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# DESIGN AND SIMULATION OF A SPHERICAL MOBILE ROBOT

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***Abstract:*** *In this paper the authors presents general information about the actual state of the spherical mobile robots research field. The first part of the paper contains aspects regarding the classification and locomotion modes of the spherical mobile robots. The second part of the article present an original design of double pendulum driven spherical mobile robot. The mechanical structure and control system of the proposed robot is presented. The paper contains the mathematical model and graphical user control interface of the spherical mobile robot. Also, the paper presents the simulation results of the dynamic behavior and locomotion process of the proposed robot, performed in MATLAB.*
***Key words:*** *spherical mobile robots, locomotion, mobile robotics, terrestrial mobile robot, rolling robot.*

## 1. INTRODUCTION

The research field of mobile robotics is focused on the development and improvement of safe robotic solutions in order to perform remote or completely autonomous tasks in high risk or difficult to access environments. Mobile robots are used to realize rescue and exploration tasks in order to protect the integrity of the human life [1].

Mobile robots can be used in multiple work environments and adapt to the specific of the locomotion surface or desired applications, using the reconfigurable structure and multimodal locomotion. A different category of mobile robots equipped with hybrid locomotion systems can be used to realize a variety of tasks in complex and changing environments, using a single robot [1].

The spherical mobile robots are a particular category of the mobile robotics which often perform the locomotion process using the rolling movement. The spherical shape of the robot's outer structure reduces the friction force between the locomotion surface and robot. The surface of the work environment is minimally damaged during the locomotion process [1].

Unlike conventional mobile robots that are designed to perform tasks on a specific surface or in a pre-established work environment, spherical mobile robots can be utilized on a wide variety of locomotion surfaces: flat or uneven terrains, dry (gravel, cement) or flooded (mud, swamp) and different meteorological conditions: dry or rainy, reduced or good visibility range, low or high temperature.

Spherical mobile robots can be designed with reconfigurable or modular structure that allows them to use the multimodal locomotion and to adapt to the work environments. Spherical robots can operate successively in multiple environments and at the limit of the separation between two environments by modifying their shape or configuration [1].

The usage of the spherical mobile robots provides advantages over conventional terrestrial mobile robots. Spherical mobile robots can perform omnidirectional locomotion, changing their moving direction without constraints or turning radius. Spherical mobile robots don't harm the work environment or the human user thankfully to their shape. They don`t flip over during the locomotion process and own a shock-resistant outer structure, which protect the electronics of the robot. Their structure can be hermetically sealed which allows the same robot to be used on different work environments: on the surface of separation between the ground and air, respectively water and air [1].

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The outer structure of the spherical mobile robots can be manufactured using durable materials to provide better shock-resistant mechanical properties and higher life expectancy of the robot usage [1].

## 2. CLASSIFICATION

Based on the specialized literature, we can affirm that spherical mobile robots are still an actual topic of interest. Research studies are performed to increase the energetical autonomy and power consumption optimization of the spherical robots. The researchers study new locomotion modalities and more versatile designs to ensure high adaptability of the robot's structure to the specific of the work environment. The actual aim is the development of an ideal autonomous spherical mobile robot for performing tasks in hostile environments for long periods of usage [1].

Spherical mobile robots can operate, according to the locomotion of the biosystems:

- in a single environment (in water [2]);
- at the limit of separation between two different environments (on the soil`s surface [3]);
- successively in multiple environments and at the limit of separation between two different environments (ex: in air and on the soil`s surface [4]).

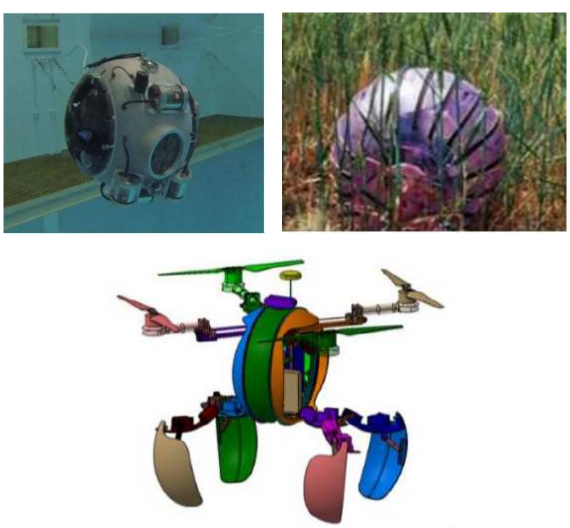

**Fig. 1.** Classification of the spherical mobile robots regarding the operating environment [2], [3], [4].

The locomotion process of the spherical mobile robots can be performed [1]:

- actively (using actuators);
- passively (using an external stimulus: wind, sea waves, etc.).

Spherical mobile robots use various types of locomotion systems and locomotion modes to perform their controlled movement [1].

Observing the locomotion process of the spherical mobile robots based on the specialized literature, we can highlight the following locomotion modes [1]:

- rolling motion;
- jumping;
- floating;
- swimming;
- flight;
- crawling;
- multimodal locomotion (ex: rolling and flight, rolling-crawling-flight, etc.)

Analyzing the nature of the energy source used, the spherical mobile robots work based on the following types of drive systems [1]:

- electrical;
- pneumatic [5];
- hydraulic;
- external magnetic fields action [6];
- action of an external stimulus (ex: wind energy).

Based on the various application fields, we observe a wide dimensional variety of the spherical mobile robots [1]:

- nanorobots with volume of the order of $\mu m^3$;
- microrobots with a volume of maximum $1\ cm^3$;
- miniature robots with a volume of the order of $cm^3$;
- macroscopic scale robots.

Referring to the nature of the spherical mobile robot's locomotion process, the following categories are distinguished:

- simple locomotion (rolling process);
- multimodal locomotion.

## 3. PROPOSED ROBOT DESIGN

The authors propose a novel spherical mobile robot design for remote terrestrial search and rescue applications.

The proposed design is equipped with a double pendulum-based drive system [1].

The spherical robot three-dimensional model was realized in SolidWorks and its behavior simulated in MATLAB.

The locomotion process is based on the modification of the robot`s center of mass position in order to generate a propulsion force which leads to the controlled movement of the spherical mobile robot [1].

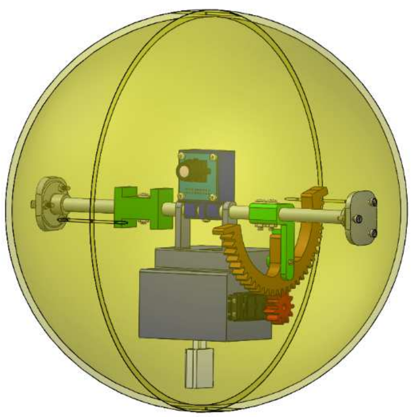

**Fig. 2.** The proposed spherical mobile robot design

The drive system is composed by two pendulums mounted on the central ax.

The blue colored upper pendulum is actuated by the FS5109M servomotor and control the linear motion of the robot: forward and backward movement.

The white colored lower pendulum is actuated by the SG90 mini servo and control the turning and side motion of the robot.

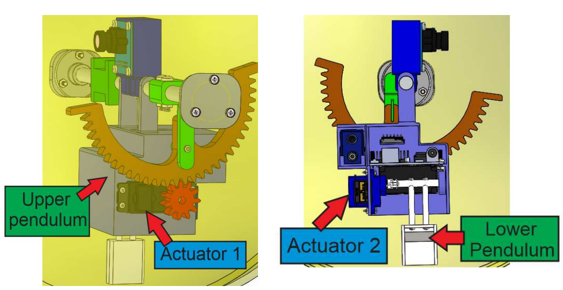


**Fig. 3.** The double pendulum based drive system of the proposed spherical mobile robot

Correlating the movement of the upper and lower pendulum we obtain precisely controlled motion trajectories.

The spherical robot`s outer diameter is 300 mm and has an approx. weight of 2600 grams.

The mechanical structure of the drive system and the electronics are placed inside the outer structure of the robot. The components are protected against shocks, damages and the destructive actions of the work environment.

In Figure 4 is illustrated the block diagram of the proposed spherical mobile robot`s functionality.

The control unit of the robot use an Arduino Uno development board. Informations are harvested remotely using the sensorial system.

Real time images are used to remotely control the spherical robot via bluetooth.

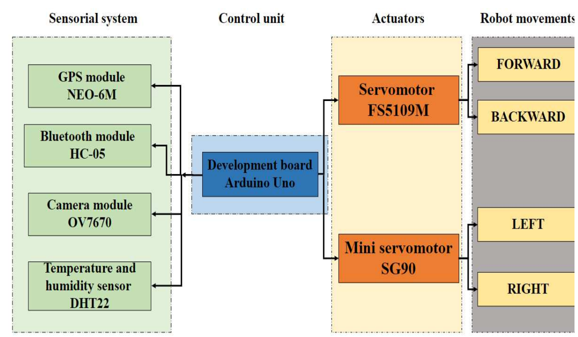


**Fig. 4.** The functionality of the spherical robot

In Figure 5 are presented the electronics used for the sensorial system, actuation, power source and control unit of the spherical robot.

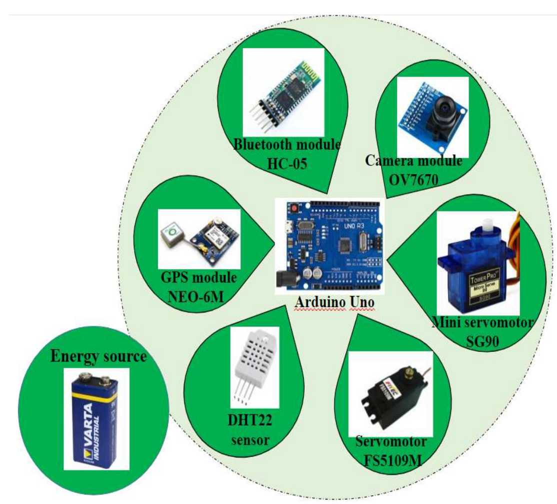


**Fig. 5.** The electronics of the spherical mobile robot

The authors propose two different camera placement methods and camera variants [1].

The spherical mobile robot`s outer structure is transparent and we have the possibility to hermetically seal it.

The left side of Fig. 6 presents two SQ mini DV cameras mounted on the outer structure of the spherical robot.

The right side of Fig. 6 illustrate an OV7670 camera module mounted centered inside the robot on the central ax.

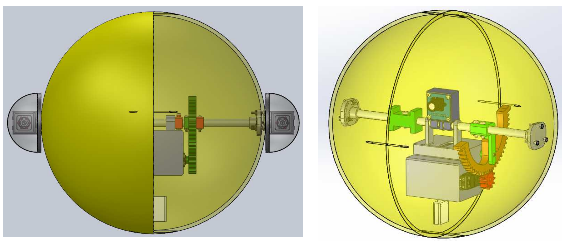

**Fig. 6.** Camera placement variants [1]

In this paper are presented three motion transmission methods to realize the angular movement between the upper pendulum and the central ax of the robot [1]:

- belt drive;
- a rubber drum attached on the FS5109N servomotor, which moves inside a mechanism with a pre-established path;
- spur gear transmission.

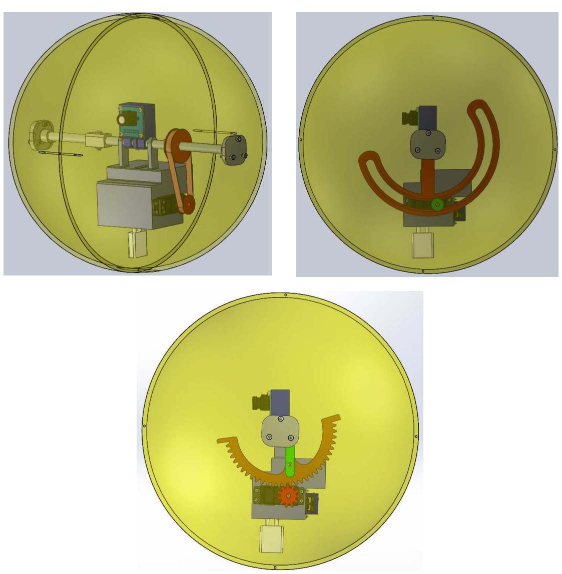

**Fig. 7.** Motion transmission system variants [1]

The angular motion between the upper pendulum and the central ax of the robot is realized using a spur gear transmission. A spur gear segment is fixed mounted, and a smaller gear moves on its contour [1].

Table 1.

**The geometrical parameters of the robot**

| Notation | Meaning |
|---|---|
| $\theta_1$ | angular movement for simplified pendulum |
| $\theta$ | angular movement of the spherical robot |
| $\omega=\dot{\theta}$ | angular velocity of the spherical robot |
| $\varepsilon=\ddot{\theta}$ | angular acceleration of the robot |
| R | radius of the spherical structure |
| M | the mass of the spherical robot |
| L | simplified pendulum length |
| $m_t$ | eccentric mass of the pendulum |
| $M_c$ | motor torque |
| g | gravitational acceleration |
| $v_x = \dot{x}$ | linear velocity of the robot |

The simplified mathematical model of the proposed spherical mobile robot is obtained applying the Lagrange`s equations.

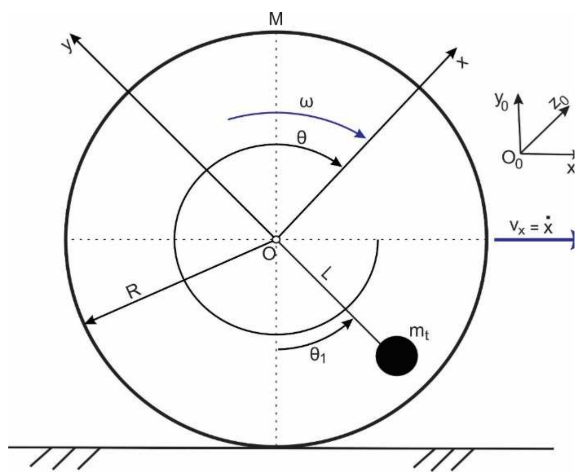


**Fig. 8** Geometrical model of the spherical robot

The proposed spherical mobile robot`s dynamic equation using Lagrange method is:

$$\ddot{\theta}_1 L + \varepsilon R\cos\theta_1 - \sin\theta_1\left(\omega R\dot{\theta}_1 + g\right) = \frac{M_c}{m_t L} \quad (1)$$

The graphical user interface proposed for the spherical mobile robot`s remote control was developed in MATLAB App Designer programming environment.

The robot`s graphical user interface has a main window, presented in Fig. 9, for remote control of the spherical robot`s locomotion and real time image acquisition about the work environment.

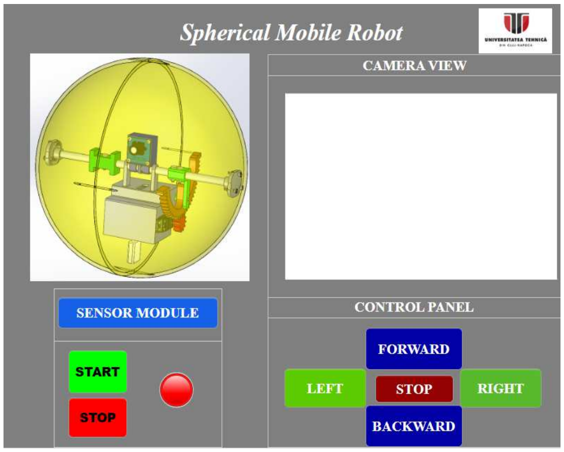


**Fig. 9** The graphical user interface for the spherical mobile robot`s control

The main window of the control interface allows the user to access a secondary user interface window, illustrated in Figure 10, to obtain additional information about the GPS location of the robot, a better view of the images and data regarding the work environment.

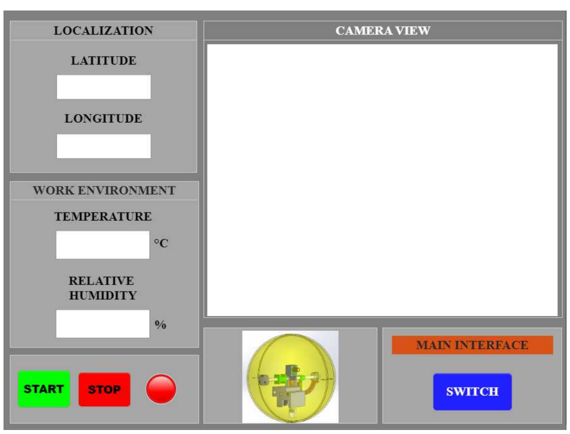


**Fig. 10** Secondary module of the graphical user interface

## 4. SIMULATIONS

The simulation of the proposed spherical mobile robot`s locomotion process and dynamic behavior was performed using the MATLAB programming environment.

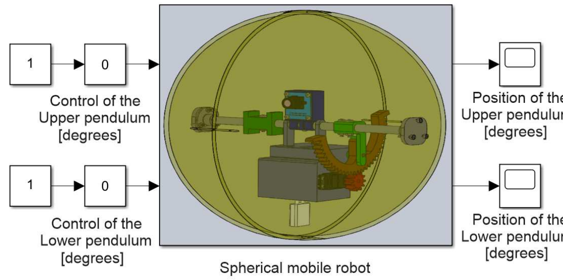


**Fig. 11** The model of the spherical mobile robot imported in MATLAB

The parameters of the proposed spherical robot design were imported from SolidWorks in MATLAB using the Simscape Multibody Link plug-in. Also, to realize the simulation of the spherical robot`s locomotion process, values are introduced for the drive systems elements in MATLAB Simulink.

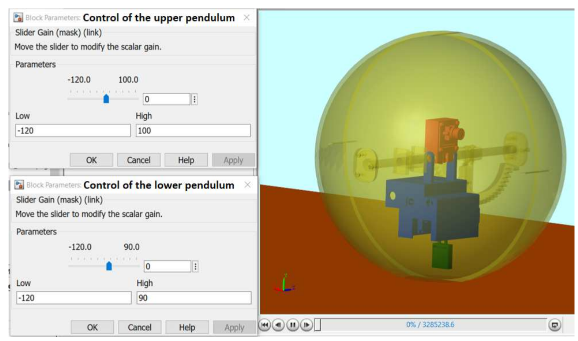


**Fig. 12** The spherical mobile robot controlled in MATLAB

The Simscape Multibody provides a tridimensional visualization environment for the spherical mobile robot`s locomotion process and dynamic behavior.

In Fig. 13 is presented the proposed spherical robot on a flat locomotion surface in MATLAB simulation program.

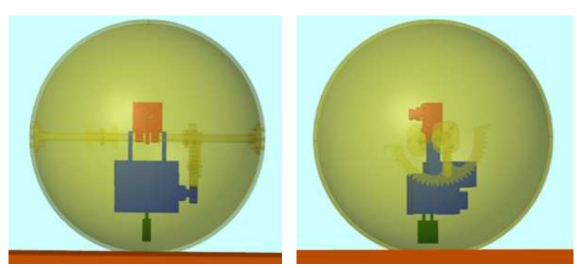

**Fig. 13.** The proposed spherical mobile robot in MATLAB environment

The locomotion process of the terrestrial spherical robot was performed on flat and uneven locomotion surfaces.

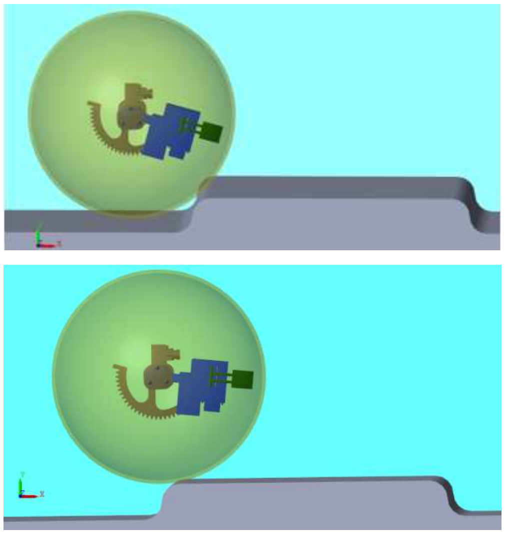

**Fig. 14.** Simulation of the obstacle climbing process of the spherical mobile robot

The locomotion process of the double pendulum driven spherical mobile robot was simulated in MATLAB on different surfaces and types of terrain.

## 5. CONCLUSION

This paper presents a terrestrial spherical mobile robot design proposed for remote search and rescue applications.

The structure of the drive system, electronics and control interface of the robot are described.

The locomotion process of the spherical robot on different types of surfaces is simulated using MATLAB.

## 6. REFFERENCES


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**Proiectarea și simularea unui robot mobil sferic**


**Rezumat:** Lucrarea tratează aspecte referitoare la domeniul de cercetare a roboților mobili sferici. În prima parte a lucrării sunt prezentate clasificarea și modalitățile de locomoție specifice roboților mobili sferici. În partea a doua a lucrării se prezintă proiectarea unui robot mobil sferic, sistemul de acționare și interfața de control realizată în MATLAB App Designer, respectiv simularea procesului de locomoție realizat în MATLAB.



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