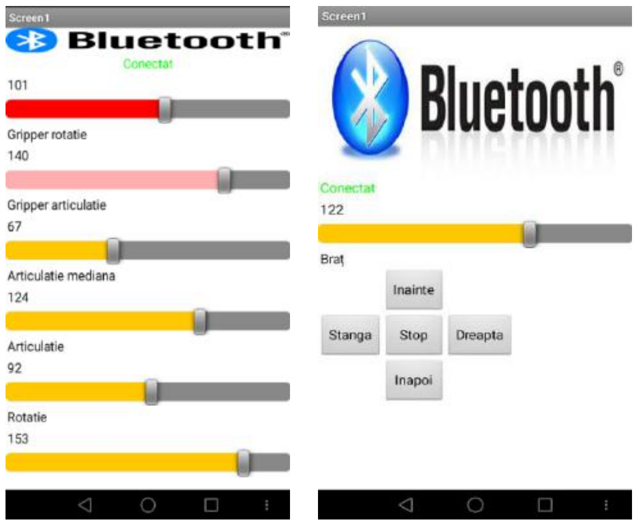

Figure 11. The android interface for command and control of the EOD robot TV-1 [5]

The power system that consists of: two 9 V batteries to power the Arduino UNO boards, two 6V batteries to power servo-motors and a 7.4 V battery for the locomotion subsystem.

The graphical interface attached to the application for the remote control of the EOD TV-1 robot allows you to connect and synchronize the Android application with the Arduino UNO development board and control the angle accessed by each servomotor of the experimental model. The application sends the specific numerical values to achieve the action of the mechanical elements in the robot's composition (Fig. 11).

IV. Field Tests

Various experiments prove that the TV-1 EOD robot can basically meet the requirements of executing tasks of EOD mission but with limitations due to the hardware and software used.

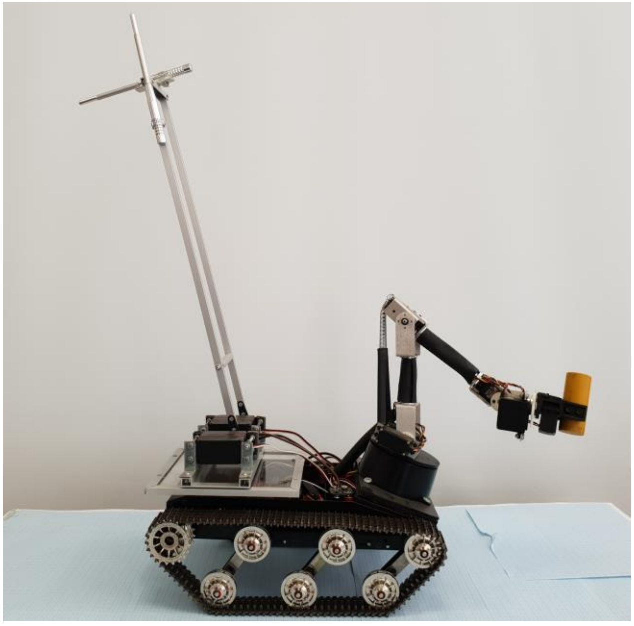

Figure 12. Manipulation test of the EOD robot TV-1

Field tests have shown that:

- the locomotion system is robust, manageable and staff efficient with acceptable speed and overcomes most obstacles encountered;
- mechanically the arm performed well with the expected loads for the arm (Fig. 12);
- the manipulator for the disruption subsystem has responded well and together with the disrupter assembly system can successfully perform disruption operations (Fig. 13);
- the robotic arm can be successfully employed against a IED in manual mode. The results show that the length of the arm link from elbow to effector needs to be longer. This will provide the ability to place or pick up objects from a greater distance;
- the wireless communications architecture for manual control of the arm was satisfactory for the expected communication ranges (line of sight) for the robot;
- command and control interfaces are intuitive but lack the integration of sensory information received from the robot;
- the operator controls the angle of each joint individually, so a number of adjustments are required to reach the exact position and orientation of the end effector. For special tasks where the precision is very important, this control method is insufficient and too slow to accomplish the given task.

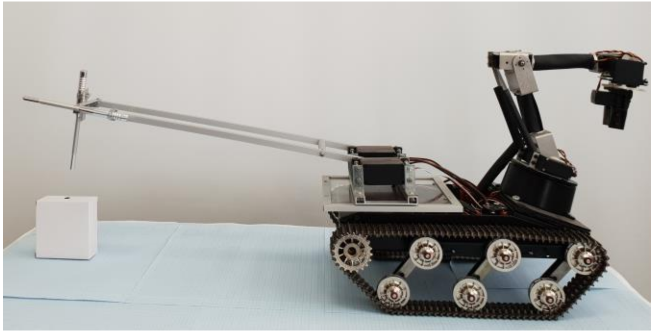

Figure 13. Disruption positioning test of the EOD robot TV-1

V. Conclusion and Future Work

The experimental model of the TVF-1 robot has been successfully developed and realized based on the general architecture of an EOD robot.

The robot is designed to replace human explosive specialists and perform EOD tasks providing completely safe conditions for human life.

The experimental model highlights: the adaptability of the EOD TVF-1 robot to the variable environment of EOD missions, the functionality of the control and control system, the use of mechatronic elements in the construction of a multifunctional robot.

This project will continue through the integration of a more complex sensory system, the development of more intuitive and user-friendly applications and interfaces in EOD missions.

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