Mechatronic System for Monitoring a Warehouse of Hydraulic and Pneumatic Equipment

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Abstract: *The paper presents an original structure for an autonomous system designed to monitor objectives of strategic importance. The system was physically developed, then validated and optimized. In this work, the authors propose a methodology for implementing the designed system for a potential beneficiary*.

Keywords: *Mechatronic system, monitoring system, drone, mobile robots*

1. Introduction

Today, there are numerous applications for robots in both industry and other fields, one of which is their use for monitoring a strategic objective. Used individually or as part of surveillance "teams," mobile robots and drones can compensate for the shortage of personnel in security patrols and, at the same time, help reduce the costs associated with this activity.

In the United States, for example, according to the Bureau of Labor Statistics, approximately one million work hours are needed each night for security guards to perform their duties, at an annual cost of around $47,000 per agent [1]. This immense workload involves mentally monotonous and often exhausting patrols in poorly lit areas, dirty environments, and similar conditions. These harsh conditions significantly increase costs for security companies due to the high employee turnover, necessitating constant recruitment, hiring, and training activities. Additionally, because of the aforementioned conditions, many recruits quit after a short period of time.

Under these circumstances, the issue of security guards requires a new and innovative solution. The use of mobile robots and drones in security and surveillance activities can address the problem outlined above. In this way, the shortage of personnel can be compensated, and costs will be significantly reduced, as expenses related to recruitment, background screening, drug testing, uniforms, and training for security guards will no longer be necessary.

Autonomous mobile robots or drones move freely within the supervised area along dynamic trajectories generated by intelligent software that optimizes movements and assigns the perfect path for each operation [2]. Thanks to the use of state-of-the-art sensors and scanners, they can identify and avoid obstacles, operating safely in the area in collaboration with people and other equipment. However, highly versatile mobile robots and drones must be used, capable of easily integrating with all types of objectives that require surveillance, as no modifications to the existing infrastructure should be necessary. A member of the surveillance team, whether a mobile robot or a drone, must have the following characteristics:

- *be autonomous:* meaning it should move freely, navigate using virtual maps of its operating area, and not be confined to predefined trajectories or closed, perimeter navigation circuits;
- *be intelligent:* their movements should adapt to each task and follow routes generated by integrated navigation software that calculates the most efficient path for each member. Additionally, they must detect and avoid all types of obstacles, whether stationary or moving, and reconfigure their route in real time;
- *it should be flexible:* meaning it should be able to perfectly adapt to the general layout of the monitored objective and not require any structural modifications; its operation should be easy and quick to implement;
- *it should be scalable:* meaning the team structure should be easily expandable by introducing new robots or drones, or reduced by eliminating some members to adapt to the

specific requirements of the monitored objective at different times; there may be operational changes in the company using the objective, such as when seasonal peaks in demand occur;
- *it should be efficient:* a management software for the entire team monitors and ensures the movement of team members and anticipates their trajectories to assign the ideal task to each member;
- *it should be precise:* each member must perform tasks with absolute accuracy, which contributes to a significant reduction in errors and an increase in the efficiency of the surveillance operation;
- it should be safe: team members operate in highly complex environments involving people, goods, layout systems, and other equipment; a series of highly precise anti-collision sensors and scanners provide stability and reliability to all their movements.

To fully harness the potential of these teams in ensuring security, it is essential to follow certain steps and carefully plan the implementation of the solution.

2. The structure of the proposed surveillance system

The solution proposed in this paper consists of creating a "team" made up of:
- several mobile robots (their number being determined by the complexity of the objective to be monitored); two design options for mobile robots have been considered, namely: tracked mobile robots (figure 1) and quadruped mobile robots (figure 2);
- a drone; two design solutions have been developed (figure 3);
- a measurement system that provides real-time information about the positions of the monitoring team members to the command unit;
- a series of sensors placed on the robots - proximity sensors, temperature sensors, humidity sensors, cameras, etc.;
- a camera mounted on the drone;
- the command unit of the system.

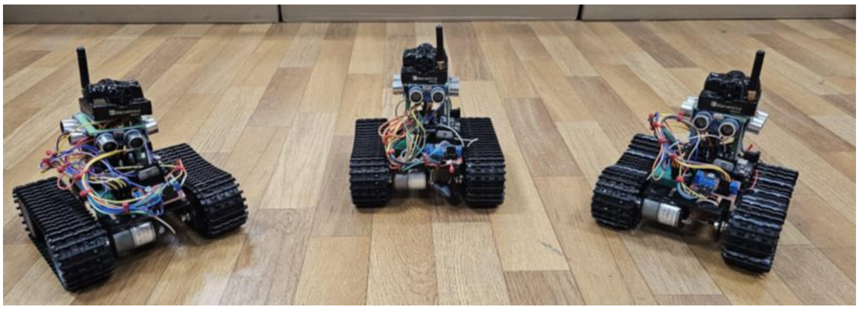

Fig. 1. Mobile tracked robots

Fig. 2. Quadruped mobile robots

Fig. 3. The drone models used

The robots patrol the monitored area; their movement follows predefined routes based on the needs and geometry of the monitored objective. The position of the robots will be tracked by a specially designed measurement system placed within the respective enclosure; any deviation of the robots from the predefined route is corrected in real-time. When an "event" is detected, the system's command unit will be notified. Immediately, the measurement system will transmit the position of the mobile robot near the event to the command unit; at the same time, the command system will deploy a drone to the event area. The drone will gather additional information about the event, primarily images from the event's location. This information will be processed and analyzed in real-time, and based on it, the command unit will decide what actions should be taken.
The measurement system used is manufactured by Marvelmind [3], a company specializing in autonomous robotics, which provides users with a complex architecture designed to combine ultrasonic sensors with an Inertial Measurement Unit (IMU) and post-processing for fast-moving objects. This system uses fixed and mobile ultrasonic beacons to accurately track (± 2 cm) the location of mobile robots and drones. Its setup and operation are managed via a router and a configuration application. The location of a mobile beacon is calculated based on the propagation delay of an ultrasonic signal to a set of stationary ultrasonic beacons using trilateration, a geodetic method based on measuring the sides of the triangles in a network. Trilateration is the foundation of GPS; the method involves determining distances, which are then used to calculate angles. Once calculated, these angles can be used alongside the distances to determine the position of target points.
The proposed system, as a whole, is a mechatronic system because:

- the mobile robots and drones are typical mechatronic products;
- the mobile robots and drones are equipped with a series of sensors that transmit real-time information about the environment in which they operate;
- each "member" autonomously performs its task, only calling on the central unit in situations it cannot resolve alone;
- there is an internal measurement system that tracks the positions of the mobile robots and the drone in real-time;
- the "members" of the team can communicate with each other and with the central unit through special communication interfaces;
- the entire process is controlled by a command unit structured around a PC.

It is therefore a complex mechatronic structure that can be seen as one that aligns with the principles underlying the new industrial revolution – Industry 4.0 [4].
The system was created, for validation purposes, using mostly components available in the Mechatronics and Precision Mechanics Department, with the rest being inexpensive, standardized, and easily accessible components.
The authors aimed to provide users of such systems with an intelligent surveillance solution that could be easily implemented at an acceptable cost.

3. The methodology for implementing the developed system for a potential user

In order to implement the developed system for a potential user, such as a warehouse for hydraulic and pneumatic automation equipment, the algorithm presented in figure 4 was developed.

The proposed implementation methodology involves the following steps: evaluating the monitored area, creating a map of this area, identifying the hardware structure of the robots, determining the trajectory of the mobile robots, identifying the events that need to be reported, and activating the system.
Evaluating the monitored area involves measuring the surfaces considered so that the optimal number of robots required for efficient monitoring of the working area can be determined. At this stage, it is also useful to identify the main obstacles that robots may encounter, such as architectural elements, furniture, etc. Interaction with human elements will not be considered at this stage. Additionally, factors that may negatively impact the operation of mobile robots or interfere with drone functionality are considered, such as areas with high or low temperatures, increased humidity, or areas where robots could be exposed to certain corrosive chemical elements, etc..
Indoor mapping involves creating detailed maps of buildings, rooms, and other enclosed environments. It utilizes technologies such as lidar, 3D sensors, cameras, and indoor GPS to determine the dimensions and structure of the monitored space. The technology is evolving rapidly, making mapping more accessible and accurate [5].
Mapping robots are a modern solution, and with their help, the necessary maps can be created quickly and correctly. Today, mapping robots are an indispensable tool in the exploration and optimization of complex interior spaces.

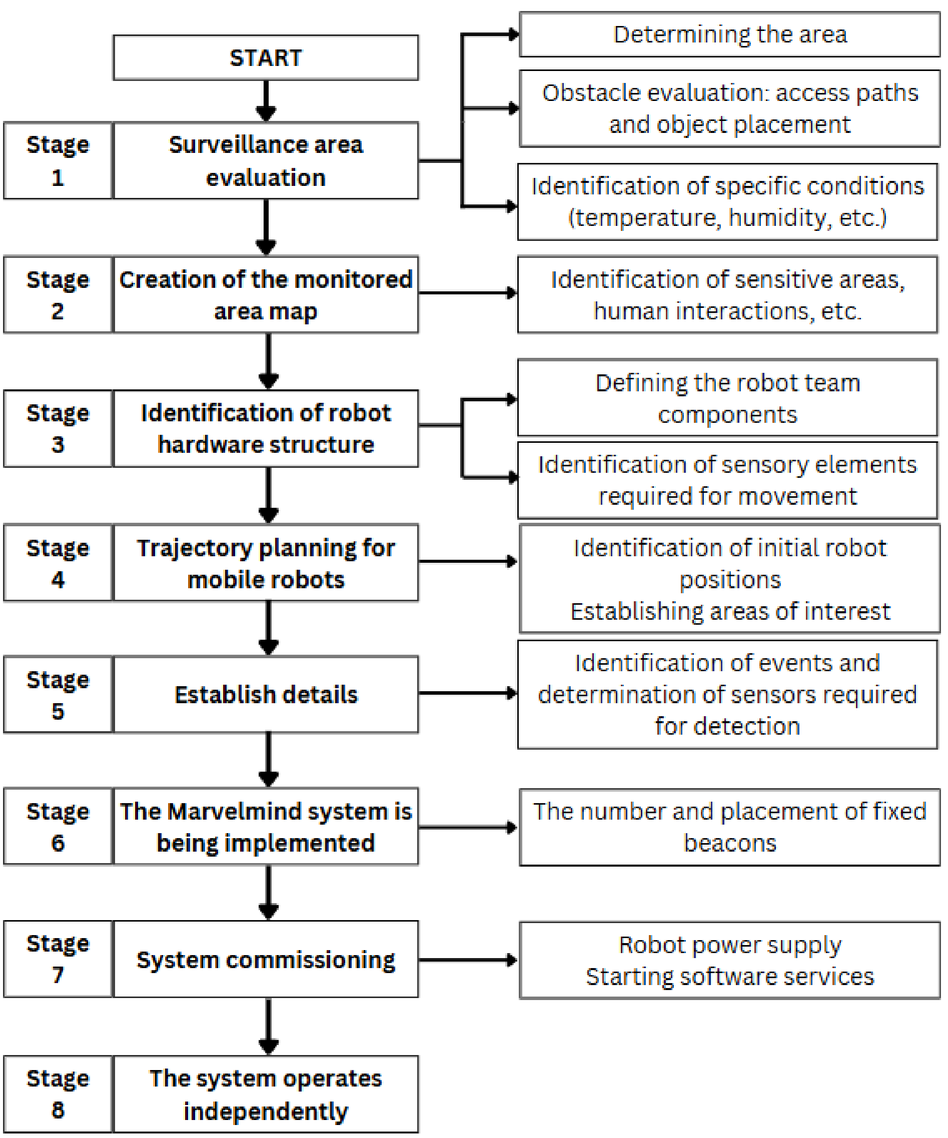

Fig. 4. The logical diagram of the implementation algorithm

As already mentioned, mobile robots are equipped with a variety of sensors, enabling precise navigation while simultaneously creating digital maps. Among these, we can mention:

- Lidar (Light Detection and Ranging) sensors, used to measure distances and generate detailed 3D representations of the environment;
- Ultrasonic sensors, often used for obstacle detection;
- RGB and RGB-D cameras, designed for capturing visual images and depth information;
- Inertial Measurement Units (IMUs) - monitor the robot's movement and orientation using accelerometers and gyroscopes, contributing to autonomous navigation;
- IR (infrared) sensors help detect proximity and object contours, being effective in low-light conditions;
- Pressure and contact sensors to prevent collisions.

SLAM (Simultaneous Localization and Mapping) technologies, based on combinations of sensors, allow the robot to localize itself and simultaneously map the space. Recent innovations, such as stereoscopic cameras and sensors with artificial intelligence, significantly increase mapping accuracy, opening up new possibilities for robots working in complex environments.

After the system is set up, it will operate autonomously, and intervention will only occur for maintenance operations. If necessary, any of the previously specified parameters (map, number of robots, etc.) can be modified at any time.

After the system is installed and powered on, it will operate according to the following logic:

- The Marvelmind measurement system reads the position of each member at any given moment in time;
- The location of the event is identified using sensors placed on the mobile robots;
- If an anomaly is detected, the drone moves to the coordinates of the mobile robot that sensed the event;
- The drone positions itself near the critical location and provides additional information about the event to the control systems;

The control system decides on the actions to be taken depending on the nature of the event.

4. Conclusions

The continuous development of mobile robots, drones, sensors, and transducers, which enable real-time data acquisition from the system, along with the increased processing power of computing systems, has created the conditions for integrating intelligent solutions for monitoring strategic objectives. In this way, in the initial phase, it is possible to track and record the parameters of interest from the monitored area to identify "events" and then determine the necessary measures.

The proposed system is capable of identifying and avoiding obstacles, operating safely in the monitored area, while also being cost-effective and easy to implement.

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