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Remote Controlled Wheeled Mobile Robot for Humanitarian Demining Purposes

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Abstract. There are millions of lethal land-mines that have been left in many countries after conflicts. They represent a particularly acute problem in developing countries and nations already economically hard hit by war. The problem of unexploded mines has become a serious international issue, with many people striving to find a solution. These mines kill or injure thousands individuals each year, most of them civilians. This paper will present an extended work on a wheeled mobile robot for humanitarian demining.

Introduction

Even if hostilities have ended, mines continue to make casualty, thousands of people being killed each year in the world. Many mines usually used did not have auto-destruction or auto-neutralization mechanism. From that moment, those explosive objects are active weapons even after the end of military conflicts. There are millions of lethal land-mines that have been left in many countries after a conflict, which represent a particularly acute problem in developing countries and nations already economically hard hit by war [1].

Mine clearance is a very dangerous job that not many people are willing to take up, and involves hours of careful searching in the ground. This is why mobile robots could be used to go out and search mines on the ground. They are more expendable than a human life, and they could be easily replaced if a mine is set off. Robots could be used to set off the mines because they can be designed to withstand minimum damage. They could become far more efficient at clearing mines than humans [2].

Demining for civilian or humanitarian purposes is different than the military task. In the military, the goal is to breach a line for passage quickly and under all conditions, and therefore it is unrealistic to aim for 100% clearance. By comparison, in humanitarian demining the goal is to restore an area back to an economically productive state. In humanitarian demining the priority is strictly on clearance reliability, while in military contexts speed is typically paramount [3].

It has been recognized that developing modular and cheap robotic systems that could offer reliable, cheap and fast solutions for the demining operations is an important challenge. The development and implementation of robotics in mine clearance is attractive and it is building up momentum to spare human lives and enhance safety by avoiding physical contact with the source of danger in mined area, improve accuracy, help in mined area reduction, increase productivity and enhance effectiveness of repetitive tasks, necessary in the demining process [4]. Solving this problem presents challenges in robotic mechanics and mobility, sensors and sensor fusion, autonomous or semi autonomous navigation and machine intelligence.

Even if there are some reported researches into individual, mine-seeking robots is still at the early stages [2, 3, 5, 6, 7, 8, 9, 10, 11]. In their current status, they lack flexibility and yet they represent a costly solution for mine clearance operation. But, if designed and applied at the right place for the right task, they can be effective solutions.

The automation of an application such as the detection and removal of antipersonnel mines implies the use of autonomous or teleoperated mobile robots. These robots follow a predefined path, send the recorded data to their expert-system (in charge of processing the collected data), mark the ground when a mine is detected with a probability of predefined level and possibly remove the detected mine.

In this paper, an extended work on the design and the control of a simple, modular and cheap solution of wheeled mobile robot for humanitarian demining purposes will be presented.

Robot Architecture and Kinematics

A construction using three wheels insures a permanent contact with the ground without adding any suspension. The repairing requirements lead us to a modular design of our robot: three similar units of driving and steering wheels are fixed on the main frame. The fastening and the connections of the units to the frame should be as simple as possible to allow a quick removal. In case of breakdown or damage a module can be easily replaced by a new one. The defective unit will either be repaired locally or returned to the factory for more important repair, or thrown away if it is badly damaged. The wheels can be removed and replaced very easily because of the modular conception. All the wheel modules are identical and they are fastened to the robot frame with fast screw connections.

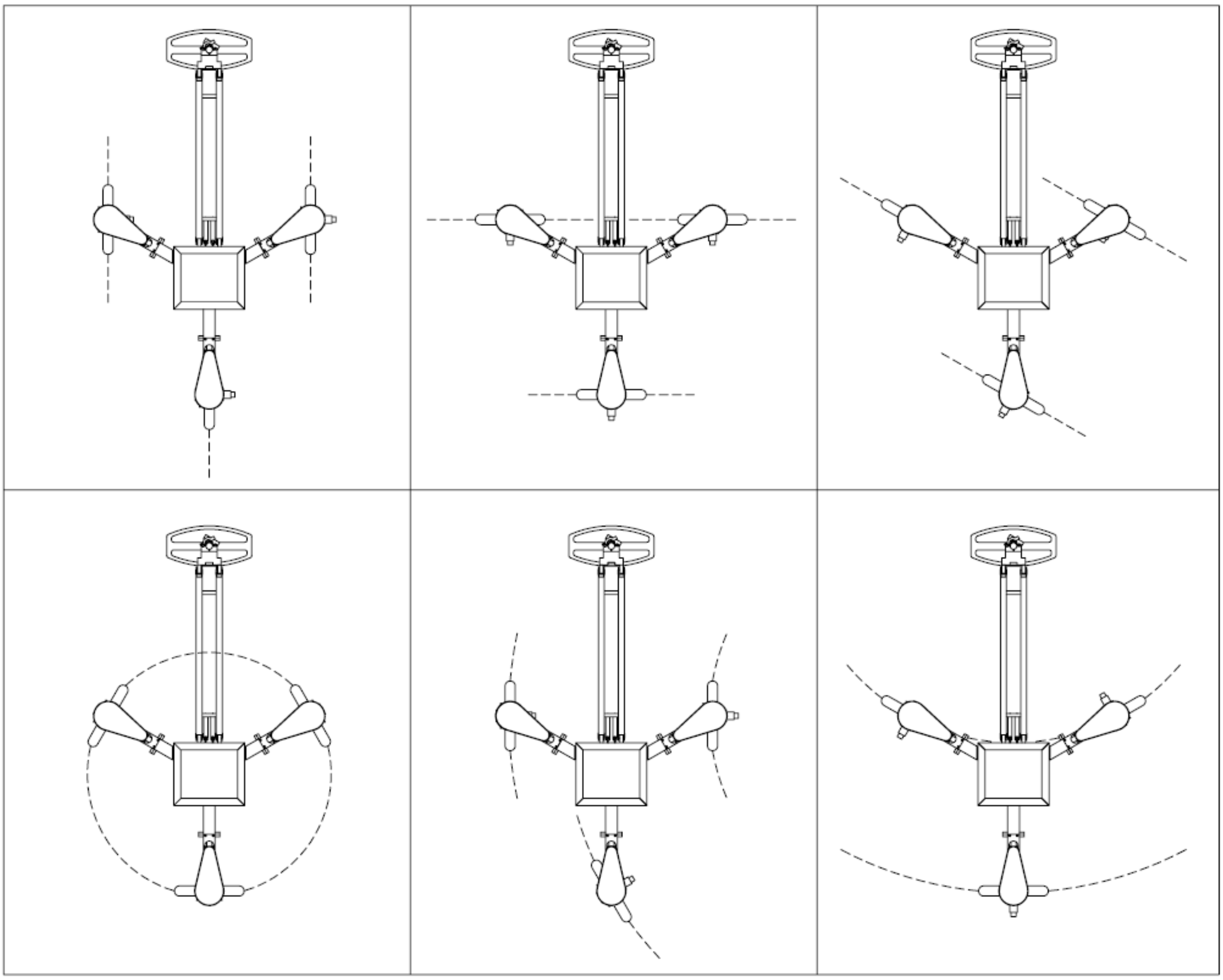

Fig. 1. Possible trajectories of the robot

Thanks to the three steered standard wheels, we get an omni-directional mobile robot. It can perform a linear motion in any direction relative to its body; follow circular trajectories in different configuration or turn around its center (Fig. 1). In contrast, a robot with synchronous drive can only perform linear motion. This means that a synchronous drive robot cannot follow smooth circular trajectories and cannot turn in place.

As drawbacks of this robot architecture, we can mention: the wheels should be very well aligned in order to avoid wheels slippage; when turning the wheels in place, on a surface with vegetation, it is happen with a high friction; using a passive arm for metal detector, it is difficult to maintain an approximately constant distance between metal detector and the ground during surface scanning (metal detector may touch the ground, fact that could make the mine exploded, see Fig. 2).

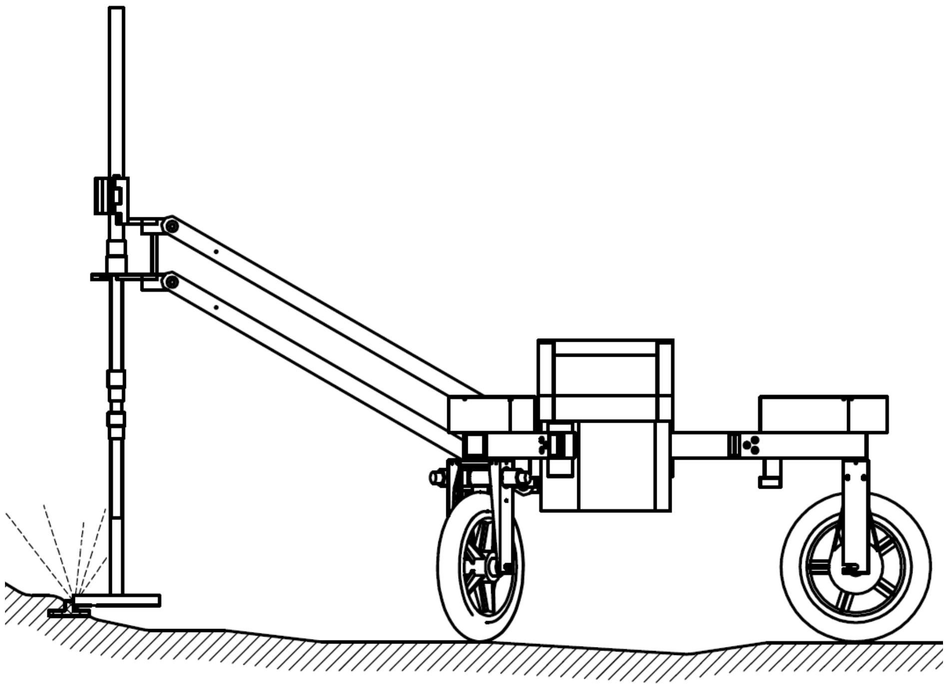

Fig. 2. Metal detector touching the ground

To improve the wheels alignment precision, new encoders have been used on the output shaft of the reducers responsible with wheels orientation (Fig. 3). Using this solution, the errors introduced by gears will be eliminated. Also, the number of impulses measured for a complete orientation of the wheel will be much smaller.

In a previous design of the robot, the scanning arm was passive, which follows the shape of the ground thanks to some flexible springs. But this springs are not able to react on difficult terrain when the robot is fast moving. This may produce a collision between metal detector and the ground. If this collision is happening when a mine is under the metal detector, it may explode. This is why the new design is using an active arm actuated by a motor and a screw-nut transmission, as we see in Fig. 3.

An horizontal ultrasonic sensor is used to detect the obstacles and a vertical oriented ultrasonic sensor is used to measure the distance between the metal detector and the ground (Fig. 4). Based on the information sent by these sensors, the arm will be moved up or down, in order too keep an approximately constant distance between the detector and the scanned surface (if the distance is too short, we may have collision, if it is to high, the mine could not be detected).

In order to write inverse kinematics equations, we assume that our mobile robot is moving on a plane and there exists no sliding skidding friction, but the rotation of the wheel about its own axis and also the orientation of this wheel about a vertical axis are allowed (Fig. 4), and we consider three coordinate frames to be used: the floor reference frame, $X_f Y_f Z_f$; the mobile robot with its origin at the center of the platform, $X_R Y_R Y_R$; and, the wheel coordinate frame with its origin at the center of each wheel, $X_w Y_w Y_w$.

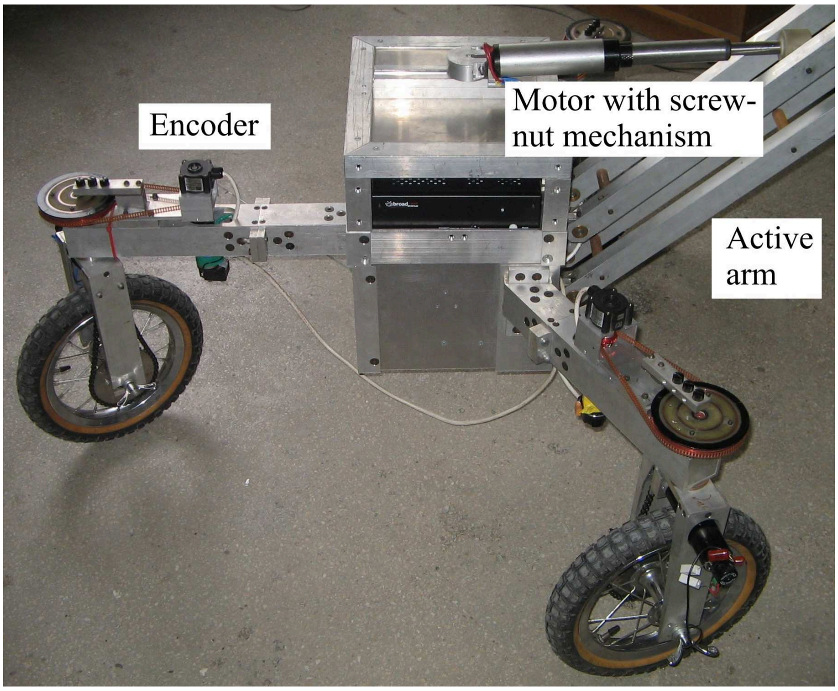

Fig. 3. Improved prototype of TriDem robot

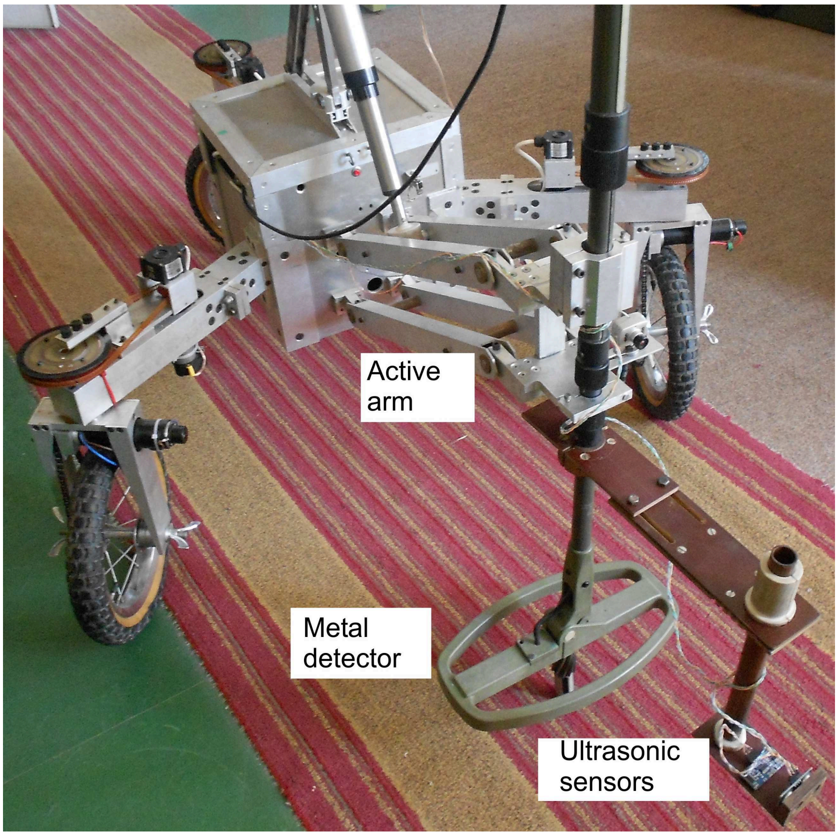

Fig. 4. The last version of TriDem robot

Inverse kinematics of the robot, based on Fig. 5, is written as following:

$$\begin{bmatrix}\dot{\beta}_1+\dot{\varphi}_1\\ \dot{\theta}_1\end{bmatrix}=\frac{1}{r\left(\frac{l_2}{3}\sin\varphi_1-\frac{l_1}{2}\cos\varphi_1\right)}\cdot\begin{bmatrix}-r\sin\varphi_1 & -r\cos\varphi_1\\ -\frac{l_1}{2} & -\frac{l_2}{3}\end{bmatrix}\cdot\begin{bmatrix}v_{O_{Rx}}\\ v_{O_{Ry}}\end{bmatrix} \quad (1)$$

$$\begin{bmatrix}\dot{\beta}_2+\dot{\varphi}_2\\ \dot{\theta}_2\end{bmatrix}=\frac{1}{r\left(\frac{l_2}{3}\sin\varphi_2+\frac{l_1}{2}\cos\varphi_2\right)}\cdot\begin{bmatrix}-r\sin\varphi_2 & -r\cos\varphi_2\\ -\frac{l_1}{2} & -\frac{l_2}{3}\end{bmatrix}\cdot\begin{bmatrix}v_{O_{Rx}}\\ v_{O_{Ry}}\end{bmatrix} \quad (2)$$

$$\begin{bmatrix}\dot{\beta}_3+\dot{\varphi}_3\\ \dot{\theta}_3\end{bmatrix}=\frac{1}{-r\frac{2l_2}{3}\sin\varphi_3}\cdot\begin{bmatrix}-r\sin\varphi_3 & -r\cos\varphi_3\\ 0 & \frac{2l_2}{3}\end{bmatrix}\cdot\begin{bmatrix}v_{O_{Rx}}\\ v_{O_{Ry}}\end{bmatrix} \quad (3)$$

where: θ_i is the rotating angle of the wheel i $(i=1,\ 2,\ 3)$, φ_i is its steering angle, measured from X_{wi} to X_R, and β_i is the angle between X_f and X_{wi}; r is the wheel radius, $\dot{\theta}_i$ is the angular velocity of the wheel i; $\dot{\beta}_i+\dot{\varphi}_i$ is the orientation angular velocity of the wheel i; $v_{O_{Rx}}$ and $v_{O_{Rx}}$ are velocities of the robot along x and y axes.

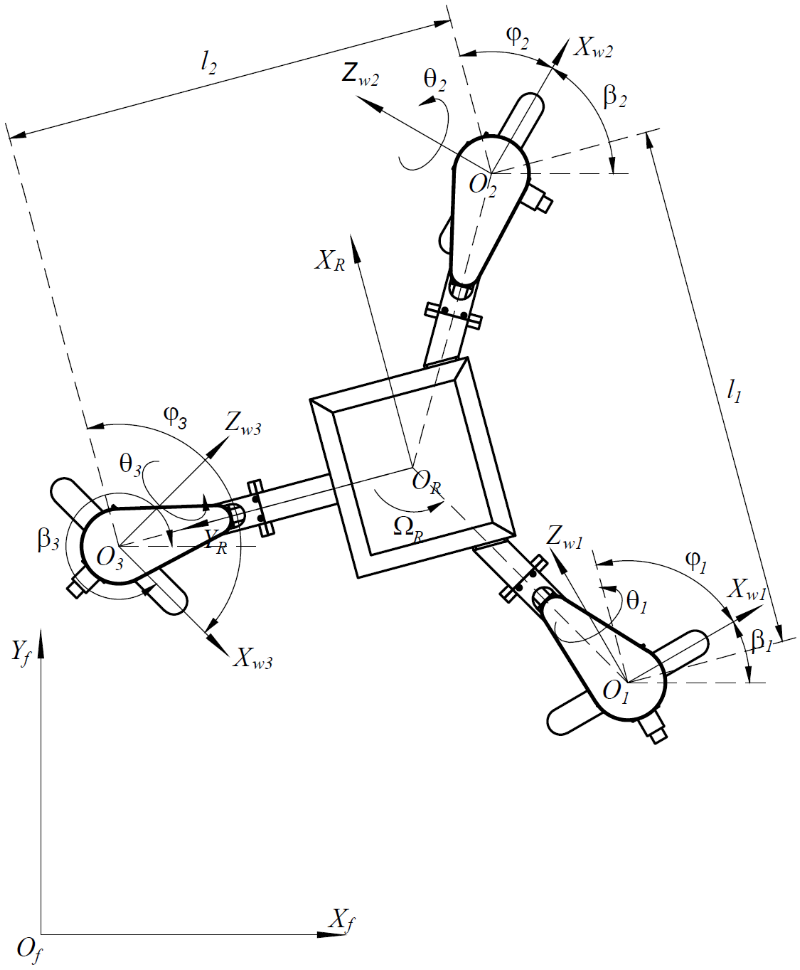

Fig. 5. Robot kinematics

TriDem is an omni-directional robot, having three d.o.f. So, we may define three independent coordinates. However, only three inputs are not enough to avoid singularity positions, at least two active wheels (two driving and two steering motors) being necessary [12, 13]. In such conditions, our system is redundant, with θ_1, θ_2, θ_3 and φ_1, φ_2, φ_3 as active joint variables. For given linear and angular velocities of the robot, the system tries to calculate the joint angular velocities in real time, imposing β_1, β_2, β_3.

Robot Control

The last prototype of TriDem mobile robot is controlled by a wireless joystick. An overall view of the robot control hardware is shown in Fig. 6. A microcontroller disposed on the robot is responsible for the robot control. The joystick is connected to a computer, via an USB port. The commands of the human operator are send to the robot thru this joystick and wireless connection between computer and microcontroller. Information concerning robot movements, presence of an obstacle, presence of a mine, etc., are sent from microcontroller to the computer. All these parameters may be visualised by human operator thanks to a graphical user interface (see Fig. 7). A wireless video camera, disposed on the robot arm, send images to the same graphical interface, so that human operator is informed about the work environment of the robot.

In most robotic applications, the robot has to be operated by an inexperienced user. Therefore, a simple and intuitive interface is required especially when the robot has many motors and degrees of freedom. We developed such an interface for TriDem.

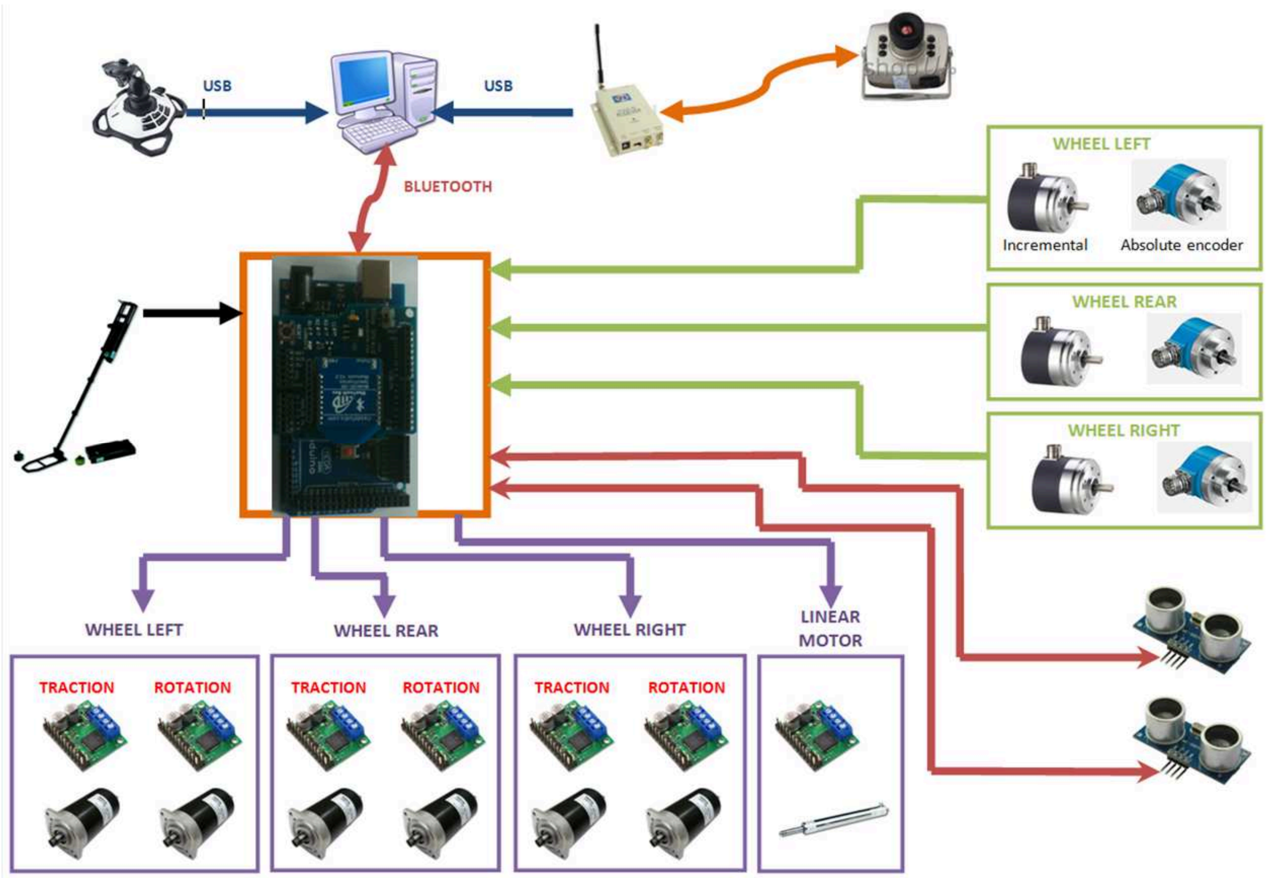

Fig. 6. Robot control hardware

In Fig. 7, we have used next notations: 1 - image from video camera; 2 - buttons for Bluetooth connection between robot and computer; 3 - display of the trajectory mode of the robot; 4 - diagram of the distance between metal detector and the ground (measured by one vertical ultrasonic sensor); 5 - picture of the wheels rotation animation; 6 - direct animation of robot; 7 - status information of the wheels; 8 - button for opening 9 window; 9 - window for setting thresholds of the metal detector.

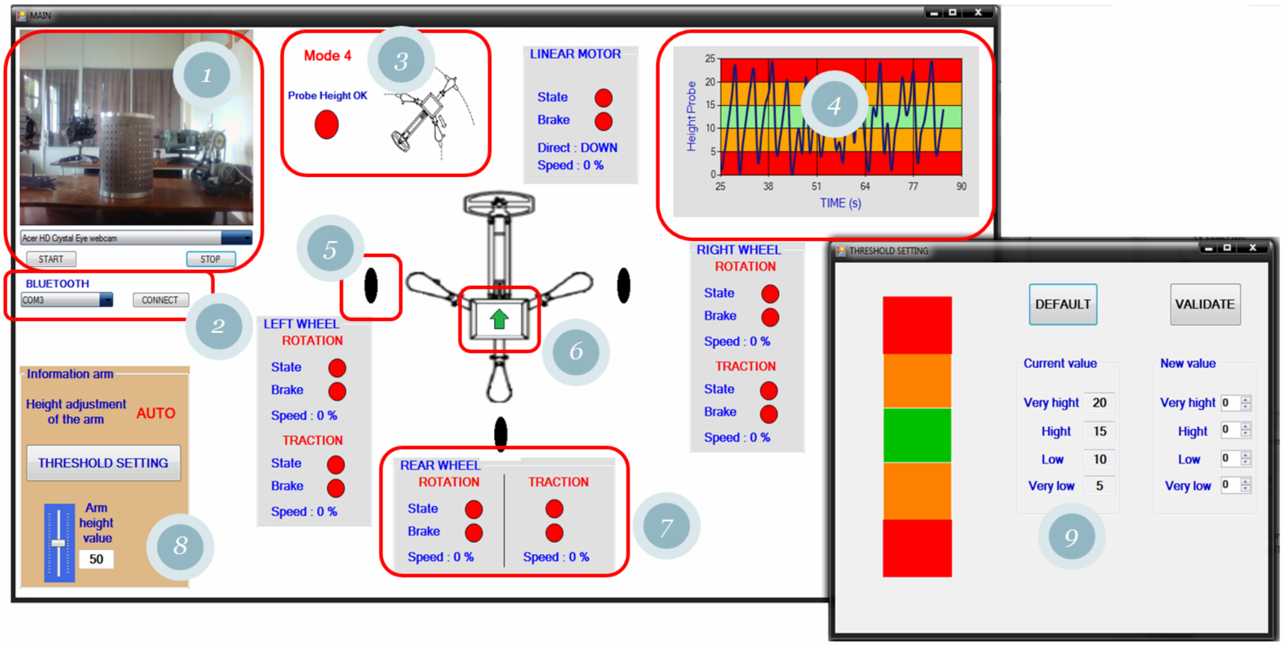

Fig. 7. Graphical user interface

Summary

Mine clearance is a very dangerous job that not many people are willing to take up, and involves hours of careful searching in the ground. This is why mobile robots could be used to go out and search mines on the ground. They are more expendable than a human life, and they could be easily replaced if a mine is set off. Robots could be used to set off the mines because they can be designed to withstand minimum damage. They could become far more efficient at clearing mines than humans. It has been recognized that developing modular and cheap robotic systems that could offer reliable, cheap and fast solutions for the demining operations is an important challenge. In this paper, an extended work on the design and the control of a simple, modular and cheap solution of wheeled mobile robot for humanitarian demining purposes will be presented. After a presentation of the robot architecture and kinematics, an overall robot control hardware and a graphical user interface are discussed.

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