

SESSION A:

EARTH MOVING AND TRANSPORTATION MACHINERY

Mechatronic system for monitoring crane lifting operations

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ABSTRACT

Cranes are equipment that performs lifting and handling operations of loads with various masses and geometric configurations. Their safe use is regulated by the obligation to equip them with safety devices to limit the loads. The paper presents the development of a mechatronic system based on the integration of new technologies developed in the field of sensors and artificial intelligence in the field of lifting equipment. The implementation of the mechatronic system contributes to increasing the safety level of lifting machinery, by reducing the risk of accidents, ensuring the protection of operators and workers, as well as maintaining the integrity of the handled objects and those in the vicinity of the installation. The adoption of advanced technologies and intelligent systems to support the operation of equipment with the potential to cause accidents, accelerates the transition to automation of construction works.

KEYWORDS

Lifting machinery, Safety, Crane AI, Mechatronic cranes.

1. INTRODUCTION

Lifting plants are indispensable equipment in many industrial fields and in any construction work, used for the handling of materials, equipment and prefabricated elements. It is known that cranes are plants with a high potential for accidents, and the operational safety of these equipment is an essential priority. Statistics show that a significant proportion of work accidents are generated by technical failures, human errors in the absence of complete monitoring and warning systems. These realities justify the need to supplement the existing safety systems, by integrating intelligent solutions, capable of increasing the degree of safety and efficiency in operation. The successive stages of the transition from fully manual to automatic operation, culminating in the development of autonomous construction equipment, figure 1, are also found in the field of lifting installations.

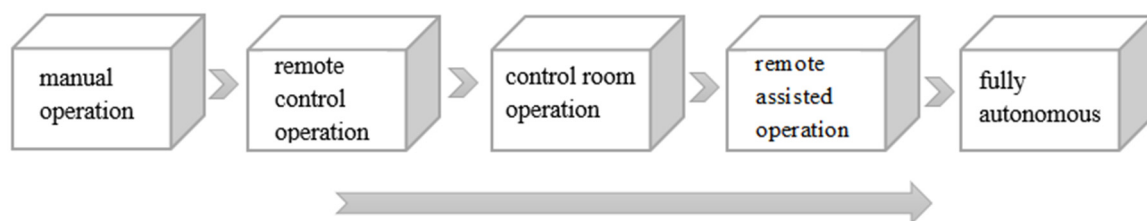


Figure 1: Construction equipment automation levels

Compared to other branches of industry, the transition of construction equipment to automation is at an early stage of development. Manufacturers are developing equipment that integrates different levels of automatic control, up to the possibility of their autonomous operation. In the field of lifting installations, research on the implementation of automation levels has mainly focused on applications that require the reproduction of predetermined sequences of movements. Among the different types of lifting installations, gantry cranes are considered among the most suitable for implementing advanced levels of automation, as they operate in a well-defined workspace, and in certain industrial environments obstacles present fixed positions.

Usually, on construction sites, the handling of loads of any kind is carried out with tower cranes, mobile cranes, crawler cranes with high lifting capacities and gantry cranes, controlled by manual control by the operator in the control cabin. The introduction of remote-control operation of lifting installations has brought numerous advantages, both in terms of operator safety and the efficiency of the work process. These include eliminating the need to carry out activities at height, the possibility of rapid evacuation of the operator in emergency situations, reducing the operator's exposure to the risks specific to the specific risks of the work environment and increasing productivity by positioning the load lifting hook faster and more precisely. The research considers the remote-assisted operation component by performing tasks autonomously.

2. TECHNOLOGICAL CONTEXT AND RECENT RESEARCH

Ensuring the safe operation of lifting installations that move on rail tracks, such as overhead cranes and new generation gantry cranes with remote control operation, is a concern determined by the situations encountered in the use of this equipment. Gantry cranes have the particularity of lifting the nominal load at any point of the workload, being frequently used in the heavy industry of mechanical takeovers, in goods warehouses, in the organizations of large infrastructure sites in order to handle materials, prefabricated (reinforced concrete beams, segments of lining rings for metro galleries, etc.), equipment, underground drilling rigs, etc. The research directions on the use of portal cranes focused on several criteria such as the management of cargo containers in a maritime terminal, monitoring the work area, the implementation of autonomous operation, etc. In the paper [1], the authors use a 3D Lidar sensor to monitor the movements of the overhead crane in an industrial workshop. The 3D Lidar sensor is placed in a fixed position inside the hall, which leads to the appearance of areas that can be obstructed by obstacles in its field of vision. The authors of the paper [2] proposed a method of three-dimensional mapping-graphing of the operating environment of overhead cranes by the combined use of a binocular camera and a laser distance measurement sensor. The solution allows for three-dimensional reconstruction of a fixed scene and improves workspace monitoring capability. Another area characterized by repetitive and intensive task manipulations is large-time terminals. The continuous increase in container flows has led to the development and implementation of self-controlled handling systems, and some operations are autonomous. As is also apparent from [3], LiDAR sensors and, in certain cases, cameras mounted on the load-bearing structure of handling equipment are frequently used in these applications for obstacle detection, monitoring the working environment and assisting autonomous operating functions.

The research results highlight both the advantages of using new monitoring and automation technologies, as well as the limitations associated with their implementation. Among the main aspects identified are:

- the high costs related to the acquisition, installation and integration of monitoring systems based on sensors and video cameras, including both the hardware components and the software applications necessary for their operation;
- the large dimensions of the workload specific to portal cranes, which require the use of efficient methods of data storage and processing, as well as formats for saving digital maps with high compression rates;
- the possibility of determining the absolute position of overhead cranes operating in enclosed spaces by using fixed markers or laser telemetry systems, similar to the location solutions used in Automated Guided Vehicles (AGVs).

These aspects outline the need to identify technical solutions that ensure an optimal compromise between the implementation costs, the accuracy of monitoring and the safety of the operation of the lifting equipment.

3. ARCHITECTURE OF THE MECHATRONIC SYSTEM

Research in the field highlights the usefulness of using sensors and smart cameras for crane workspace monitoring. Unlike the examples presented in the literature, the proposed mechatronic system concept aims to identify the existing obstacles in the workspace of gantry cranes used on construction sites, by placing the mechatronic system directly on the load lifter. This approach is based on the fact that construction sites are working environments characterized by high dynamics, in which the configuration of the cranes' workspace is constantly changing, so that temporary obstacles may arise whose presence and position are not known a priori by the operator.

The intelligent mechatronic system developed to increase safety in crane operation, Figure 2, is based on the integration of new technologies developed in the field of sensors and artificial intelligence into the field of lifting equipment. The concept of the intelligent mechatronic system comprises a 3D LiDAR sensor, SBC (Single-Board Computer) and intelligent camera, which allow detailed scanning of the hook's operating space in real time, generating a three-dimensional model of the environment, detecting and signaling any obstacle that may be in the direction of the hook's movement.

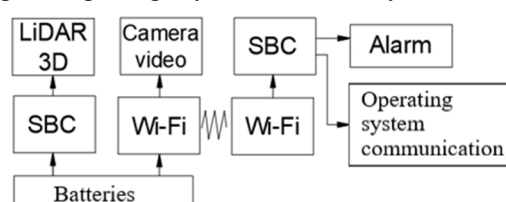


Figure 2: Mechatronic system diagram

The intelligent mechatronic system analyzes the working area in a 3D vicinity defined for the load hook, in order to achieve safe and efficient lifting/lowering operations.

A representative case is that of the portal crane used on the construction site of the M6 Bucharest metro line, figure 3, which operates from ground level and serves the workspace in the work area both on the surface and underground. In this case, the operation is done by remote control, and the operator is on the surface, in the crane running area, which does not allow him to view the underground workspace.



Figure 3: Portal crane – M6 metro line construction site, Bucharest

4. EXPERIMENTAL MODEL FOR TESTING THE FUNCTIONALITY OF THE MECHATRONIC SYSTEM

4.1. Presentation of the Laboratory Stand

In order to validate the proposed model, an experimental model of the mechatronic system was designed and made. The operation test was carried out on the laboratory stand of the Lifting Machinery Laboratory of the Faculty of Mechanical Engineering and Robotics in Constructions, U.T.C.B. The laboratory stand shown in figure 4 is equipped with all the constructive, functional elements and safety devices corresponding to the operation of a lifting installation. The overhead crane is made for educational purposes, so that its operation does not fall under the legislation of lifting installations (valid in Romania). The stand represents a functional model of a real overhead crane, having parameters from table 1:

Table 1: Parameters of the functional model of the laboratory stand

Parameter	Value
Rated load (Q)	1600 kg
Track gauge (E)	3.0 m
Track length (L)	10.0 m
Lifting Height (H)	5.0 m

The laboratory stand has the same parameters as those of the real overhead crane, the only change being the length of the track, which is 2.5 m.

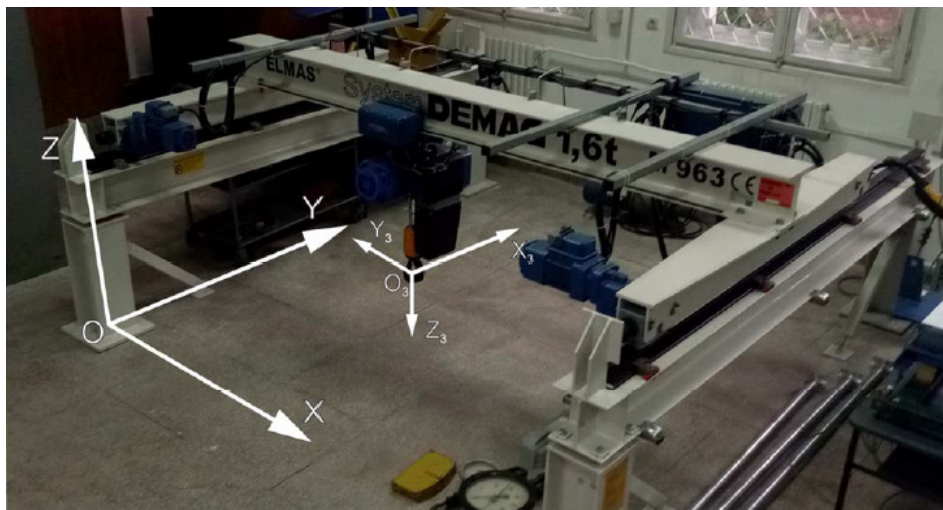


Figure 4: The laboratory stand

In order to determine the workspace of the laboratory stand, we made the kinematic diagram, figure 5.

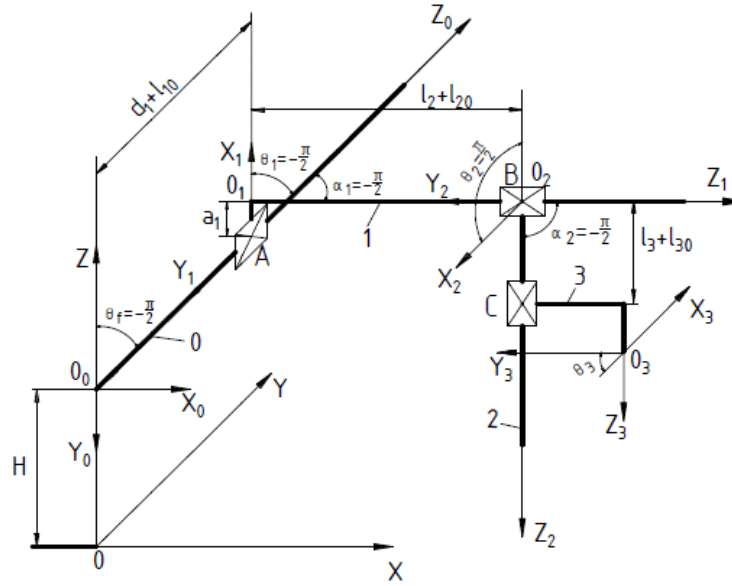


Figure 5: Kinematic scheme

The trips made by the laboratory stand are determined by the relationships (1):

$$\begin{aligned} s_x &= l_{10}, l_{10} + 60 \dots (l - l_{11}) \\ s_2 &= l_{20}, l_{20} + 100 \dots (l - l_{21}) \\ s_3 &= l_{30}, l_{30} + 100 \dots (H) \end{aligned} \quad (1)$$

4.2. Composition of the Experimental Model

We made the experimental model using the following components:

- The Raspberry Pi 5 platform is the central processing unit of the mechatronic system, being responsible for the acquisition and processing of data from the LiDAR sensor, as well as for the coordination and control of the peripheral components of the system, figure 6.a)
- MS200 Lidar sensor for distance measurement that scans the environment 360° and provides information about the position of surrounding objects. It works on the principle of dToF (Direct Time of Flight), measuring the time it takes for laser pulses to reach an object and return to the receiver, figure 6.b).
- Pan-Tilt-Zoom (PTZ) camera with 2 Degrees of Freedom (2DOF) for orientation, Figure 6.c);
- expansion board mounted on top of the Raspberry Pi 5, with the role of connecting and controlling the robot components. It integrates an ESP32-S3 coprocessor, LiDAR interface, 6-axis IMU sensor and various communication interfaces (Wi-Fi, Bluetooth, UART);
- The robot chassis is the mechanical support structure of the mechatronic system, having the role of integrating and fixing the electronic components, sensors and the propulsion system, while ensuring the rigidity and stability of the assembly during operation.

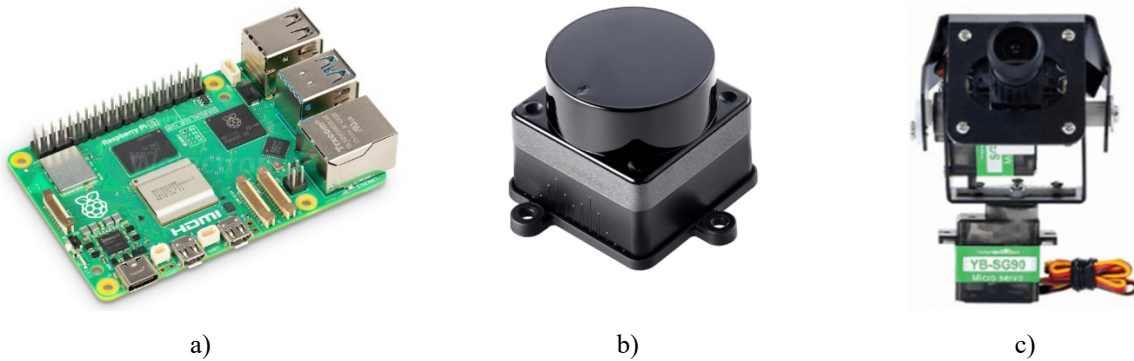


Figure 6: Elements of the experimental model; a) Raspberry Pi5 – SBC; b) 2D LiDAR; c) 5MP PTZ camera

4.3. Testing the Experimental Model

The measurements were carried out with the 2D LiDAR sensor. The experimental model was fixed on the lifting hook of the laboratory stand (Figure 7 a). Figure 7 b shows two positions of the object to be identified in the work space of the stand.



a)



b)

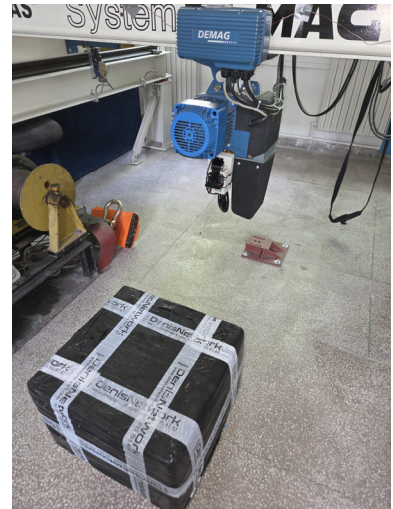
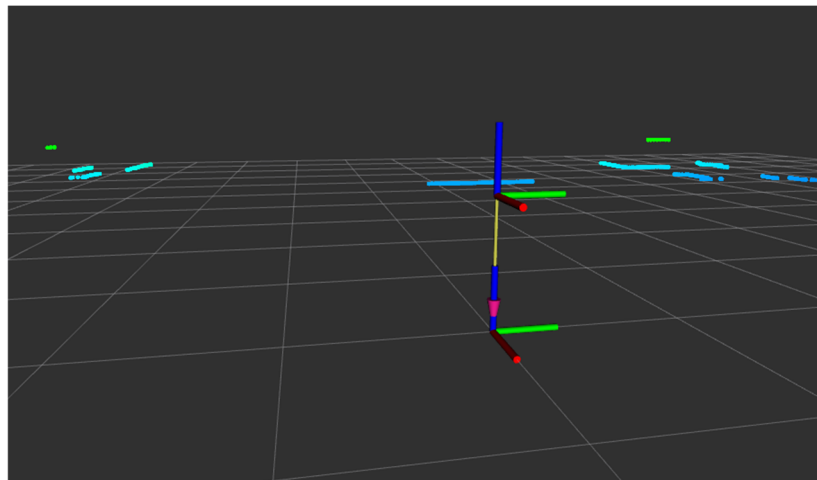
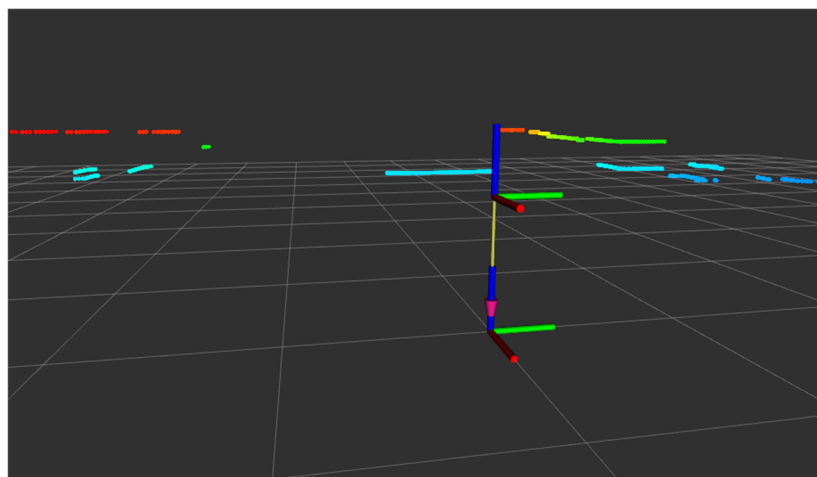


Figure 7: Testing of the experimental model: a) the experimental model fixed on the hook of the lifting mechanism; b) test positions for the identification of the obstacle

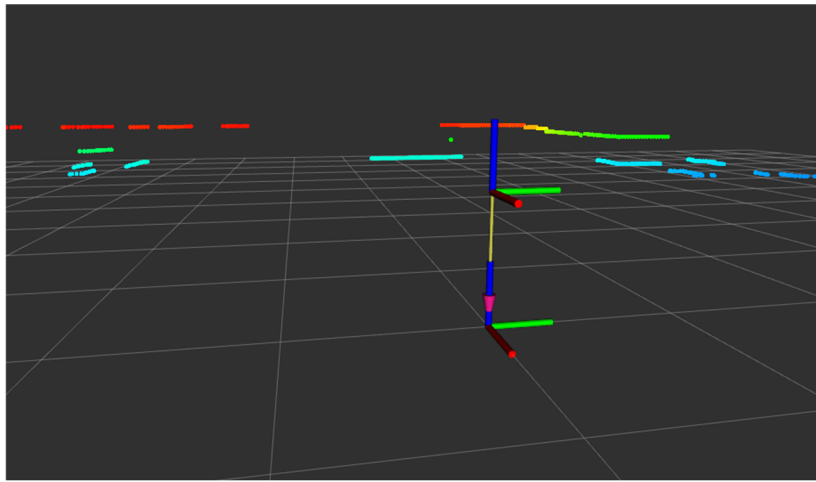
Figure 8 shows the results of the tests carried out on the previously presented object, where the change in its position with respect to the movement of the hook can be observed.



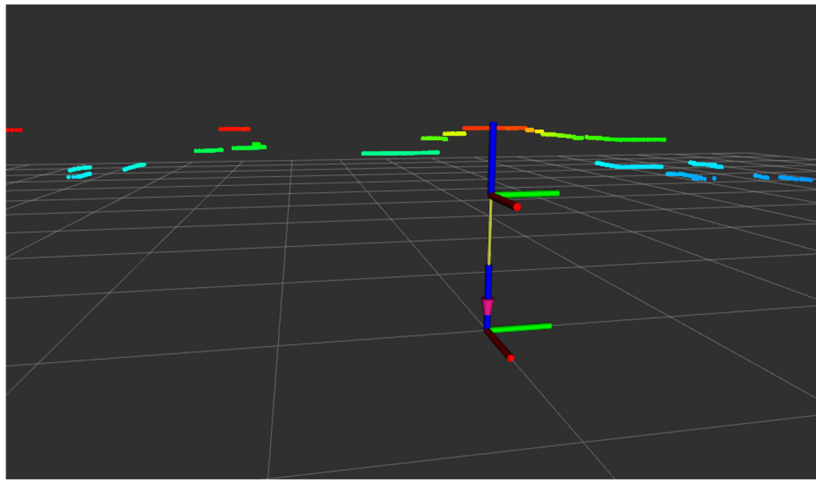
a)



b)



c)



d)

Figure 8: The point cloud generated by the 2D LiDAR sensor for identifying the object in successive positions in the booth workspace: a) the nearest position; b) intermediate position 1; c) intermediate position 2; d) distant position

Finally, the image from the video camera was superimposed on the point cloud generated by the 2D LiDAR sensor, where it is observed that the object is correctly identified.

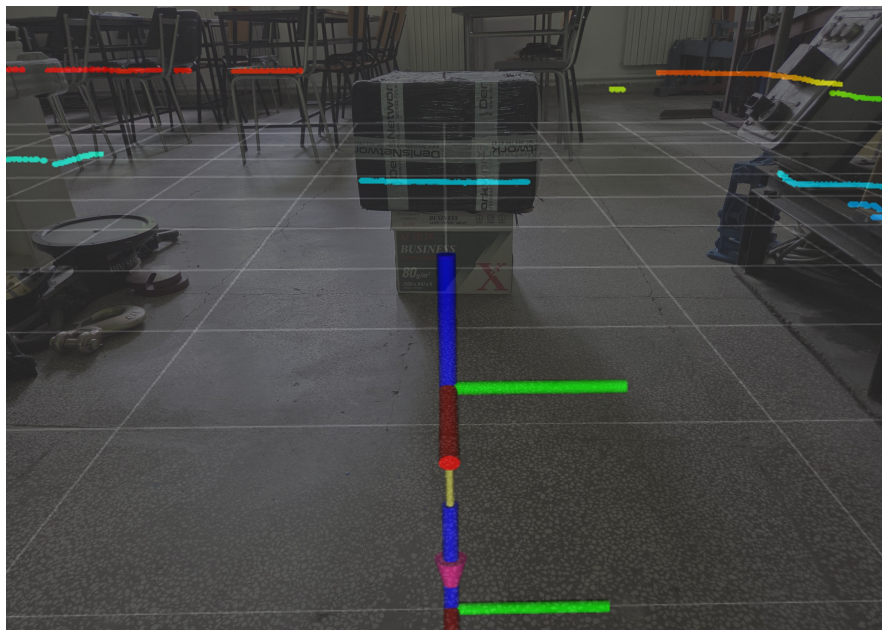


Figure 9: Overlay the images from the camcorder and the point cloud generated by the 2D LiDAR sensor and identify the object under test

4.4. Findings

As a result of the flexibility of the lifting mechanism elements, the movements of the crane cause the lifting device to oscillate. Consequently, for the implementation of the mechatronic system, it is necessary to use a smart camera stabilization device, in order to reduce the effects produced by the balance on the performance of the perception system.

5. CONCLUSIONS

The experimental model developed and tested under laboratory conditions demonstrated the feasibility of using a mechatronic system based on a 2D LiDAR sensor and a video camera to identify obstacles in the workspace of lifting installations. To validate the operation of the final solution, a 3D LiDAR sensor will be used.

The experimental results showed that the combined use of a 2D LiDAR sensor and a video camera is an effective solution for monitoring the workspace and increasing the operator's awareness of the presence of obstacles. The tests carried out confirmed the proper functioning of the system under controlled laboratory conditions and demonstrated its potential for implementation on gantry cranes used on construction sites.

The results obtained also form a basis for further developments, oriented towards the fusion of data from sensors, the estimation of distances to obstacles and the implementation of warning or automatic collision avoidance functions.

Thus, the proposed system can represent an intermediate step towards increasing the degree of automation of the lifting installations.

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