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CONTRIBUTIONS TO THE SEARCH AND RESCUE ROBOTS' DEVELOPMENT WITH TRISTAR AND WHEGS UNITS

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Abstract: *The authors are presenting in this paper, search and rescue robots (SRR) equipped with hybrid systems for locomotion. The robots are using locomotion systems with TriSTAR units, Whegs units and development directions towards multimodal locomotion systems. Design related details of the robots and locomotion units, also the robot's locomotion and control are presented.*
Key words: *mobile robot, search and rescue, hybrid, multimodal, locomotion.*

1. INTRODUCTION

Searching is a primary activity performed inside a building or under rubble, with the aim of detecting survivors or the dangers to which rescuers are exposed during rescue operations.

Activities which take place immediately after a minor or a major incident and directly addresses the risks and survival of the affected persons is described generally under the term rescue. The most important activities are the localization and rescue of the survivors, by also taking in consideration the assessment of medical condition and stabilization of them. The term rescue is also enough often utilized for replacing the search and rescue expression, which is describing in fact the activities and teams operating in this domain, while the rescue term is also often utilized to track a larger disaster management activity necessary to support salvation teams and injured persons [1], [2].

The regular search and rescue process normally requires two paths: strategic and tactical. Strategic operations are mainly focusing on the coordination and planning for the entire mission, which involves mobile robots with sensor systems, wireless communication networks or logistical backup. The response of the rescue teams during a natural disaster is always a race against the clock, by trying to reach all potential survivors as soon as possible.

Rescue robots help rescuers in a catastrophe by providing video images in real time and other necessary information regarding the situation. The rescue robots could be used for military applications also, because often the operations are enough similar between the two domains. However, certain tasks specific to search and rescue robots are significantly different from their military counterparts. Also, the human-robot interaction is totally different in search and rescue robots compared to military robots [3].

2. DESIGN OF SRR

It`s quite challenging to develop and build a robot which operate in different scenarios and terrains for various purposes. Thus, there are several factors that can contribute to the design, functionality and feasibility of a SRR.

To overcome this type of challenges, robots are made for specific operations with well-defined purposes in well-known environments. Thus, depending on the mission of the robot, it can be designed in various shapes and sizes [5].

2.1 The dimensions of the robot

When it comes to size, the decision to build a large or small robot is a difficult one, as each brings advantages and disadvantages. The large robots, through their structure, allow them to be equipped with several search and rescue devices,

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such as sensors, more powerful actuators and the necessary supplies. This ability can be disadvantageous because a larger mass involves higher power consumption during the locomotion and other robot functions, and the batteries needed to power a large robot could be detrimental to its operation. However, large robots tend to be more adaptable at overcoming obstacles that could easily stop a smaller robot [6].

Unlike large robots, small robots can reach much easier inaccessible areas to human or canine personnel. They may also operate on a much smaller power source, but may have fewer functional elements, such as sensors or radiocommunication systems. The funds required to support a smaller robot may be considerably smaller than if the robots were large. It should also be noted that the loss of a smaller robot in a mission is easier to bear financially [5], [6].

2.2 The locomotion system of the robot

Another significant factor in designing a robot is choosing the robot's locomotion system. In the construction of mobile robots, conventional wheels have been and they are still used, these being the simplest to control, having many years of rigorous research in their development as a method of travel for the automotive industry. Recently, the utilization of legs for the robots has been desired because, using the living world as inspiration, this offered the prospect of moving through almost any terrestrial environment with great flexibility, which would be beneficial to the general purposes of mobile robots in search and rescue operations.

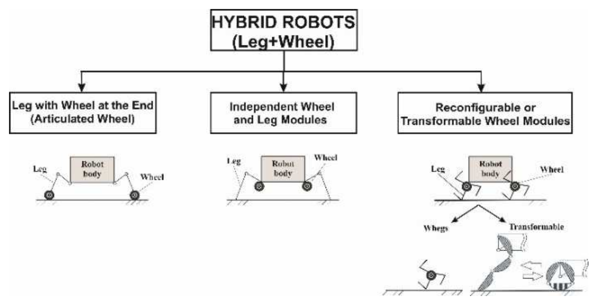
Other useful locomotion systems used in this field are those on tracks or those moving by crawling specific to snake-type robots. Although the performance of robots with tracks is quite good on rough terrain, they can encounter trouble during the stair climbing process.

- *Hybrid Leg-Wheel locomotion system*

Due to the fact that both locomotion possibilities (wheels and legs) have advantages desired by robot designers, in the last years more attempts were done to combine them and obtain robots with leg-wheel type hybrid locomotion systems.

These systems (leg-wheel) can be classified into three categories, as shown in Fig. 1 [7]:

- articulated wheels (modules using leg with wheels at their end);
- separate wheel and leg modules;
- transformable / reconfigurable wheel modules.



a) b) c)

Fig. 1. Hybrid locomotion system categories [7]

There are other hybrid systems that combine tracks with wheels, tracks with legs or tracks with wheels and legs [8].

The first three robots which the authors have proposed in the paper fall into the third category presented in Fig. 1 (c).

The paper is structured in the following way: in the 3rd part are presented the SRR developed and proposed by the authors, in the 4th part future research directions are presented, and the conclusions of the paper are presented in the 5th part.

3. MODELLING AND DEVELOPMENT OF THE SRR WITH TRISTAR AND WHEGS UNITS

By developing an efficient robot locomotion system, alternative solutions are provided to many problems from this domain. By using such a system, the robot must have the possibility to overcome multiple types of obstacles that may arise during the search and rescue process [9].

In order to make the best decision and choose the right type of locomotion system to be used in a SRR, is important to consider also the environment where the task proposed is performed, the type of task and the size of the robot which will perform it [10].

For this purpose, the paper presents the constructive variants of robots for search and rescue proposed by the authors

3.1 The first constructive variant – SRR with TriSTAR units

The first proposed constructive variant is a mobile robot with a hybrid locomotion system consisting of four TriSTAR units, two being active and two passive (Fig. 2). The robot is also equipped with LED light sources, smoke sensor, proximity sensors, battery and an Arduino board for control.

The size of the proposed robot are 872 mm (Length) x 620 mm (Width) x 400 mm (Height) and it was developed for buildings which are damaged by disasters or rough terrain. One of biggest advantages of this robot is that it overcomes various obstacles as well as stairs. During the design process of the robot, the focus was mainly on the locomotion system to have the possibility to successfully use it in the search and rescue field [11].

a) b)

Fig. 2. The designed robot a) and the locomotion unit used b)

The TriSTAR unit is built of 3 legs which are positioned on 120 degrees, having also a conventional wheel mounted at their end. There are two types of TriSTAR units, passive and active, the difference being that the passive units are not having gear system and are not actuated by any kind of motor [11], [12].

A simplified operation diagram for the SRR is presented in Fig. 3. The power supply is represented by a 12V battery, which powers the DROK motor driver. The driver controls the movement of the two drive elements via the Topran 108792 DC motors and at the same time powers the Arduino Uno development board with 5V.

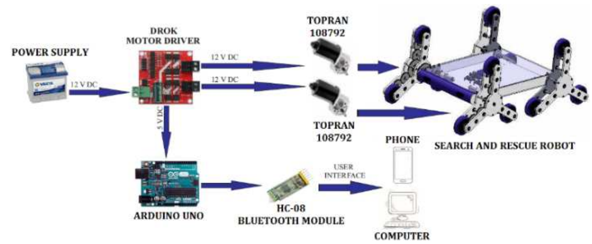
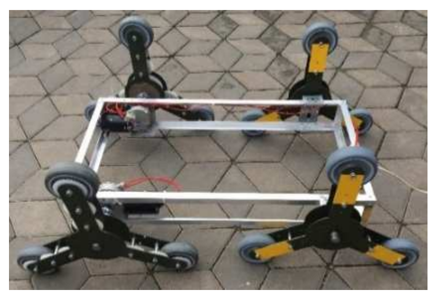


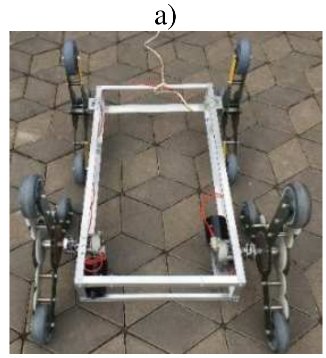
Fig. 3. Diagram of the SRR

The remote control for the robot is performed by the human operator via the graphical user interface (GUI) installed on a mobile device. The control signal for the motors and enabling Bluetooth communication is made by Arduino Uno.

A prototype was developed and built to test and validate the locomotion units proposed (Fig. 4). Two Topran DC motors with reducer (108792 series) were used to drive the prototype [11], [13].



a)



b)

Fig. 4. Experimental prototype of the proposed robot platform

Various scenarios have been proposed for testing and validating the experimental prototype built and the locomotion process. The robot was tested on surfaces coinciding to those found in the search and rescue area.

Thus, in Fig. 5, you can see images from the robot testing on: straight paved surfaces, straight gravel road, grass surfaces, mud, stairs, different categories of gravel comparable to rubble.

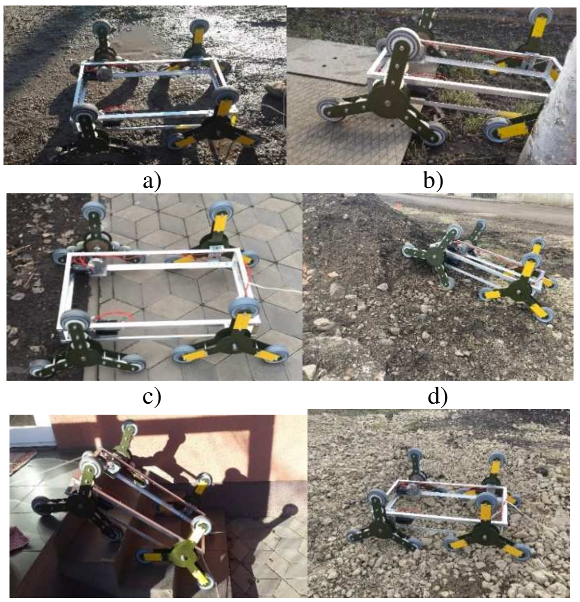


Fig. 5. Images from testing performed outside with the experimental prototype on various locomotion terrains [11]

After the experimental tests were done, the following conclusions can be drawn [11]:

- The operating environment of the search and rescue mobile robot is a difficult and harsh one that requires a flexible locomotion system, to ensure the possibility to adapt to various categories of terrain;
- To avoid blocking the wheels on the proposed solution (because of debris or mud which can get inside of the sprockets or axles from the transmission system) it is required to have a closed and sealed transmission system for the TriSTAR locomotion units;
- Due to the size of the robot, the wheels and the materials used, problems may occur when transporting it, so it is highly recommended to decrease the robot dimensions, so the robot can be transported, inside a backpack for example;
- If the robot has to overcome obstacles like steps of the stairs, the locomotion units have to be designed alike as to avoid interference with the steps, otherwise the robot will remain stuck on the stairs without being able to continue the mission;
- In case of the proposed locomotion unit, it is necessary to increase the size of the wheels of the TriSTAR units and improve the platform structure of the robot to allow a better flexibility to the specifics of the locomotion surface;
- An improvement could be the power supply from batteries, but this comes with the disadvantage of increasing the robot's weight and a limited energy autonomy. It is known that when the cable is supplied, the robot's mobility is limited by the power cable, however the energy autonomy is unlimited.

Following the experiments with the prototype, the authors proposed a SRR using a locomotion system consisting of 2 improved TriSTAR locomotion units and 2 conventional wheels.

Depending on the situation on the ground, the platform can be used with four TriSTAR locomotion units or with four conventional wheels [14], [15], [16]. Fig. 6 shows the new hybrid robot model for search and rescue [11].

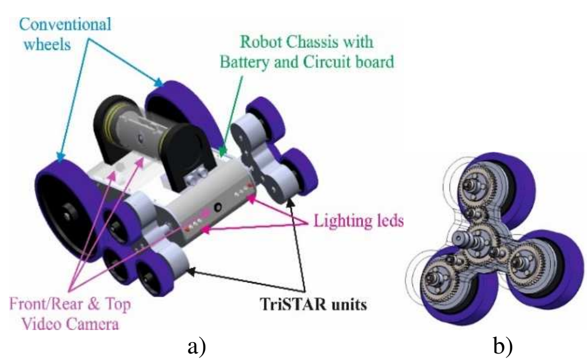


Fig. 6. 3D model of the SRR with hybrid locomotion a) and TriSTAR locomotion unit b) [10]

The dimensions of the proposed improved robot are the following: 400 mm (Length) x 380 mm (Width) x 180 mm (Height), for an easier transportation. The robot contains multiple video cameras, sensors, LEDs as light source, Arduino development board, battery as power source and 4 GHM-01 DC motors with gear reducer [17].

As can be observed in Figure 8, it is also possible to equip the robot with a serial robotic arm. The robotic arm has 5 degrees of freedom and is equipped at its extremity with a video camera.

The locomotion units have been improved by designing them with the possibility to be sealed to prevent debris or mud from reaching the gears and blocking them.

Compared to the first locomotion unit design (Fig. 2b), the second proposed TriSTAR unit (Fig. 6b) shows improvements in the design of the gear transmission.

The geometry of the TriSTAR unit allows it to switch between walking locomotion - automatic climbing mode and wheeled locomotion - advancing mode by using only one drive motor [11], [12], [15].

The 3D model of the locomotion unit was designed and developed considering the challenges experienced during the field tryouts. The TriSTAR unit (Fig. 6b) has a total height of 200 mm, and the maximum height of the possible overcomed obstacles is 100 mm [11], [14].

- *Control of the TriSTAR SRR*

To have the possibility to remotely control the robot and the special modules during search and rescue operations, a GUI (Fig. 7) was developed in Matlab.

This contains a main window for monitoring in real time the environment, concerned by accidents and natural calamities and for controlling the movement of robot.

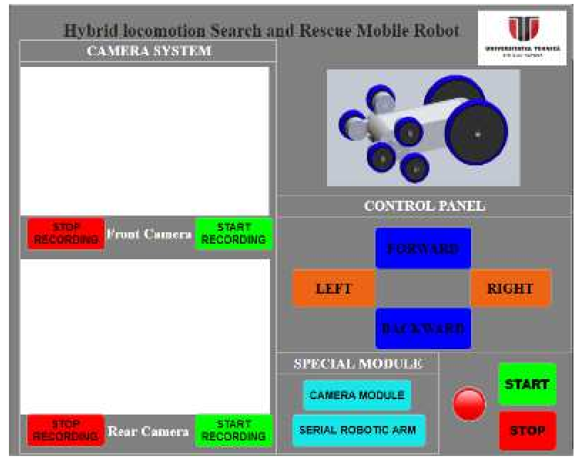


Fig. 7. The main GUI for controlling the robot and the special modules developed in Matlab [11]

To use the functionalities from the special modules (serial robotic arm and camera module), the main window provides access into the secondary GUI (Fig. 8 and Fig. 9) [11].

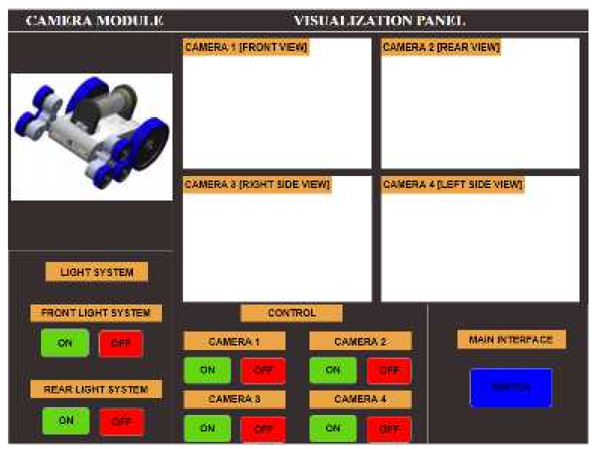


Fig. 8. The secondary graphical interface for controlling the special modules developed in Matlab [11]

The graphical interface of the camera module (Fig. 8) controls the light sources and provides in real time detailed monitoring of the surroundings from field. The light sources and video cameras have the possibility to be turned on and off remotely in order to decrease the energy consumption by the robot [11], [14].

The graphical interface of the robotic arm module (Fig. 9), is used for precisely controlling the angular position of the rotation joints of the robot and the robotic gripper.

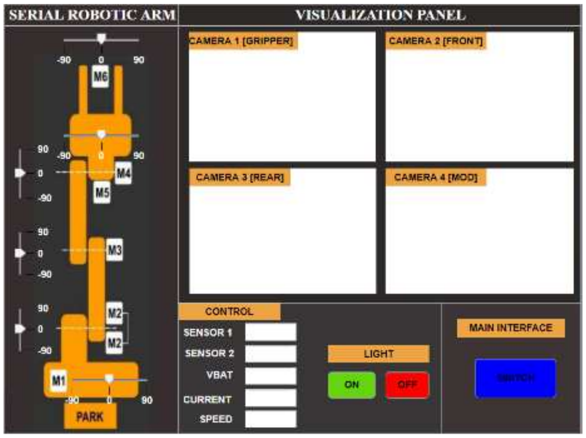


Fig. 9. Secondary GUI for controlling the robotic serial arm used by the mobile robot [11]

The secondary GUI for controlling the 2 special modules and their functions have a key button that gives the possibility of switching back to the main control interface of the SRR [11].

On the gripper (Fig. 10) there is installed an additional light source and a video camera to provide precise and safe handling during the removal of obstacles and inspect the operating environment [11], [14].

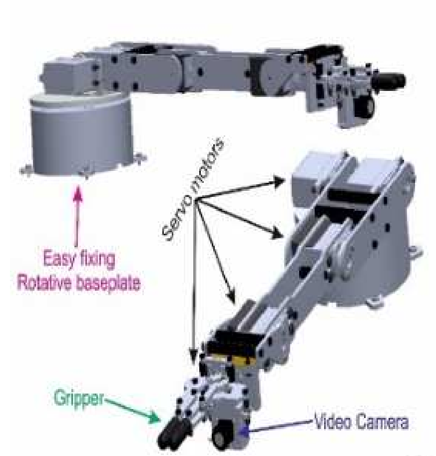


Fig. 10. Special module – Serial robotic arm [11]

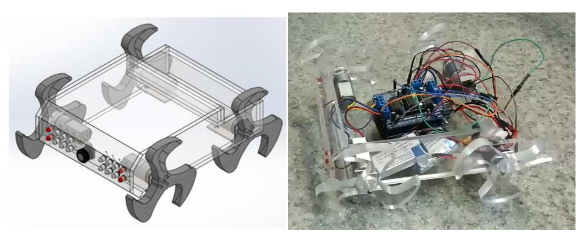
3.2 The second constructive variant - SRR with Whegs units

In the article is proposed a robot for search and rescue field using a locomotion system that has four Whegs units (Fig. 11).

First of all, as size, it was decided to develop a solution as small as possible, but at the same time to have sensors onboard to provide information about the environment in which the robot will operate. The small size can facilitate a lower cost for the robot development, given variety of the possible operating environment. The risk of damage / destruction of the robot during operation can be quite high depending on its mission. Therefore, the small size and design using materials with reduced cost and good mechanical properties has to become a priority. Another important factor is that the size of the robot makes it possible for the human operator to transport it inside a backpack to the location which needs to be inspected.

Secondly, it was necessary to identify a locomotion method that would allow the robot to run inside an operation area as wide as possible, especially given its small size. The small size and proper locomotion process allow the robot to search in narrow or hard-to-reach work environments.

The proposed robot (Fig. 9) is equipped with a front camera with night vision, but also has ten white LEDs for lighting and four red LEDs for signaling the direction changes on the front.



a) b)

Fig. 11. CAD model and prototype of proposed robot with Whegs locomotion units

The robot contains an Arduino development board necessary to control the DC motors used for driving the locomotion units. Up to six sensors of various types can also be connected to this board depending on the needs of the operator or the specifics of the rescue operation.

The dimensions for the robot are 200 mm (L) x 150 mm (W) x 60 mm (H) and it weighs 2800 g.

- *Controlling of the Whegs unit SRR*

The operation diagram for the robot is presented in Fig. 12. The robot receives the control signals from a computer via the ESP module, and the commands are transmitted to the DC motors using the L239 driver.

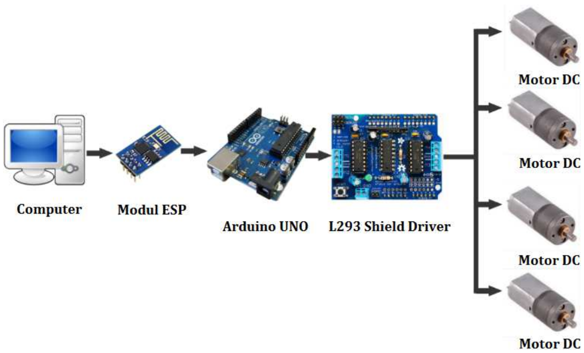


Fig. 12. Flow chart for controlling the robot with Whegs locomotion units

The mobile search and rescue robot is controlled by an Arduino UNO R3 development board which has an Atmega328P microcontroller. This board was chosen because it is a financially accessible platform, easy to use and meets the requirements for controlling the robot and electronic components.

The development board can be supplied with an input voltage between 5 and 12 V. The proposed robot is powered by two Li-polymer batteries with a nominal voltage of 7.4 V connected in parallel, to obtain the necessary current for the actuation of the motors.

The control process of the 4 D.C. motors is made using the Adafruit L293D driver shield.

The remote control of the robot is performed using the ESP8266 Wi-Fi module. This module allows the communication between the Arduino board and the graphical control interface via a Wi-Fi network.

The camera used is connected to the TS832 wireless transmitter, which transmits the information via radio waves to the RC832 receiver at a maximum distance of 5 km on a certain frequency. The receiver decodes the signal and sends it to the graphical user interface of the control device for monitoring in real time the work environment.

The proposed robot can be controlled remotely by a control interface using wireless communication using a computer or a smartphone application.

The graphical control interface for the proposed robot is designed and developed in Matlab App Designer programming environment. The main control window (Fig. 13) of the mobile robot allows access to a secondary graphical interface. The secondary interface (Fig. 14) allows to control the robot's locomotion process, the visualization of the operational environment in real time, signaling the change of direction during the locomotion process and controlling the LED light system.

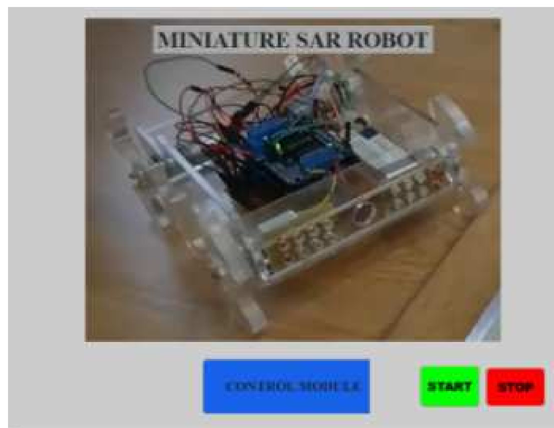


Fig. 13. The main control window of the graphical user interface

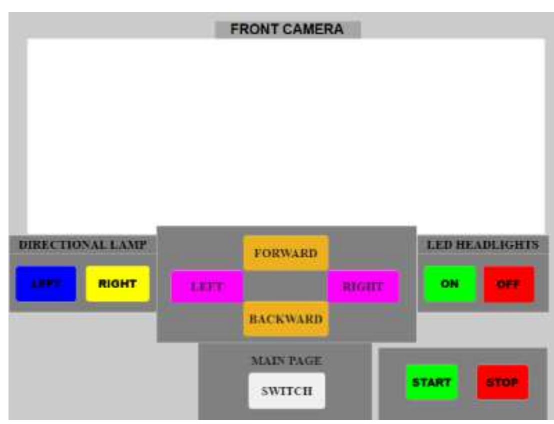


Fig. 14. The secondary interface for the robot`s locomotion and functions control (b)

Each Whegs locomotion unit is actuated. Thus, four DC motors with reducer were used to ensure the locomotion process of the proposed SRR.

- *Simulations of the Whegs unit SRR*

The SRR with Whegs units used for locomotion was tested inside the laboratory. Images obtained during the robot locomotion process tests are shown below (Fig. 16).

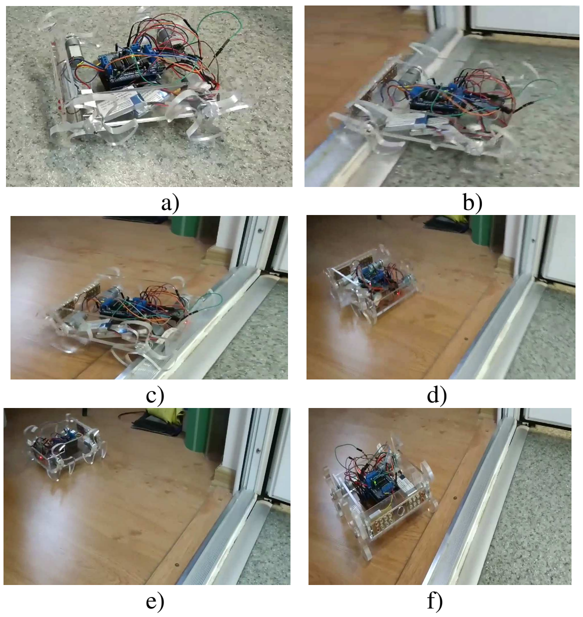


Fig. 15. Pictures from experimental simulation of the SRR`s locomotion process using Whegs units

The images captured by the robot's camera during the tests performed in the laboratory are presented in Fig. 16.

Fig. 16. Images achieved with the prototype`s video camera

4. DEVELOPMENT DIRECTIONS

Mobile robots with multimodal locomotion have two or more distinct ways of performing the locomotion process, combining the advantages of their use. The multimodal locomotion is recommended for search and rescue applications because they can be used in multiple operating environments, rough terrains and they can overcome obstacles that are impossible to avoid for mobile robots with conventional locomotion systems.

We propose a mobile SRR prototype with multimodal locomotion, which can move on the ground using the Whegs locomotion units and has the possibility to overcome obstacles through flight, using propellers. The CAD model for the robot proposed is presented in Fig. 17.

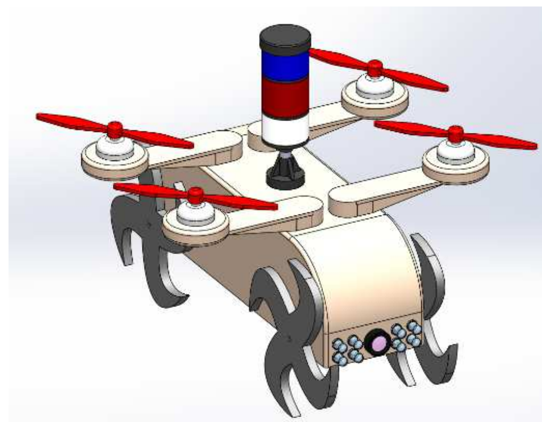


Fig. 17. Proposing a SRR with multimodal locomotion

This robot is equipped with video cameras, both in the front and in the back, also under it, to obtain real-time images to identify lost or injured people during the search and rescue operations.

The robot is also equipped with a warning device that contains two light modules of blue and red color, respectively a sound module, to be easily identified during the search and rescue process.

The robot will be controlled remotely and locate injured people using a GPS module.

The robot requires a suspension system for the terrestrial locomotion process due to four-point contact between the Whegs units and the locomotion surface.

Mobile robots with multimodal locomotion are ideal for search and rescue operations because they are not restricted by the nature of the locomotion surface or the size of the obstacle.

5. CONCLUSION

The authors propose in this paper SRR with hybrid locomotion systems combined from TriSTAR units, Whegs units and development directions towards multimodal locomotion systems. Although the hybrid systems have many advantages, it is still very difficult to obtain a locomotion system that can be used on any type of terrain. However, the usage of a multimodal locomotion system could be a future solution due to the promising advantages.

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Contribuții la dezvoltarea roboților de căutare și salvare cu unități TriSTAR și Whegs

Rezumat: Autorii prezintă în această lucrare roboți de căutare și salvare cu sisteme hibride de locomoție. Roboții folosesc sisteme de locomoție cu unități TriSTAR, unități Whegs și direcții de dezvoltare către sisteme de locomoție multimodale. Sunt prezentate detalii legate de proiectarea roboților și unităților de locomoție, precum și locomoția și controlul robotului.

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