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A SMALL-SIZED ROBOT PROTOTYPE DEVELOPMENT USING 3D PRINTING

Igor NEVLIUDOV*, Vladyslav YEVSIEIEV*, Svitlana MAKSYMOVA*, Olena CHALA*

* Faculty of Automatics and Computerized Technologies , Department of Computer-Integrated Technologies, Automation and Robotics, Ukraine, Kharkiv National University of Radioelectronics, Nauky ave. 14, Kharkiv, Ukraine

igor.nevliudov@nure.ua, vladyslav.yevsieiev@nure.ua, svitlana.milyutina@nure.ua, olena.chala@nure.ua

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Abstract: Our article is devoted to the development of a small robot prototype using 3D printing technology. Particular attention is paid to its use in conditions associated with the destruction of reinforced concrete panel buildings, which becomes especially relevant in connection with man-made destruction as a result of military operations in Ukraine. The robot is an innovative technology solution designed to improve rescue, recovery and safety operations in environments where traditional methods may not be effective. In this article, we will look at the development process and functional features of this mobile robot, and also discuss the prospects for its use in complex and emergency situations.

Key words: 3D Printing, mobile robot, small-sized robot, prototype, assembly

1. INTRODUCTION

In modern conditions of destructive man-made disasters and military events that can cover various regions of the world, issues of safety and efficiency of restoration are becoming increasingly relevant. One of the important accents when studying damaged buildings built on the principle of reinforced concrete panel structures is its fragility, unpredictability of behavior, as well as minimal working spaces inside or between the slabs. This complicates search and rescue operations and structural analysis of the strength of damaged buildings. An example of such destroyed buildings in the city of Kharkov, Ukraine, as a result of the military aggression of the Russian Federation is shown in Fig. 1.

Fig. 1. Example of destroyed panel houses in Kharkov due to the war

Taking into account the peculiarities of structural damage to reinforced concrete panel buildings when hit by a shell or missile, they can be as follows:

- punching and penetration. A projectile or missile can cause penetration through the surface layers of reinforced concrete. This can create holes, cause panel deformation and lead to structural collapse in the form of panels collapsing or partial destruction;
- formation of cracks and shedding. A projectile hit can cause cracks in the concrete structure. This can lead to shedding of surface layers and, possibly, further destruction of the structure;
- compression and deformation. Impact impacts can cause compression and deformation of reinforced concrete panels. This can lead to a loss of strength and a change in the shape of the structure, partial collapse of the building's structural elements;
- general destruction and collapse. Once hit by a projectile, general destruction and even collapse of parts or the entire building may occur, especially if structural elements are significantly damaged.

It can be seen that the use of classical mobile robots for conducting research in damaged buildings is not advisable due to the minimally limited working space. Such conditions arise when building panel structures are assembled. Due to the large dimensions of such robots, the likelihood of a mobile robot falling into rubble increases. It becomes possible to lose it completely. This can lead to high costs due to the high cost of the robot itself, which can reach ~$5,000-15,000 or more. Examples of such mobile robots are shown in Fig. 2.

Therefore, the development of small-sized robots is relevant. Of particular interest is the use of additive 3D printing technologies to produce most of the parts of these robots. Plenty of authors use such a technology for soft robotics [4]-[6], but we propose to use it for our small robots. They will be able to quickly and effectively interact inside destroyed reinforced concrete panel structures in a limited working space. This represents an important step in ensuring safety and rapid investigation of damage sites to make appropriate decisions regarding the condition of the building. It should be noted separately here that such a solution is cheap.

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a)

b)

c)

Fig. 2. Classic mobile robots for conducting research in damaged buildings

2. DESIGN OF A MOBILE ROBOT

Robots for working in man-made disaster zones, especially in areas with limited work space, must be designed taking into account the specifics of their operation. As part of these studies, we will introduce the following requirements for the mobile robot design being developed:

– compact size and maneuverability: the robot must be compact in order to easily penetrate limited and hard-to-reach places, such as between reinforced concrete structures;
– intelligent navigation system: development of intelligent navigation algorithms that allow robot to avoid obstacles and correctly route in difficult conditions;
– cameras and sensors: using cameras, laser sensors and other sensors to navigate and search for problem areas in structures;
– stability and distance control: robots must be stable and able to withstand uneven surfaces and be capable of distance control to avoid risks to the operator;
– protection from external factors: the design must be protected from dust to ensure reliable operation in contaminated environments.
– safety: the use of safe materials and additional safety measures to avoid emergency situations, especially in conditions of collapses or hazardous areas.
– range and duration of operation: Ensuring sufficient range and duration of operation in one cycle to effectively perform tasks in limited access conditions.

Based on the requirements stated above, there was developed a design concept for a small-sized mobile robot, a sketch of which is presented in Fig. 3.

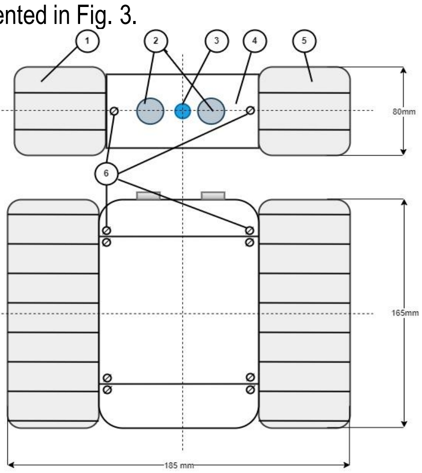

Fig. 3. A small-sized mobile robot design sketch

Let us describe the designation of the main elements that are indicated on a small-sized mobile robot design sketch (Fig. 3). 1,5 – caterpillars; 2 – ultrasonic sensor HC-SR04; 3 – camera OV2640; 4 – a mobile robot housing obtained using 3D printing; 6 – hardware for fastening housing elements.

The next stage is the development of a small-sized mobile robot detailed 3D model. The choice of the SolidWorks CAD system for developing a mobile robot 3D model was justified by its wide capabilities in the field of mechanical design and many years of success in the engineering field. SolidWorks provides an intuitive interface and powerful tools, allowing you to create complex mechanical designs with high precision. Its integration with CAM systems provides efficient preparation for 3D printing, making SolidWorks the optimal choice for developing innovative and technically complex projects, such as mobile robots. Based on the SolidWorks CAD system, a detailed assembly of a small-sized mobile robot was designed; the "explosive" model is shown in Figure 4.

To print the designed parts, we will use an Anet 8a Plus 3D printer with the following printing parameters: plastic – PLA; printing characteristics: extruder temperature 200 0C, table 56 0C; extruder diameter – 0.2 mm; layer height – 0.2 mm; line width – 0.3 mm. To prepare stl files for printing, the Ultimaker Cura 5.2.2 slicer was used. The obtained 3D printing results are presented in Table 1.

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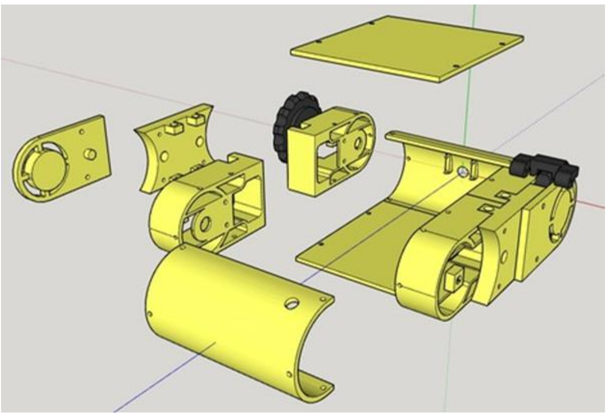
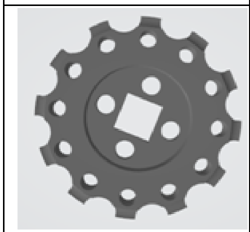
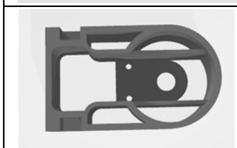
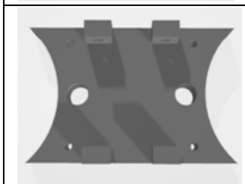
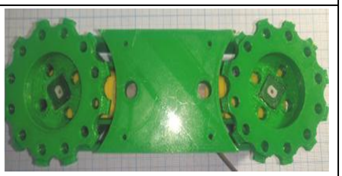
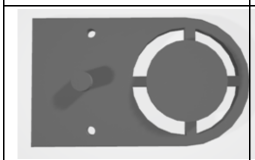
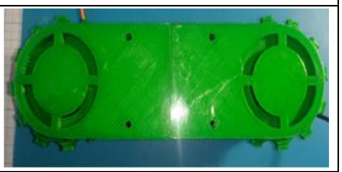
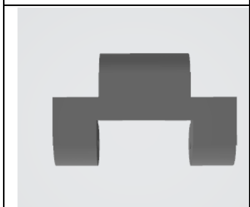
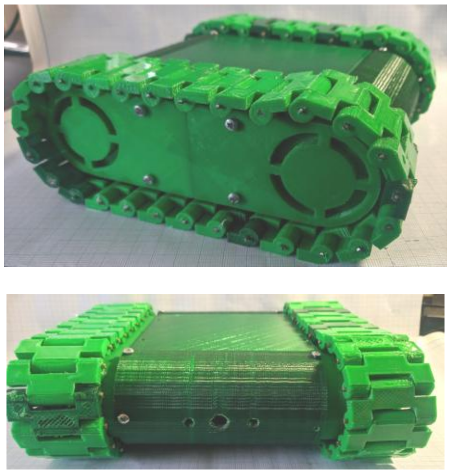


Fig. 4. Classic mobile robots for conducting research in damaged buildings

Tab. 1. Obtained 3D printing results

3D model in SolidWorks	Physical design in assembly
	
	
	
	
	

The assembled housing design of a small-sized mobile robot for research in the zone of man-made disasters, obtained on the basis of 3D printing, is shown in Fig. 5.



a)

b)

Fig. 5. Assembled housing design of a small-sized mobile robot a) side view; b) front view

3. A MOBILE ROBOT CONTROL SYSTEM DEVELOPMENT

Considering the small overall dimensions of a compact mobile robot, to develop a control system it is necessary to select micro-controller modules that provide the following requirements: small overall dimensions, support for wireless information networks (Wi-Fi), the ability to create an access point with support for the HTTP protocol (HTTPS) and connection support cameras for computer vision system. Based on these requirements, the following micro-controller modules were analyzed, which are presented in Fig. 6.

a)

b)

c)

Fig. 6. Microcontroller modules a) ESP32-CAM [7], b) OpenMV Cam H7 R2 [8], c) Raspberry Pi Zero W [9]

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Each analyzed module supports hardware connections of different video cameras models with the ability to support transmitted image quality UXGA 1600x1200 (15 fps) / SVGA 800x600 (30 fps). But at the same time they have fundamental differences, for example, Raspberry Pi Zero W+Cam allows you to deploy Raspberry OS/OS Android on it with support for C++ and Python languages, OpenMV Cam H7 R2 is designed for programming in the MicroPython language. At the same time, the basic operating principle is similar to the ESP32-CAM, which is programmed through the Arduino IDE (in a C-like language). Considering that the main task assigned to the mobile robot control system is to control movement and transmit the video stream to the operator, the main selection criteria will be the following parameters: power supply features, overall dimensions of the hardware module, weight and price.

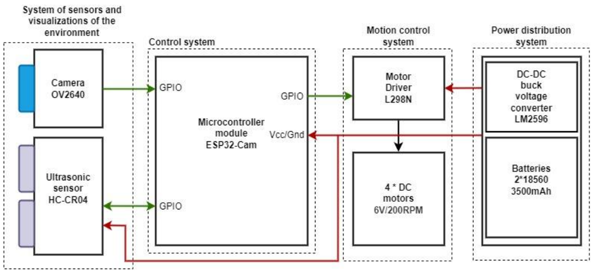

Fig. 7. A small-sized mobile robot control block diagram

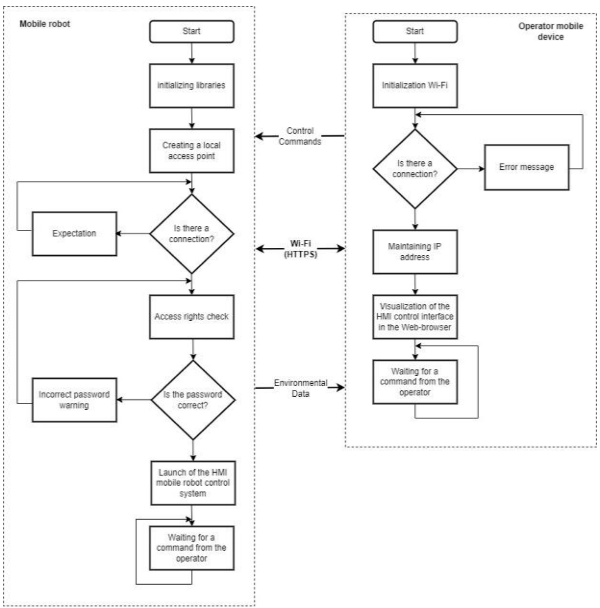

Fig. 8. Generalized control algorithm for a small-sized mobile robot

Based on own experience [7, 10, 11] with these hardware modules, the authors consider it inappropriate to use the Raspberry Pi Zero W, since for its stable operation it is necessary to provide it with 5V 2.5A power. If these recommendations are not followed, the Raspberry Pi Zero W may freeze and reboot. This module also has large overall dimensions. The ESP32-CAM module and OpenMV Cam H7 R2 operate stably with a power supply of 5V 1A. At the same time, they have approximately the same overall dimensions. They also have different price criteria, ESP32-CAM is about 6 times cheaper than OpenMV Cam H7 R2. As a result, to develop an experimental mobile robot prototype on omnidirectional wheels, ESP32-CAM will be used for a control system. Based on the selected microcontroller module, we will develop a control block diagram (Fig. 7).

A general algorithm for controlling a small-sized mobile robot using wireless data transmission technologies is presented in Fig. 8.

4. EXPERIMENTAL RESEARCH AND ANALYSIS OF THE RESULTS OBTAINED

To conduct research, an experimental small-sized mobile robot prototype was assembled to work in areas of man-made disasters such as destruction or partial destruction of reinforced concrete panel houses and buildings. A general view of the assembled prototype during field testing is shown in Fig. 9.

Fig. 9. Assembled small-sized mobile robot prototype general view

The purpose of the first experiment was to test the operating time of a mobile robot and find the distance of a stable control signal with the streaming video transmission. To conduct the experiment, a location was chosen that contained small fragments of concrete and graphite, as well as complex terrain. The results obtained are presented in Table 2.

Tab. 1. Results of testing the operating time of a mobile robot and finding the distance of a stable control signal with streaming video transmission

Parameters	Value
Test results (without additional antenna)	
Continuous operation time	~ 15 hours
Video stream transmission (open area)	~ 50-70 meters
Video stream transmission (reinforced concrete structure)	~ 35-55 meters
Test results (with additional antenna)	
Continuous operation time	~ 15 hours
Video stream transmission (open area)	~ 170-200 meters
Video stream transmission (reinforced concrete structure)	~ 100-150 meters

As can be seen from the obtained experimental values, the developed mobile robot for working in areas of man-made disasters makes it possible to confidently receive a video stream about the surrounding space, as a result of which to conduct research and analysis of the degree of damage to reinforced concrete structures at distances of 100-150 meters using an additional antenna that is installed to the ESP32-Cam module. The cost of the developed mobile robot housing was less than $10 At the same time, the total price of the developed mobile robot does not exceed $300-350, taking into account the cost of PLA plastic, and the printing time with the above slicer parameters was ~ 72 hours.

5. CONCLUSIONS

The article proposes the development of a small-sized mobile robot, the body of which is created using 3D printing technology. Currently, in conditions of war, destruction of panel buildings has become extremely common. It is advisable to use mobile robots to study them. Moreover, such robots had to be small to provide access to the cracks formed by the folded panels. Moreover, the risk of loss or destruction of such robots is high, so the cost should be as low as possible.

The development of just such a robot is proposed in this article. Studies have shown that the developed robot can work without recharging the batteries for up to 15 hours. Without an antenna, Video stream transmission (open area) ranged from 50 to 70 meters depending on the direction of signal transmission, Video stream transmission (reinforced concrete structure) ranged from 35 to 55 meters depending on the thickness and number of reinforced concrete structures. With an antenna, ideo stream transmission (open area) was from 170 to 200 meters, and Video stream transmission (reinforced concrete structure) was from 100 to 150 meters. Remote control will be possible from any mobile device: phone, tablet, etc. This robot is under development. In the future, it is planned to improve the model for greater impact resistance.

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Igor Nevliudov: https://orcid.org/0000-0002-9837-2309/

Vladyslav Yevsieiev: https://orcid.org/0000-0002-2590-7085

Svitlana Maksymova: https://orcid.org/0000-0002-1375-9337

Olena Chala: https://orcid.org/0000-0003-2454-3774