ISSN 2007-9737

Classical Autonomous Navigation for a Biped Robot Using ROS2

Miguel López[1], Olga Félix[1], Marco Negrete[2], César Martínez[3], José Gutiérrez[1], Luis Contreras[4]

[1] Benemérita Universidad Autónoma de Puebla, Facultad de Ciencias de la Electrónica, Mexico

[2] Universidad Nacional Autónoma de México, Facultad de Ingenierías, Mexico

[3] Universidad de las Américas Puebla, Escuela de Ingenierías, Mexico

[4] Tokio Information Design Professional University, Japan

lz224470177@alm.buap.mx, {olga.felix. jose.gutierrez}@correo.buap.mx, marco.negrete@ingenieria.unam.edu, cesar.martinez@udlap.mx, tenshi.unam@gmail.com

Abstract. This paper presents the implementation and experimental validation of a classical autonomous navigation framework adapted to the Unitree G1 biped robot. The proposed system integrates LiDAR-based perception, occupancy grid maps, probabilistic localization, global path planning, and velocity-based trajectory following developed within the ROS2 framework. A static map of the environment is used as the main spatial representation, while Adaptive Monte Carlo Localization estimates the robot pose with respect to the map. A global path planner based on the A* algorithm computes collision-free routes between the initial robot position and a user-defined goal. The resulting path is followed by generating velocity commands compatible with the robot motion interface. Unlike conventional mobile robot platforms, the use of a biped robot introduces additional challenges related to odometry quality, body motion, and sensor stability. The system was evaluated in an indoor environment using a LiDAR sensor and a ROS2-based navigation pipeline. The results demonstrate that classical navigation methods can be adapted to biped robots when proper frame transformations, localization, map representation, and command interfaces are considered.

Keywords. Biped robot, autonomous navigation, unitree G1, ROS2.

1 Introduction

In recent years, and thanks to the increase in the number of companies related to the development of biped robots, these platforms have gained significant relevance due to their multiple applications, including assistance, research, inspection, and exploration, mainly because of their ability to navigate environments designed for humans [15, 1, 14].

A major advantage of biped robots over wheeled mobile robots is their capability to overcome certain obstacles, move over uneven surfaces, and operate in spaces where humanoid morphology proves advantageous. However, autonomous navigation on this type of platform remains a challenge due to factors such as locomotion complexity, dynamic stability, odometry uncertainty, and loss of localization caused by the type and intensity of the robot's motion [2, 8, 7].

Classical navigation architectures based on mapping, localization, path planning, and motion control are among the most widely used approaches for terrestrial robots, especially differential and omnidirectional platforms, due to

their stable motion and accurate displacement control [3, 9]. However, their direct application to biped robots depends on adapting the way the environment is represented, the pose estimation process, and the generation of motion commands to the robot's capabilities.

This work presents the implementation and experimental validation of a classical autonomous navigation architecture on the Unitree G1 biped robot. The system uses a LiDAR sensor for environment perception, an occupancy map as the spatial representation, AMCL for probabilistic localization, and the A* algorithm for global path planning. The generated trajectory is converted into velocity commands that allow the robot to move toward a goal within an indoor test environment.

The main contribution of this work is not the proposal of a new localization or path planning algorithm, but the practical adaptation of a classical ROS2-based navigation pipeline to a real biped robotic platform.

Unlike conventional wheeled mobile robots, the Unitree G1 presents additional implementation challenges related to body oscillations, sensor motion, odometry uncertainty, and the need to translate standard velocity commands into the robot locomotion interface.

Therefore, the contributions of this paper are summarized as follows: (i) the integration of LiDAR-based perception, occupancy-grid mapping, AMCL localization, A*-based global planning, and velocity-based trajectory following on a Unitree G1 biped robot; (ii) the implementation of a ROS2 communication interface between standard navigation commands and the internal locomotion request topic of the robot; and (iii) an experimental evaluation of the navigation performance in a real indoor environment considering navigation time, final pose error, and collision-free goal reaching.

2 Related Work

Autonomous navigation has been widely studied within the field of mobile robotics, mainly in kinematic configurations with differential drive, Ackermann-type drive, and omnidirectional drive. In this type of robot, classical navigation architectures typically consist of a series of modules responsible for representing the environment through mapping, estimating the position of the robot, path planning, and following it through motion commands [5, 13, 10].

These systems have proven to be efficient and effective in structured indoor environments, where it is possible to create occupancy maps and use distance sensors and probabilistic localization algorithms.

Within these navigation systems, one of the fundamental elements is path planning. To accomplish this task, there is a wide variety of techniques ranging from classical methods to those based on artificial intelligence for route planning [17, 12]. Among the classical strategies, one of the most widely used due to its low computational cost and its high ability to find collision-free paths is the A* algorithm.

This methodology consists of avoiding collisions through the use of a heuristic function [16, 6].

By working with occupancy maps, this algorithm allows for the calculation of a route from a starting position to a defined destination, evaluating the cost of movement between free cells and avoiding those that represent obstacles.

In navigation systems based on ROS and ROS2, these classical methods have been integrated into modular architectures that allow for the combination of different sensors, localization methods, planners, and motion controllers to be combined [11, 4]. This has made ROS a widely used tool for the development and validation of autonomous navigation systems in indoor environments. However, most of these implementations have been designed for wheeled mobile robots, which exhibit more stable motion, more reliable odometry, and fewer variations in sensor orientation during movement.

Compared with wheeled robots, biped robots present additional challenges because their locomotion generates body oscillations, leading to variations in sensor orientation and greater uncertainty in odometry estimation.

These factors directly influence the robot localization, the alignment with the occupancy map, and the tracking of the planned trajectory.

For this reason, adapting classical navigation methods to biped robots requires careful consideration of transformations between reference frames, sensor stability, localization quality, and how planned trajectories are converted into commands executable by the robot.

In this context, the present work focuses on the implementation of a classical navigation architecture based on ROS2 on the Unitree G1 biped robot. The system combines LiDAR-based perception, occupancy maps, probabilistic localization using AMCL, global path planning with A*, and the generation of velocity commands to evaluate the feasibility of applying classical autonomous navigation methods on a humanoid platform.

3 Proposed ROS2-Based Navigation Architecture

The proposed system follows a classical autonomous navigation architecture implemented within the ROS2 framework. The architecture integrates environment perception, two-dimensional map representation, probabilistic localization, global path planning, trajectory following, and velocity command conversion for the Unitree G1 biped robot.

Although these modules are commonly used in wheeled mobile robots, their integration on a biped platform requires additional considerations related to body motion, sensor stability, odometry uncertainty, and compatibility with the robot locomotion interface.

The complete navigation pipeline starts with the acquisition of three-dimensional LiDAR data from the Livox MID360 sensor. This information is converted into a two-dimensional laser scan representation and then used for occupancy grid mapping and localization.

Once the robot pose is estimated with respect to the map, the global planner computes a collision-free path toward a user-defined goal. Finally, the trajectory following module generates velocity commands, which are converted into locomotion requests compatible with the Unitree G1 control interface.

Table 1. navigation system configuration used in the experimental tests

Parameter	Configuration
Robot platform	Unitree G1
Operating system	Ubuntu 20.04
Middleware	ROS2 Foxy
Main sensor	Livox MID360 LiDAR
Sensor processing	3D point cloud to 2D laser scan
Main frames	*map*, *odom*, *base_link*, *mid360_link*
Sensor topic	*/scan_mid360*
Mapping method	*slam_toolbox*
Localization method	AMCL
Navigation stack	*pumas_nav2*
Global planner	A* algorithm
Command interface	*/cmd_vel* to */api/loco/request*

3.1 Hardware and Software Configuration

The system was implemented on the Unitree G1 biped robot using Ubuntu 20.04 and ROS2 Foxy as the main software environment. The robot is equipped with a Livox MID360 3D LiDAR sensor, which provides spatial information of the surrounding environment. The navigation modules run on the robot computer and communicate through ROS2 topics, messages, and coordinate transformations.

The main reference frames used in the navigation system are *map*, *odom*, *base_link*, and *mid360_link*. The *map* frame represents the global reference associated with the occupancy grid, while the *odom* frame represents the local odometric reference. The *base_link* frame is attached to the robot body, and the *mid360_link* frame corresponds to the LiDAR sensor reference.

The correct definition and publication of these transformations is essential for localization, planning, and motion execution.

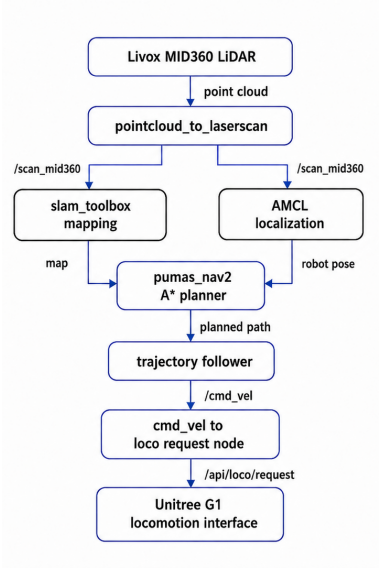

Fig. 1. ROS2 communication flow of the proposed navigation architecture

Figure 1 shows the communication flow of the proposed ROS2 navigation architecture. The diagram summarizes the main processing stages, from LiDAR data acquisition and scan conversion to mapping, localization, path planning, trajectory following, and command conversion for the Unitree G1 locomotion interface.

3.2 LiDAR Data Processing

The Livox MID360 sensor provides environment information as a three-dimensional point cloud. However, the classical navigation modules used in this work operate on two-dimensional laser scan data. For this reason, the point cloud is converted into a *LaserScan* message using the *pointcloud_to_laserscan* package.

This conversion allows the navigation system to use the LiDAR data as if it were produced by a conventional planar laser scanner. The resulting scan is published on the */scan_mid360* topic and is used by both the mapping and localization modules. This processing stage is particularly important for the biped robot because body oscillations can introduce variations in the perceived point cloud during walking.

3.3 Occupancy Grid Mapping

The environment is represented using a two-dimensional occupancy grid map generated with the *slam_toolbox* package. In this representation, the workspace is divided into discrete cells, where each cell stores information about whether the corresponding region is free, occupied, or unknown. This map provides the spatial representation required for localization and path planning.

During the mapping stage, the converted LiDAR scans are used to estimate the structure of the indoor environment. Once the map is generated, it is used as a static reference for the autonomous navigation tests. The occupancy grid allows the planner to identify traversable regions and avoid cells associated with obstacles.

3.4 AMCL Localization and TF Frames

Robot localization is performed using Adaptive Monte Carlo Localization. AMCL estimates the pose of the robot within the previously generated map by comparing the laser scan measurements with the expected observations obtained from the occupancy grid. The estimated pose is represented with respect to the *map* frame and is continuously updated during navigation.

The localization process depends on the correct relationship between the *map*, *odom*, and *base_link* frames. In the implemented architecture, the robot state information is used to publish the transformation between *odom* and *base_link*. AMCL then provides the correction between the *map* and *odom* frames. This structure allows the navigation system to maintain a consistent estimate of the robot pose during motion.

3.5 Global Path Planning

Global path planning is performed using the A* algorithm integrated within the *pumas_nav2* navigation stack. The planner uses the occupancy grid map to compute a collision-free route from the current estimated robot pose to a user-defined goal. During this process, the algorithm evaluates the cost of moving between neighboring free cells while avoiding occupied or unknown regions.

The generated global path provides a sequence of poses that the robot must follow to reach the goal. Since the robot operates in a mapped indoor environment, the use of an occupancy grid based planner is suitable for the proposed experimental scenario. However, unlike wheeled robots, the execution of the path on a biped platform depends on the walking behavior, body orientation changes, and the ability of the locomotion controller to track velocity commands.

In a biped robot, localization is affected by body oscillations, step induced motion, and odometry uncertainty. Therefore, the stability of the LiDAR frame and the consistency of the TF tree are critical aspects for reliable navigation.

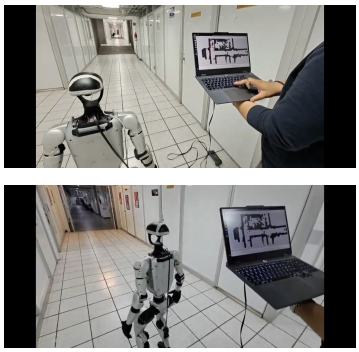

Fig. 2. Experimental navigation scenario in a T-shaped corridor. The robot starts before the intersection, turns at the corridor junction, and continues toward the goal position

3.6 Velocity Command Conversion

The trajectory-following stage generates velocity commands using *geometry_msgs/Twist* messages published on the */cmd_vel* topic. These commands include linear, lateral, and angular velocity components that describe the desired motion of the robot in the navigation frame.

In the proposed architecture, trajectory following is performed by the *simple_move_node*, which receives the planned path and computes velocity commands according to the relative position between the robot and the next target point on the path. The robot pose is obtained from the TF transformation between the *map* and *base_link* frames. For each control cycle, the heading error with respect to the next path point is calculated.

The linear velocity is reduced when the heading error is large and increased when the robot is aligned with the path, while the angular velocity is computed as a nonlinear function of the heading error. During path following, the next target point is selected from the planned path according to the robot progress along the current path segment. The path is considered completed when the distance between the robot and the final goal is below the configured path goal tolerance.

However, the Unitree G1 does not directly execute standard */cmd_vel* commands as a conventional mobile base. Therefore, an intermediate ROS2 node is used to convert the velocity commands into requests compatible with the robot locomotion interface. This node subscribes to */cmd_vel* and publishes the corresponding locomotion requests on the */api/loco/request* topic.

This conversion stage is one of the key implementation aspects of the proposed system, since it connects the standard ROS2 navigation pipeline with the specific control interface of the biped robot. As a result, classical navigation commands can be executed by the Unitree G1 locomotion controller.

4 Experimental Setup

The experimental tests were carried out in a controlled indoor environment. The evaluated scenario consisted of an obstacle-free navigation path of approximately 4.5 m, where the Unitree G1 robot had to move from a fixed initial position to a fixed goal position while turning around a corner.

The same initial and final poses were used in all trials in order to evaluate repeatability, final position error, final orientation error, and navigation time.

4.1 Test Environment

The test environment corresponded to a structured indoor space with an obstacle free navigation path.

The robot was required to move from a fixed initial pose to a fixed goal pose while turning around a corner.

Table 2. Main implementation parameters used in the navigation system

Parameter	Value
Map resolution	0.05 m/cell
Scan topic	*/scan_mid360*
Point cloud topic	*/livox/lidar*
LiDAR height range	0.05–0.50 m
Laser minimum range	0.3 m
Laser maximum range	20.0 m
Scan time	0.05 s
AMCL frames	*map*, *odom*, *base_link*
AMCL noise	$\alpha_1 = 0.01$, $\alpha_2 = 0.01$, $\alpha_3 = 0.1$, $\alpha_4 = 0.1$
Inflation radius	0.22 m
Cost radius	0.25 m
Controller frequency	30 Hz
Minimum linear speed	0.05 m/s
Maximum linear speed	0.8 m/s
Maximum lateral speed	0.8 m/s
Maximum angular speed	1.25 rad/s
Fine distance tolerance	0.03 m
Path goal tolerance	0.20 m
Angular tolerance	0.05 rad

This scenario was selected to evaluate the repeatability of the navigation architecture, the final pose accuracy, and the consistency of the trajectory following behavior under controlled conditions.

An occupancy map of the environment was generated using the *slam_toolbox* package and LiDAR information converted into *LaserScan* messages. The resulting map was used as a static reference for localization and path planning during the experimental trials.

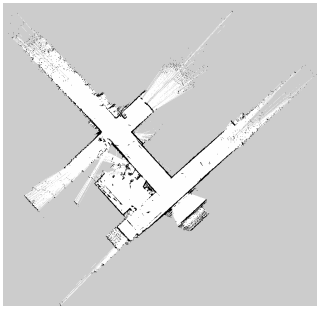

Fig. 3. Occupancy grid map of the T-shaped corridor used for localization and path planning

4.2 Navigation Configuration

For the tests performed, the system used the */scan_mid360* topic as the main input for the sensor information. The main reference frames considered were *map*, *odom*, *base_link*, and *mid360_link*. Localization was performed using AMCL, while path planning was carried out using the A* algorithm, integrated within the *pumas_nav2* navigation stack.

The velocity commands generated by the system were published on */cmd_vel* and later converted into requests compatible with the Unitree G1 locomotion interface.

4.3 Implementation Parameters

In order to improve the reproducibility of the proposed navigation system, the main implementation parameters used during the experimental tests are summarized in Table 2. These parameters include the map representation, LiDAR scan conversion, localization settings, obstacle inflation, velocity limits, and trajectory-following parameters used by the navigation pipeline.

The occupancy grid map was generated using LiDAR data converted into a two-dimensional laser scan. The scan conversion node projected the Livox MID360 point cloud into the *mid360_link* frame and published the resulting scan on the */scan_mid360* topic. The AMCL localization module used this scan topic together with the generated map to estimate the robot pose during navigation. The velocity commands generated by

the trajectory following module were limited before being converted into locomotion requests for the Unitree G1 robot.

4.4 Evaluation Procedure

To evaluate the system, the robot was placed at an initial position within the previously generated map. Subsequently, a navigation goal was defined within the test environment.

From the estimated pose of the robot and the target position, the global planner generated a collision-free trajectory. Finally, the tracking system converts the trajectory into velocity commands that allow the robot to move toward the defined goal.

5 Results and Discussion

The experimental evaluation was performed in an indoor obstacle-free scenario in order to quantify the navigation performance of the proposed ROS2-based architecture on the Unitree G1 biped robot.

The robot was commanded to navigate from the same initial position to the same final goal in all trials. The executed path had a length of approximately 4.5 m and required the robot to turn around a corner before reaching the desired final position and orientation.

A total of 15 experimental trials were conducted. For each trial, the navigation time, final position error, final orientation error, and collision occurrence were recorded.

The final position error was computed as the Euclidean distance between the desired final position and the final robot position. The final orientation error was computed as the absolute difference between the desired final heading and the final robot heading.

The robot successfully reached the goal in all 15 trials without collisions. The average navigation time was 48.4 s with a standard deviation of 1.64 s.

The final position error was 0.121 m with a standard deviation of 0.038 m, while the final orientation error was 10.67° with a standard deviation of 5.69°. The quantitative results are summarized in Table 3.

The obtained results show that the proposed navigation architecture allowed the Unitree G1 robot to reach the desired goal consistently under controlled indoor conditions.

The absence of collisions during the 15 trials indicates that the generated path and velocity commands were suitable for the evaluated scenario. In addition, the low variability in navigation time suggests that the system produced repeatable behavior when the same initial and final conditions were used.

The final position error remained within a range suitable for the evaluated indoor navigation task. However, the orientation error presented higher variability than the position error. This behavior can be associated with the locomotion characteristics of the biped robot, since body oscillations, step transitions, and small odometry deviations can affect the final heading correction.

These effects are particularly relevant in biped platforms, where the LiDAR frame and the robot base frame may experience small variations during walking.

Although the results demonstrate that a classical ROS2-based navigation pipeline can be adapted to the Unitree G1 biped robot, the evaluation was performed in a controlled obstacle free scenario. Therefore, additional experiments in cluttered environments and with different path configurations are required to further evaluate obstacle avoidance, localization robustness, and trajectory tracking accuracy.

6 Conclusion and Future Work

In this work, the implementation of a classical autonomous navigation architecture on the Unitree G1 humanoid robot was presented. The proposed system was composed of LiDAR-based perception, occupancy-grid mapping, probabilistic localization using AMCL, global path planning with the A* algorithm, and trajectory following through velocity commands compatible with the robot locomotion system.

The experimental tests demonstrated that the Unitree G1 robot was able to reach a fixed goal position in a controlled indoor scenario over 15 repeated trials. The robot completed the

Table 3. quantitative navigation results over repeated trials

Metric	Value
Number of trials	15
Path length	4.5 m
Successful trials	15
Success rate	100%
Collisions	0
Navigation time	48.4 $\pm$ 1.64 s
Final position error	0.121 $\pm$ 0.038 m
Final orientation error	10.67 $\pm$ 5.69°

Fig. 4. RViz visualization of the navigation test in the T-shaped corridor. The upper image shows the goal pose definition, including the desired final position and orientation. The lower image shows the planned path and the initial execution of the trajectory-following stage

navigation task without collisions, achieving an average navigation time of 48.4 s, an average final position error of 0.121 m, and an average final orientation error of 10.67°. These results provide evidence that classical navigation methods can be adapted to a biped robotic platform when the perception, localization, planning, and command conversion stages are properly configured.

The main limitations observed during the experiments are related to the locomotion characteristics of the biped robot. Body movement, sensor variations when taking steps, and uncertainty in odometry affected the stability of localization and the execution of the planned trajectory. Despite these limitations, within the tests performed, the final position and orientation errors were acceptable for the proposed indoor navigation task.

As future work, the system can be improved by incorporating more robust localization strategies, filtering the LiDAR data to reduce the effect of body movement, improving the trajectory following stage, and evaluating the navigation system in larger and more complex environments.

Acknowledgments

The authors would like to thank the Secretaría de Ciencia, Humanidades, Tecnología e Innovación (SECIHTI) for its support. The authors also acknowledge the Benemérita Universidad Autónoma de Puebla (BUAP), Facultad de Ciencias de la Electrónica, for its academic support. The authors are grateful to the Universidad Nacional Autónoma de México (UNAM), Facultad de Ingeniería, for providing access to the laboratory facilities and robotic equipment used during the experimental validation of this work, supported through project PAPIIT IN118226.

References

1. **Denny, J., Elyas, M., D'costa, S. A., D'Souza, R. D. (2016).** Humanoid robots–past, present and the future. European Journal of Advances in Engineering and Technology, Vol. 3, No. 5, pp. 8–15.
2. **Gao, Z., Chen, X., Yu, Z., Zhu, M., Zhang, R., Fu, Z., Li, C., Li, Q., Han, L., Huang, Q. (2021).** Autonomous navigation with human observation for a biped robot. 2021 IEEE International Conference on Unmanned Systems (ICUS), IEEE, pp. 780–785.
3. **Guaragnella, G., Cardellicchio, A., Patruno, C., Nitti, M., Pedrocchi, N., Ren'o, V. (2026).** Artificial intelligence in autonomous mobile robot navigation: From classical approaches to intelligent adaptation. Advanced Intelligent Systems, pp. e202501376.

4. **Jahan, M. I., Ahmad, H. B. (2026).** Mobile robot mapping and navigation system with raspberry pi and multiple sensors using ros2. AIP Conference Proceedings, AIP Publishing LLC, Vol. 3462, No. 1, pp. 020001.
5. **Kala, R. (2023).** Autonomous mobile robots: Planning, navigation and simulation. Elsevier.
6. **Karur, K., Sharma, N., Dharmatti, C., Siegel, J. E. (2021).** A survey of path planning algorithms for mobile robots. Vehicles, Vol. 3, No. 3, pp. 448–468.
7. **Li, Z., Zeng, J., Chen, S., Sreenath, K. (2023).** Autonomous navigation of underactuated bipedal robots in height-constrained environments. The International Journal of Robotics Research, Vol. 42, No. 8, pp. 565–585.
8. **Lobos-Tsunekawa, K., Leiva, F., Ruiz-del Solar, J. (2018).** Visual navigation for biped humanoid robots using deep reinforcement learning. IEEE Robotics and Automation Letters, Vol. 3, No. 4, pp. 3247–3254.
9. **Nahavandi, S., Alizadehsani, R., Nahavandi, D., Mohamed, S., Mohajer, N., Rokonuzzaman, M., Hossain, I. (2025).** A comprehensive review on autonomous navigation. ACM Computing Surveys, Vol. 57, No. 9, pp. 1–67.
10. **Nasti, S. M., Chishti, M. A., Najar, Z. A. (2024).** A comprehensive review of path planning techniques for mobile robot navigation in known and unknown environments. Authorea Preprints.
11. **Oriakhi, V. N. (2025).** Autonomous navigation for differential drive robots: Grid-based fastslam with amcl in ros2. International Journal of Latest Technology in Engineering, Management & Applied Science, Vol. 14, No. 1, pp. 147–178.
12. **Qin, H., Shao, S., Wang, T., Yu, X., Jiang, Y., Cao, Z. (2023).** Review of autonomous path planning algorithms for mobile robots. Drones, Vol. 7, No. 3, pp. 211.
13. **S'anchez-Ib'a nez, J. R., P'erez-del Pulgar, C. J., Garc'ia-Cerezo, A. (2021).** Path planning for autonomous mobile robots: A review. Sensors, Vol. 21, No. 23, pp. 7898.
14. **Shen, Z., Wu, Y. (2016).** Investigation of practical use of humanoid robots in elderly care centres. Proceedings of the Fourth International Conference on Human Agent Interaction, pp. 63–66.
15. **Tuna, G., Tuna, A., Ahmetoglu, E., Kusco, H. (2019).** A survey on the use of humanoid robots in primary education: Prospects, research challenges and future research directions. Cypriot Journal of Educational Sciences, Vol. 14, No. 3, pp. 361–373.
16. **Xu, X., Zeng, J., Zhao, Y., Lü, X. (2024).** Research on global path planning algorithm for mobile robots based on improved a*. Expert Systems with Applications, Vol. 243, pp. 122922.
17. **Yu, J., Nguyen, T. T., Dao, T. K., Nguyen, T. T. (2024).** Global path planning algorithm for mobile robots: A review. Journal of Network Intelligence, Vol. 9, pp. 643–657.

Article received on 16/03/2026; accepted on 18/07/2026.
**Corresponding author is Miguel López.*