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MOBILE ROBOTIC PLATFORM FOR FIREFIGHTING – CONCEPT DEVELOPMENT, FINISSING AND MOCKUP BUILDUP

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Abstract: *This paper presents the concept development and building of a mobile platform for firefighting and disaster interventions using competitive design principles combined with specific engineering software packages. Fire is the most common risk that occurs on our national territory, its prevalence making it of special interest. It is a phenomenon that affects important areas of economic and social life (construction, installations, forests, means of transport, agricultural crops). In this context, the intervention for limiting, removing or counteracting the risk factors is very important for the timely and qualified response in emergency situations. Also, having accurate and detailed information from as close as possible can aid the intervention team in the decision-making process related to the intervention plan.*

Key words: *mobile platform, robotic platform, firefighting robot, teleoperated robot*

1. INTRODUCTION

The objective of the paper was to develop a mobile platform for emergency prevention and intervention in case of fires and natural disasters. The work presents the development process of a remotely controlled mobile robot, having a modular design and high flexibly so that the same platform can be used for several types of applications, being adapted in this case for fire intervention in situations with low visibility and high temperatures, in case of underground fires (tunnels, car parks) or fires in places with risk of explosion or major accidents (industrial spaces, chemical or petrochemical plants). The use of the robot presumes the removal of the human operator from the intervention area. The communication between the operator and the robot is done through teleoperation. Because the role of the robot is to replace human operators in dangerous situations and the fact that full autonomy in this case is not recommended, a human-robot team was considered. To design, test and simulate the robot, software packages like SolidWorks, Catia/Dalmia and PTC Mathcad were used.

The most important result obtained is a mobile platform with four driving wheels that allow for the water cannon to be easily driven towards the fire. Mobility is ensured by four DC motors with worm gearboxes, which allows moving on rough terrain with increased flexibility, the two robotic joints that are attached on the mobile platform and used to direct the water jet.

2. GENERAL ASPECTS

The issue has emerged as a real need to the interventions to underground fires or fires in places with a high risk of explosion or major accidents. Taking into account the risks and the physical requirements to which the intervention staff is exposed, the work developed a remotely controlled mobile robot, designed so that the same platform can work with several types of specialized equipment, being in this case adapted for firefighting interventions in situations with low visibility and high temperatures (Figure 1).

Fig. 1 Firefighting using human operator (top image) and mobile robot asisted (bottom images) [2]

The use of a robot in areas with dangerous firefighting activities, search and rescue or cleaning of hazardous materials, involves the removal of the human operator from the physical location. The interaction with the environment is ensured through a communication channel.

Because the role of the robot is to aid humans in situations that are dangerous to life and health and that the level of autonomy of the robot is limited, a human-robot team is created. Information is being provided by the robot to the operator to support decision making.

Mobile robots are made in a wide range of sizes, with different travel speeds and designed with different systems that ensure their stability or mobility (Figure 2).

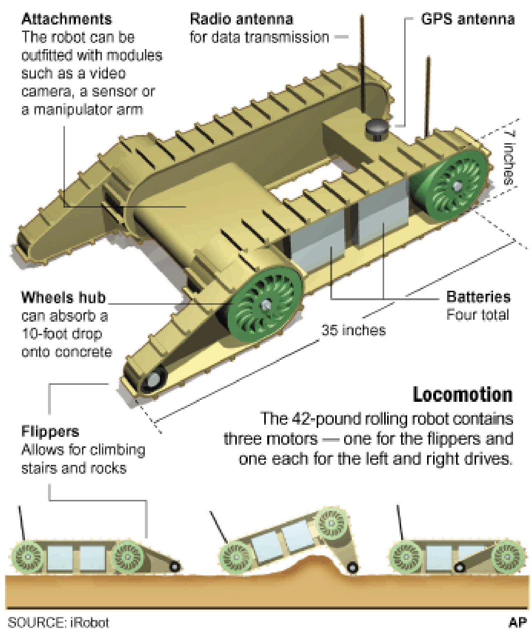

Fig. 2 PacBot track system [1]

Having high load capacity and good stability, tracked platforms can be used to fight fires, by carrying remotely operated fire hoses or other specialized equipment.

Stepping mobile robots are dynamic multi-body systems consisting of a platform with several legs. The legs have structures like the kinematic chains of manipulator-type robots. Given their performance characteristics, two-legged and four-legged mobile robots, with various sensorics equipment attached, find their place in search and rescue operations during or post disaster interventions. (Figure 3)

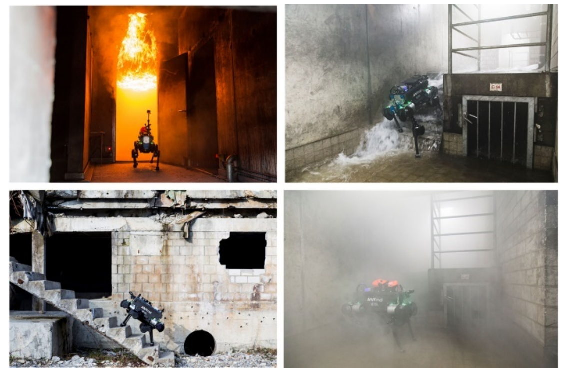

Fig. 3“ANYmal” for legged mobile robotic platform[2]

Robotic fire-fighting systems are designed to perform the following tasks:

- Primary: fire control and suppression
- Secondary: location and analysis of fires, monitoring of dangerous variables; search and rescue.

Firefighting robots can be classified, according to their ability to move, into stationary or mobile.

Stationary robots (Figure 4) are robotic equipment consisting of water or foam gun, electrically or electro-hydraulically operated. They are used to spread the extinguishing agent onto the fire or to cool down an area to protect it from thermal radiation.

Fig. 4 CONQUEST water gun (AKRONBRASS) [3]

Mobile firefighting robots can be classified into aerial (drones) or ground robots (UGV). In addition to drones equipped with thermal cameras, that help firefighters investigate and evaluate the fire attack plan (Figure 5), there are air vehicles used to extinguish the fire by spilling substances that interrupt the combustion process (Figure 6) or cause counterfire in case of terrestrial vegetation fires, in order to control its spread.

Fig. 5 Thermal camera equipped drone [4]

Fig. 6 Water jet equipped drone [4]

Drones with a thermal camera are used for large fires, where the density of smoke makes it difficult to observe their development. The thermal camera identifies the epicenter of the fire with a high degree of accuracy (Figure 7) so that firefighters can focus on the right place.

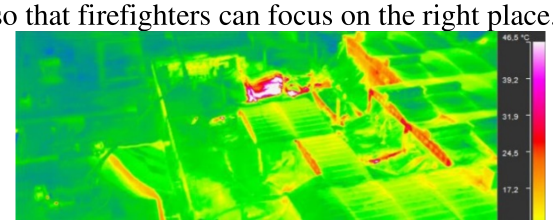

Fig. 7 The image shows the focal point of a fire [4]

The most common terrestrial firefighting robots are equipped with locomotion systems on wheels/tracks. There are also projects of stepping robots (Figure 8) but most of the equipment used for the intervention are provided with wheels or tracks (Figure 9), due to their stability and load-bearing capacity.

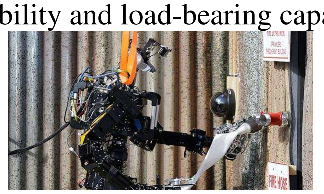

Fig. 8 SAFFiR firefighting robot[5]

Fig. 9 Tracked terestrial robot [6]

3. CONCEPT DEVELOPMENT

One problem to be solved was to identify technical solutions for automating the operation of extinguishing a fire with the help of a mobile platform and to aid firefighters in dangerous situations. The removal of the human operator from the physical location of the robot, involves the interaction with it through a communication channel. The information provided by the robot being important for decision-making in the effective organization of the intervention.

Another problem was finding solutions to ensure efficient mobility, focusing on the speed of reaction and availability of equipment that are part of the locomotion system of the platform.

In order to achieve the above stated goals, the DAMIC methodology for product development was used, in accordance with Lean 6 Sigma principles (see Figure 10).

The following steps were performed:

• Definition of the problem, the way the customer is affected, but also the objectives of reducing this dissatisfaction.
• Measurement - of any indicator that we consider relevant enough for the studied problem.
• Analysis of the root cause.
• Improvement - is based on identifying the root cause and isolating it, in order to reduce or eradicate the problem.
• Control / keeping under control - once the corrective action is implemented, the final effort is focused on maintaining the competitive level reached. [7][8]

Fig. 10 DMAIC 6SIGMA[9]

As for the methodology, the first step was to document and collect information regarding existing means for firefighting and disaster interventions.

Based on collected data, measurable parameters were identified and analyzed using specific competitive development tools – such as Analytic Hierarchy Process, Quality Function Deployment and PUGH method.

In the third step a set of functional requirements were identified and analyzed in order to create a hierarchy for objective functions.

The fourth step consisted in corelating the functions with the desired concept parts in order to determine if the importance/cost balance was attained. Having a viable concept of mobile platform, it was put into practice in the form of a 3D model. It is composed of a mobile platform with a 4-wheel drive, to which an orientation system composed of axes 1 and 2 of an industrial robot was attached. The components of the final concept can be seen in the figure below.

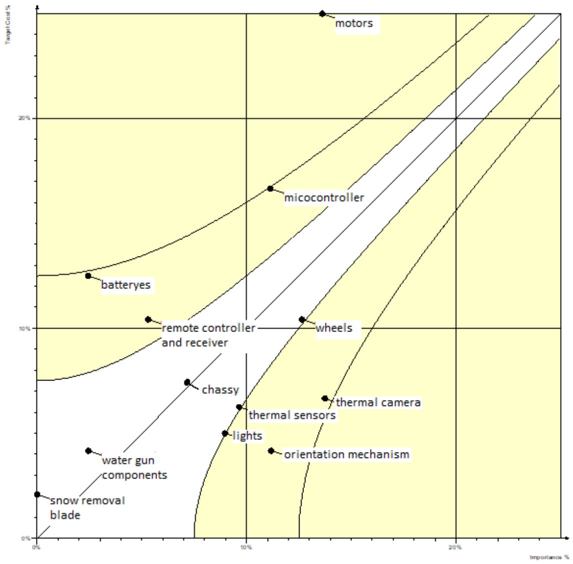

Fig. 11 Cost/importance diagram

As can be seen in the figure above, the use of competitive design tools and methods, delivered a balanced product both from the point of view of functionality, but also costs.

3.1. Final Concept

Starting from the idea of mobile firefighting robots, a concept of a ROV (Remote Operated Vehicle) was developed. It can be controlled remotely with a remote control used for movement, operation of the water gun and orientation equipment. It is also able to send and receive signals and images necessary for the efficient management of fire response team.

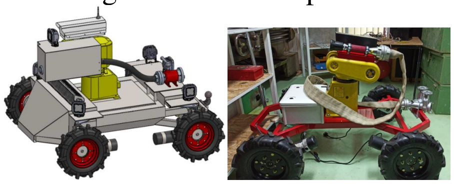

Fig. 12 ROV for firefightinh – CAD model and mocup

The central element of the platform is the chassis. It is designed with longitudinal and transverse symmetry, on two levels, of steel pipe with rectangular profile 50x30x2mm assembled by welding.

In order to ensure proper resistance, finite element analysis was used. SolidWorks software package was used to validate the chassis resistance. Some of the results of the analysis are presented in Figures 13 and 14. For the testing of the chassis a carrying weight of 150kg was considered. The model was constrained in the four supports where the wheels are to be fixed and loaded in the middle of the chassis where the support plate for the robotic arm, the batteries and the control electronics box are to be placed. As can be seen in Figure 12, the displacement of the middle segment is less than 0.4 mm.

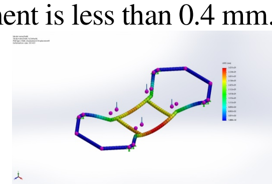

Fig. 13 URES analisys of the chassy

Even though stress analysis and displacement analysis returned good results, because one of the main concerns was user safety, a further factor of safety (FOS) analysis was undertaken. The Figure 13 shows the analysis using a factor of safety of 5.

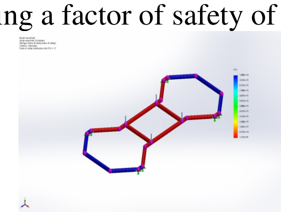

Fig. 14 Factor of safety analisys of the chassy

As can be seen in Figure 13 the result suggested that a further strengthening of the middle areas is desirable. For this reason, an additional platform was attached on top in order to reinforce the entire chassis. The figure below shows the final chassis model.

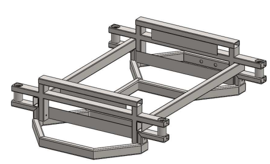

Fig. 15 Isometric view of the final frame

In order to facilitate movement and direction control a steering system based on a motor and direction bar was implemented. Figure 16 presents a cross-section through the subassembly for wheel direction control.

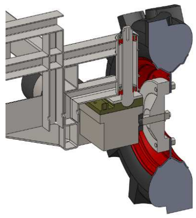

Fig. 16 Cross-section through the pivoting mechanism

The steering system is engaged by an "elastic rack mechanism" provided with a DC electric motor. The position of the rail of the steering assembly is determined with the use of angular displacement sensors. The figure below shows the steering assembly on one of the decks of the platform.

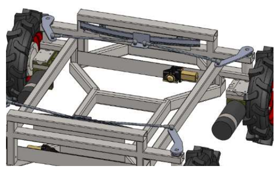

Fig. 17 Overview of the steering mechanism

Having the steering system on both axles allows varied movement on curved or straight paths.

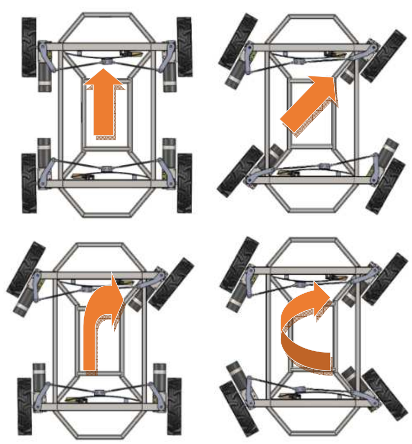

Fig. 18 Linear or circular movement paths

For the positioning of the water discharge assembly in the desired direction, an articulated arm with 2 joints was chosen, since only rotational movements around the Ox and Oz axes was considered necessary. The water discharge assembly was dimensioned starting from the characteristics of a standard discharge pipe provided with a rod valve and water jet adjustment. The actuation was designed by means of mechanisms operated by DC electric motors. The elastic rack presented in the Figure 19 allowed for actuating the valve. Its movement on a circular arc of 90º ensures the adjustment of the flow.

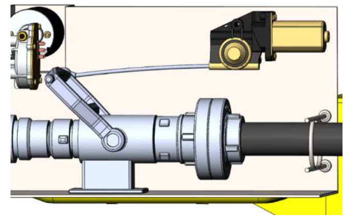

Fig. 19 Opening mechanism for the gun nozzle

The discharge pipe system for adjusting the water jet in the form of a "fog" or compact jet, is driven by a chain drive and a worm wheel gearbox actuated by a DC electric motor.

The electronic equipment for the acquisition of thermal video images and information about the operating environment (temperature, toxic gases or fuels) are positioned in the protection box located on the robotic arm, according to the figure below.

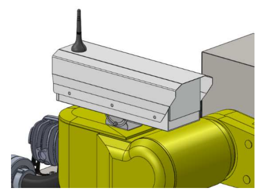

Fig. 20 Camera and sensors box

3.2. Mockup

As can be seen from the image below, the final mockup design was simplified. A special attention was given towards main functionalities related to firefighting. The chassis was kept on a single level, and the wheels had no direction control.

The tap actuation and water jet adjustment systems were also abandoned, with another version of the discharge pipe being installed on the robotic arm, as is seen in the figure below.

Fig. 21 Mockup: a) chasy with motors and wheels, b)discharge nozzle on the robotic arm

The motor control of the actuation system was created with the help of drivers with the structure of an H-bridge with N-channel MOSFET transistors.

4. CONCLUSIONS

The use of competitive development tools and techniques allowed the development of a balanced concept of a mobile platform for firefighting and disaster intervention.

The platform developed and presented in this paper displays several advantages in terms of implementing teleoperated mobile platforms in fire and disaster control applications. These include increased safety of intervention personnel, increased flexibility in navigating rough terrain and increased carrying capacity.

These functionalities are the basis of a teleoperated mobile platform with a metal structure of rectangular profiles, 4 DC gear motors and 2 FANUC robot axes that assist the intervention personnel by transporting firefighting equipment. A remote control having 6 channels is used to control the movements of the mobile platform, the robot arm and the water cannon. Considering that during the intervention the principles of individual and collective safety as well as that of operative efficiency must be observed, the intervention technique used is very important. In order to ensure an adequate technique, information is needed. The sensors on the platform provide information, aiding the intervention personnel in the decision-making process.

Further studies will be done regarding control algorithms for an increased flexibility and autonomy in firefighting and disasters interventions.

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Platform mobila robotizata pentru stingerea incendiilor – conceptie, dezvoltare si construire macheta

Rezumat: Incendiul este cel mai frecvent risc care apare pe teritoriul național, prevalența sa fiind o situație de urgență specială, un fenomen care afectează zone importante ale vieții economice și sociale. În acest context, intervenția pentru limitarea, înlăturarea sau combaterea factorilor de risc este foarte importantă pentru răspunsul în timp util și calificat în situații de urgență. Având în vedere că în timpul intervenției trebuie respectate principiile siguranței individuale și colective, precum și cea a eficienței operative, tehnica de intervenție folosită este foarte importantă, fiind necesară dezvoltarea și perfecționarea acesteia. Astfel, se consideră atât înlocuirea echipamentului din dotarea structurilor de intervenție cu o tehnică nouă, specializată pe tipuri de riscuri care generează situații de urgență și scăderea riscului factorului uman prin înlocuirea cu sisteme robotice în timpul intervențiilor.

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