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STUDIES CONCERNING MOBILE ROBOTS USING MAGNETIC LOCOMOTION UNITS

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Abstract: *In the first part of the paper, the authors conduct a study on mobile robots equipped with magnetic locomotion units. The second part presents the robot developed by the authors, a system capable of moving on both metallic and non-metallic surfaces, equipped with two magnetic units and a spherical rolling element for stability. The proposed robot was tested on horizontal, inclined, and vertical surfaces.*

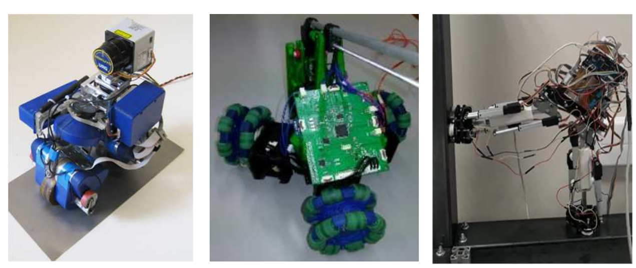
Keywords: *mobile robots, magnetic locomotion, inspection robots, climbing robots, hybrid locomotion.*

1. INTRODUCTION

Climbing mobile robots have become essential tools for inspection and monitoring tasks, enabling access to environments that are difficult or unsafe for human operators. These systems deliver accurate and reliable data, supporting the safety and efficiency of operations across a wide range of industrial applications. Furthermore, their use reduces inspection time and operational costs by eliminating the need for scaffolding, as well as the disassembly or relocation of large and heavy components.

To maintain adherence to inclined or vertical surfaces, two systems are typically used: pneumatic vacuum mechanisms or magnetic elements. In terms of size and the ability to maintain position without electrical power, a robot with magnetic locomotion elements is preferred over one using pneumatic vacuum mechanisms. Magnetic adhesion refers to the ability of an object or material to stick to or attach to a metallic surface due to magnetic forces. This adhesion can be achieved through either permanent magnets or electromagnets.

Magnetic locomotion units offer significant advantages in terms of mobility and accessibility, allowing robots to access difficult areas and perform detailed inspections without requiring additional infrastructure. This technology reduces the risk for operators while improving the efficiency and accuracy of inspections across various fields. Several representative examples of robots with magnetic locomotion elements from the literature [1], [2], [3], [4], [5], [6] are presented below.



a) b) c)

Fig. 1. Examples of robots: a) The Magnebike robot [2], b) The OmniClimber robot [3], c) The HyReCRo robot with magnetic gripping [4].

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The HyReCRo robot equipped with magnetic gripping is illustrated in Figure 1(c). HyReCRo is a bipedal robot with each leg provided with a magnetic gripper. The robot is designed to move step by step and to explore challenging environments, using an innovative magnetic gripping system.

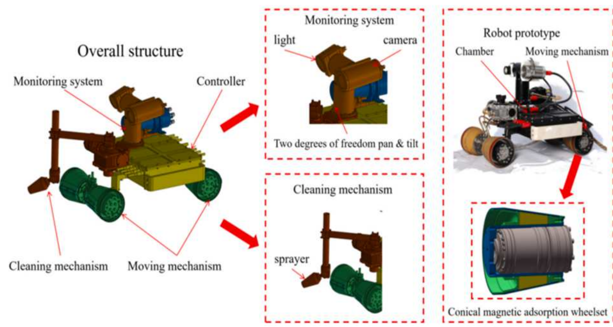
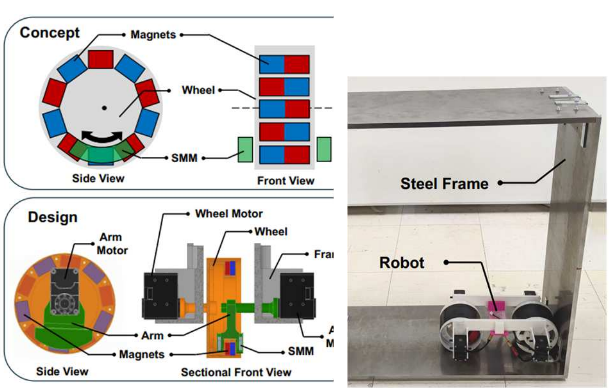


Fig. 2. General structure of the robot and its magnetic wheel sets for cylindrical steel structures [5].

The robot shown in Figure 2, [5] is designed for cleaning offshore underwater cylindrical structures. It is capable of passively adapting to different curvatures and diameters. The robot uses sets of conical magnetic wheels optimized for maximum adhesion force and minimal weight, and its performance has been validated through experiments [5].



a) b)

Fig. 3. a) Conceptual design of the paired horizontal magnetic wheel configuration enabling adjustable magnetic adhesion; b) The corresponding fabricated prototype [6].

The robot found in Figure 3, [6] is another example of a wall-climbing robot that use an innovative magnetic wheel design. These wheels utilize soft magnetic materials (SMM) to control and reduce the adhesion force in a specific direction, which improves operational safety. This technology enables the robot to transition more easily between surfaces and reduces the risk of falling, ensuring more stable adhesion during wall-climbing operations.

Other developments in the field of robots with magnetic locomotion units are also documented in the specialized literature [7], [8], [9], [10].

Based on the previously presented examples [1], [2], [3], [4], [6], and the analysis of various approaches found in the literature [7], [8], [9], [10], the following classification of climbing mobile robots with magnetic locomotion elements can be established:

- according to application domain: infrastructure, energy, construction, ocean engineering, or aerospace engineering;
- according to the adhesion method: magnetic adhesion, negative pressure adsorption, or bio-inspired adhesion;
- according to the locomotion system used: wheels, legs, tracks, or hybrid locomotion systems.

The robot proposed by the authors is classified as the category of hybrid robots, incorporating a locomotion unit that combines wheels and legs. Hybrid locomotion robots combine the advantage of individual locomotion systems—in this case, the advantages of wheeled and legged mobility.

Compared to the robots discussed in the specialized literature [11], [12], the proposed robot features a simpler structure, using permanent magnets for its two locomotion units (designed as hexagonal prisms). The robot is driven by two DC motors and includes a magnetic roller at the rear for structural stabilization. Due to the hybrid locomotion units, the robot exhibits increased adaptability when exploring irregular surfaces, while manufacturing costs are reduced through the use of 3D printing technology.

The structure of the article is as follows: Section 2 presents the mechanical and electronic architecture of the robot; Section 3 describes the experimental testing; and Section 4 outlines the conclusions and future development directions.

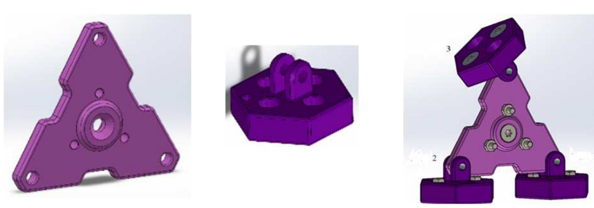
2. MECHANICAL AND ELECTRONIC ARCHITECTURE OF THE ROBOT

2.1 Mechanical architecture of the robot

The proposed robot is a mobile robot with two rotational magnetic locomotion units. Each locomotion unit has a triangular shape with prismatic elements at its extremities (labeled 1, 2, and 3, referred to as legs or modules).

The proposed locomotion unit is classified under the category of hybrid leg-wheel systems, as it consists of a triangular support driven by a DC motor (the triangular support performs a rotational motion). Mounted on this support are three magnet-equipped modules, regarded as legs. Locomotion is achieved through the attachment and detachment of these magnetic modules to and from the surface.

To prevent the modules from becoming stuck in an unfavorable position after stepping, tension springs are integrated to return them to their initial position—an essential condition for continued stepping. Rotational couplings are placed between the support and the modules, and the magnets are mounted in the modules using screws and washers.



a) b) c)

Fig. 4. 3D model of the locomotion units: a) triangular support, b) module, c) assembled locomotion unit [13].

Each unit consists of three sets of neodymium permanent magnets arranged at 120° intervals and is driven by geared DC motors.

The proposed locomotion units require sufficient torque not only for forward movement but also for detaching the magnets from the surface, eliminating the need for an additional detachment mechanism.

To ensure reliable surface contact and locomotion, axially polarized magnet sets are used, generating enough attractive force to maintain contact using only a single pair of magnets.

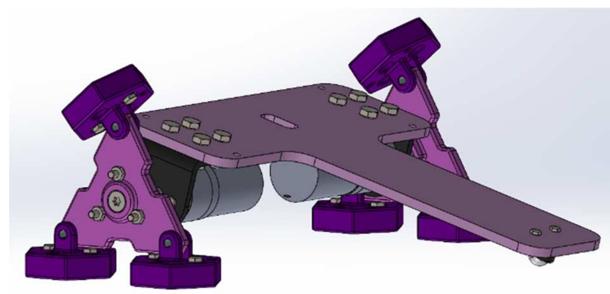


Fig. 5. 3D model of the proposed differentioal mobile robot [13].

2.2 Electronic architecture of the robot

The robot’s actuation system includes two DC motors, each integrated with Hall-effect speed/position encoders providing 48 pulses per revolution. Consequently, two motor drivers were used one for each motor and the Hall sensors can be directly read by a microcontroller via digital input ports.

For navigation and sensing, the system includes a video camera, a proximity sensor, and a temperature and humidity sensor. The data acquired by this sensor system is transmitted via wired connection using the RS485 serial communication protocol, which supports high data transfer rates over long distances (up to several kilometers).

Accordingly, the block diagram of the electronic system is shown in Figure 6:

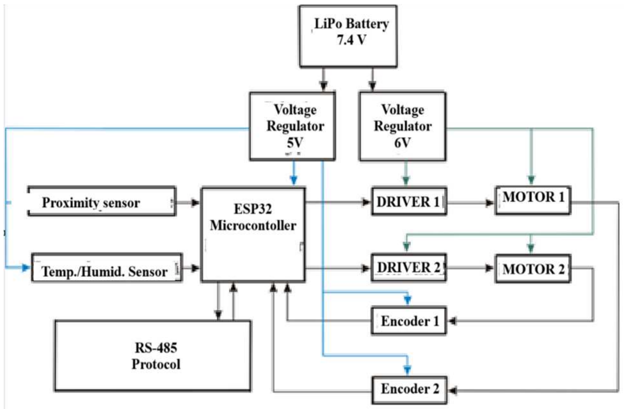


Fig. 6. Block diagram of the robot's electronic system [13].

2.3 Locomotion mechanism of the robot

To step onto the ferromagnetic surface, leg 1 detaches while leg 2 remains fixed due to the magnetic force, as shown in Figure 7 (a), (b).

The triangular shape of the unit allows leg 3 to adhere to the surface through motor rotation, after which leg 2 detaches, and the cycle continues. The tension spring keeps the leg suspended in the required position for the next step.

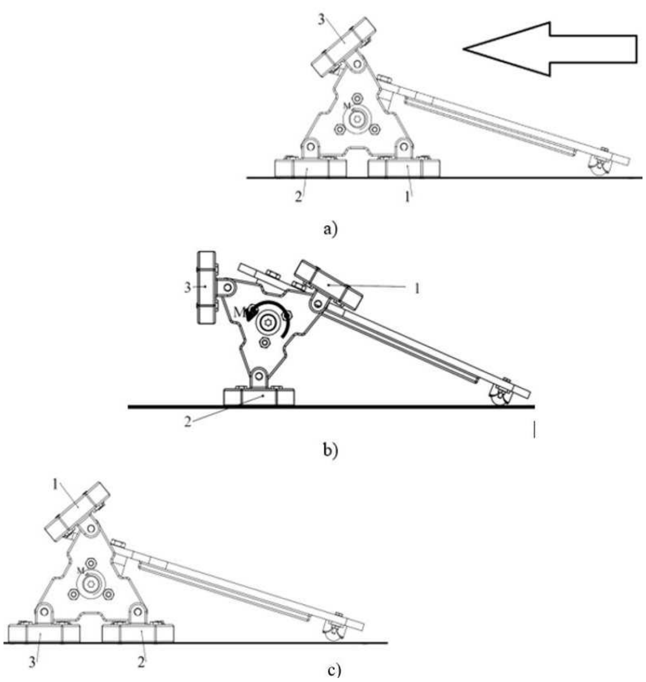


Fig.7. Operating principle of the proposed differential mobile robot [13].

3. TESTING OF THE ROBOT WITH MAGNETIC LOCOMOTION UNITS

As a starting point, the test was performed on a horizontal non-metallic surface, as shown in Figure 8.

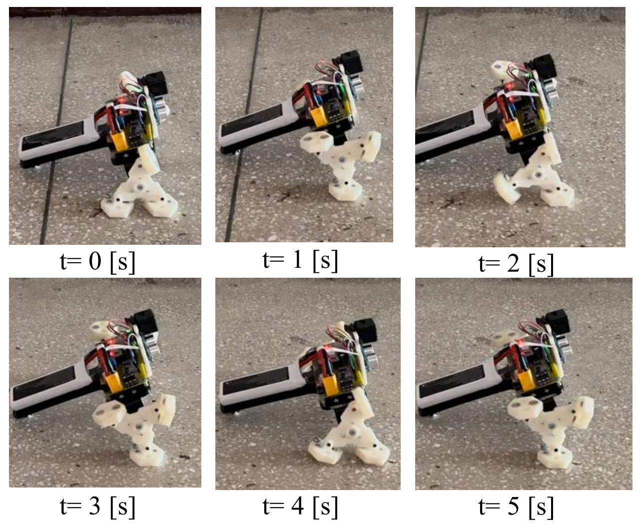


Fig. 8. Prototype movement on a non-metallic surface [13].

Additional tests involved the movement of the prototype on inclined or vertical ferromagnetic surfaces. The prototype's behavior in these scenarios is illustrated in Figure 9 and Figure 10.

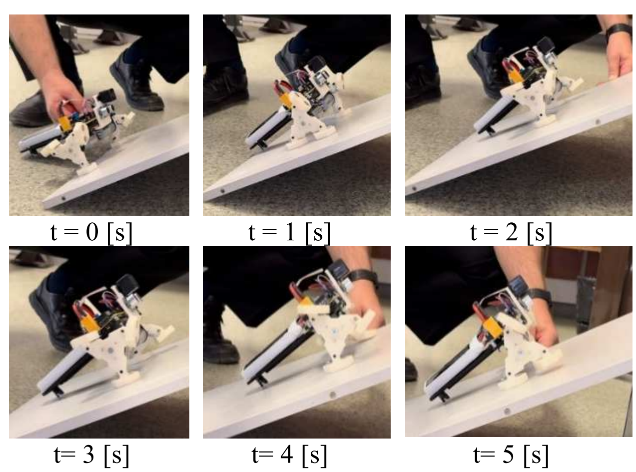
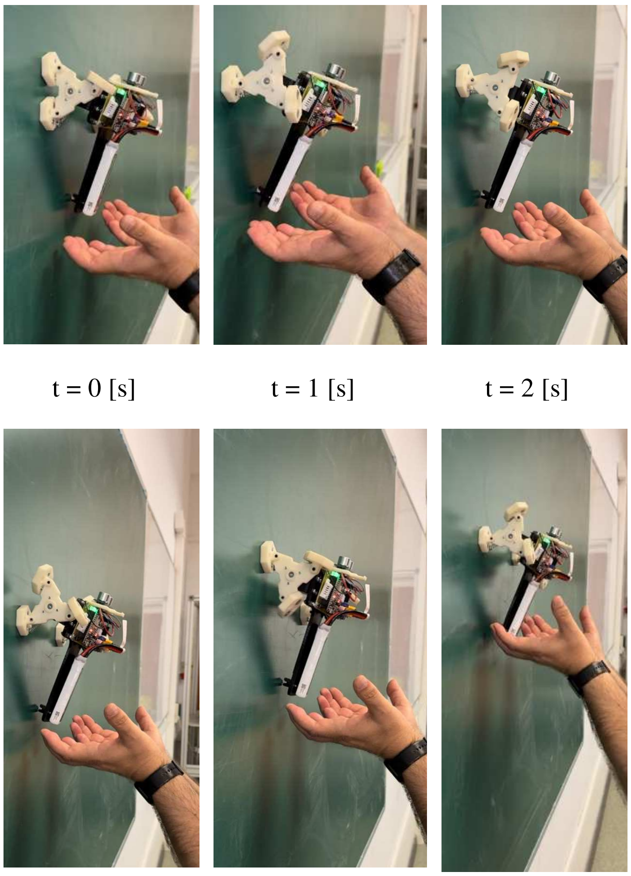


Fig. 9. Robot movement on inclined ferromagnetic surfaces [13].

During the testing process, it was observed that the robot may slip when moving on non-metallic or painted surfaces.



t = 0 [s] t = 1 [s] t = 2 [s]

t = 3 [s] t = 4 [s] t = 5 [s]

Fig. 10. Robot movement on vertical ferromagnetic surfaces [13].

During the tests performed to evaluate the prototype's behavior, it was observed that on metallic surfaces—whether horizontal, inclined, or vertical—the prototype maintained optimal contact with the surface, and the detachment process functioned properly.

4. CONCLUSION

The article presents a robot with magnetic locomotion units proposed by the authors.

The study demonstrates that magnetic locomotion enables robots to navigate inclined, vertical or even complex metallic structures environments where other locomotion methods would be impractical or impossible—including restricted-access areas, due to the robot's relatively small dimensions (180 mm, 150 mm, 100 mm). The developed prototype is capable of navigating inclined, vertical, and horizontal surfaces, with certain limitations related to surface roughness.

As future research directions, the authors aim to integrate electromagnets for the locomotion units, implement remote communication, add a video camera, reduce the overall weight and optimize the structural design.

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Studii privind roboții mobili cu unități de locomoție magnetice

Rezumat: In prima parte a lucrarii autori realizeza un studiul al roboților mobili cu unități de locomoție magnetice. In partea a doua se prezintată un robotul realizat de autori, robot ce este capabil să se deplaseze pe suprafețe metalice și nemetalice, echipat cu două unități magnetice și un element de rulare sferica pentru stabilitate. Robotul propus a fost tesat pe suprafețe orizontale, înclinate și verticale.

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