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Design and Implementation of a Microcontroller-Based Automatic Floor Mopping Robot

Elbiem Kusuma

Departement of Computer Engineering, Politeknik Harapan Bersama, Indonesia
elbimkusuma27@gmail.com

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ABSTRACT

The development of an automatic floor-cleaning robot provides an innovative solution for addressing water puddles that frequently accumulate after rainfall. Although such puddles may appear insignificant, they can pose serious safety risks by increasing the likelihood of slip-and-fall accidents, particularly in public facilities such as mosques. This study presents the design and implementation of an ESP32-based automatic floor mopping robot intended to assist mosque caretakers (marbot) in maintaining floor cleanliness more efficiently and with reduced physical effort. The system was developed using the Software Development Life Cycle methodology with the Waterfall model, which consists of four sequential stages: planning, analysis, design, and implementation. The proposed robot integrates hardware and software components to perform automated floor-cleaning operations and can be controlled through a mobile application. System testing was conducted to evaluate functionality, reliability, and operational performance, as well as to verify that the developed system operated without significant errors and fulfilled the intended design objectives. The testing results demonstrated that the robot was capable of effectively mopping mosque floors, reducing the workload of mosque caretakers, and providing a practical and efficient cleaning solution. Consequently, the proposed system has the potential to improve both cleanliness management and user safety within mosque environments.

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I. INTRODUCTION

Mosques serve as one of the primary places of worship for Muslims and function not only as venues for religious activities but also as centers for social, educational, and community development programs. Indonesia is recognized as the country with the largest Muslim population in the world, with more than 231 million Muslims. Along with the growth of the Muslim population, the number of mosques across the country has also increased significantly, currently exceeding 800,000 mosques distributed throughout various regions. In Tegal City alone, there are approximately 207 active mosques serving the local community, one of which is located in Curug Village, Pangkah District [1].

In addition to facilitating obligatory and voluntary prayers, mosques are widely utilized for various activities that contribute to the religious and social development of the community. These activities include religious studies, mosque management meetings, youth mosque organization programs, hadrah and rebana musical training, and other Islamic educational activities. The high frequency of use and the large number of visitors significantly increase human mobility within mosque premises, which directly affects the cleanliness of mosque floors and necessitates regular maintenance [2].

Maintaining the cleanliness of mosque floors is an essential aspect of ensuring the comfort, safety, and spiritual concentration of worshippers. However, conventional floor-cleaning methods are generally performed manually and often require considerable time, labor, and resources, particularly in mosques with large floor areas and high usage intensity. Consequently, the workload of mosque caretakers (marbot) becomes increasingly demanding, especially during the rainy season when mosque floors are more susceptible to water puddles, mud, and dirt carried by worshippers' footwear [3].

Recent advancements in microcontroller technology and automation systems have created opportunities to develop more effective solutions for supporting mosque maintenance activities. One promising approach is the implementation of an automatic floor-mopping robot capable of performing cleaning tasks autonomously through the integration of sensors and actuators. Compared with conventional cleaning methods, an automatic floor-mopping robot offers several advantages, including improved time efficiency, greater consistency in cleaning performance, and enhanced ease of operation. Furthermore, the robot can be programmed to clean designated areas automatically or be remotely controlled through a mobile application, enabling a more flexible and efficient cleaning process [4].

Based on these considerations, this study aims to design and implement an ESP32-based automatic floor-mopping robot to support the floor-cleaning process in mosques more efficiently. The proposed system is expected to reduce the workload of mosque caretakers, improve the effectiveness of mosque maintenance activities, and contribute to a cleaner, safer, and more comfortable worship environment for the community [5].

II. MATERIALS AND METHODS

A. Planning

The planning stage constituted the initial phase of the research and focused on identifying the problems, objectives, and system requirements associated with mosque floor-cleaning activities. Preliminary observations revealed that floor cleaning was still performed manually, requiring considerable physical effort, time, and operational resources, particularly in large mosque areas and during periods of high visitor activity. Based on these findings, an automatic floor-mopping robot was proposed as a technological solution to assist mosque caretakers in maintaining floor cleanliness more efficiently. During this stage, the system concept, operational requirements, hardware specifications, and expected functionalities of the robot were defined as the foundation for subsequent development processes [6].

B. Analysis

The analysis stage was conducted to evaluate the functional and technical requirements of the proposed system. This process involved identifying the operational characteristics of an automatic floor-mopping robot, including navigation, floor-cleaning mechanisms, obstacle detection, and remote-control capabilities. Furthermore, the analysis examined the suitability of the selected hardware and software components, such as the ESP32 microcontroller, ultrasonic sensors, DC motors, water pump, and mobile-based control application. The results of this stage served as the basis for determining system specifications and ensuring that the developed prototype would effectively address the identified operational challenges [7].

C. Design

The design stage involved developing the architecture of both the hardware and software components of the automatic floor-mopping robot. Hardware design included the integration of the ESP32 microcontroller as the central control unit, ultrasonic sensors for obstacle detection, DC motors for robot mobility, and a water pump system to support the mopping process. Meanwhile, software design focused on developing the control algorithms, communication mechanisms, and user interface for remote operation. In addition, the research design outlined the study objectives, data collection techniques, system workflow, and evaluation procedures used to assess the performance of the developed prototype. This stage ensured that all system components were systematically organized and capable of operating as an integrated unit [8].

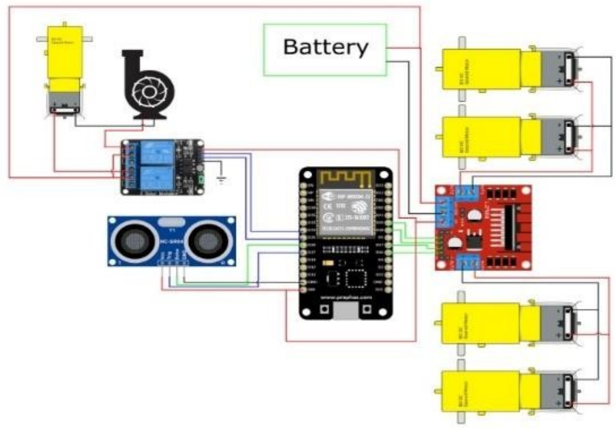

Figure 1. Schematic diagram

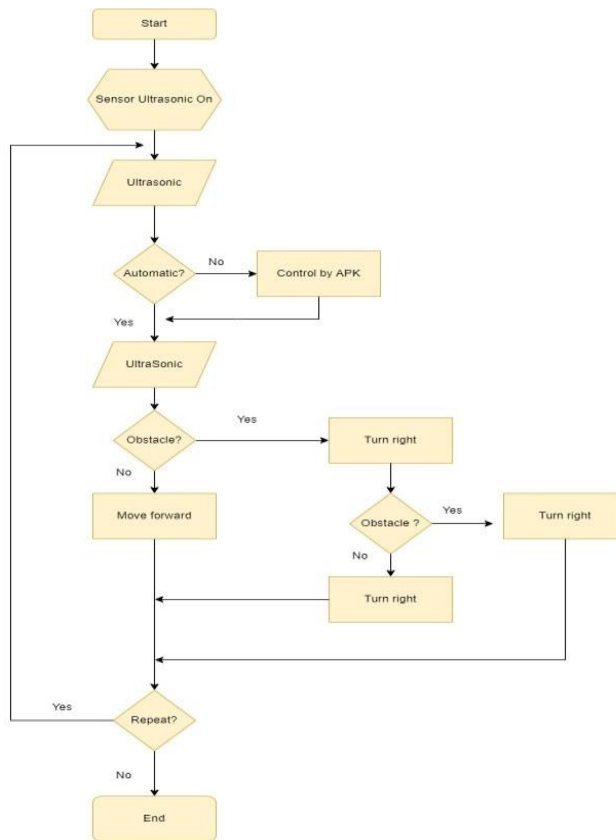

Figure 2. Flowchart system

D. Implementation

The implementation stage represented the final phase of system development, during which all hardware and software components were assembled and integrated into a functional prototype of the automatic floor-mopping robot. The developed system was then tested under operational conditions to evaluate its functionality, responsiveness, and overall performance. This stage included verification of robot movement, obstacle detection capabilities, floor-mopping effectiveness, water pump operation, and mobile application control. The implementation results demonstrated the feasibility of the proposed system as a practical solution for assisting mosque caretakers in maintaining floor cleanliness while reducing workload and improving operational efficiency [9].

III. RESULTS AND DISCUSSION

The floor is one of the primary components of a building that directly interacts with human activities on a daily basis. Within indoor environments, the floor serves as the most frequently utilized area for various activities; therefore, its cleanliness and safety must be consistently maintained. A clean floor not only contributes to the aesthetic value of a building but also plays a significant role in ensuring the comfort, health, and safety of its users. This aspect becomes particularly important in places of worship, especially mosques, where a high standard of cleanliness is required as part of the implementation of cleanliness values emphasized in Islamic teachings [10][11].

Mosques are public facilities that are routinely used by communities for various religious activities, including congregational prayers, Islamic lectures, religious studies, community discussions, and other social and educational programs. The high frequency of mosque utilization increases human mobility within the premises, making mosque floors more susceptible to dust, dirt, footprints, and water puddles resulting from ablution activities and rainy weather conditions. Consequently, floor-cleaning activities must be performed regularly to ensure that the mosque environment remains clean, comfortable, and suitable for worship [12].

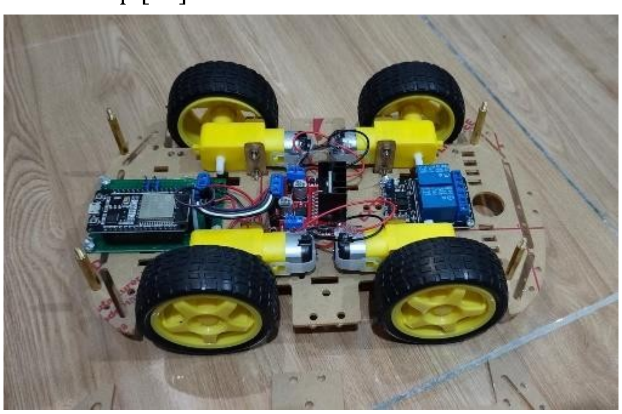

Figure 3. Implementation system

In practice, mosque floor cleaning is still predominantly performed manually by mosque caretakers (marbot) or cleaning personnel. This conventional method requires considerable physical effort, particularly in mosques with relatively large floor areas. Furthermore, manual mopping consumes a substantial amount of time, reducing the operational efficiency of mosque caretakers who are also responsible for other maintenance and management duties. These challenges highlight the need for an alternative solution through the implementation of automation technology capable of assisting human labor in a more effective and efficient manner.

Advances in microcontroller technology, embedded systems, and mobile devices have created opportunities for the development of automatic floor-mopping robots capable of performing cleaning tasks autonomously. The robot proposed in this study utilizes the ESP32 platform as the primary controller integrated with ultrasonic sensors, DC motors, a water pump, and an Android-based application for control and monitoring purposes. The ultrasonic sensor enables the robot to detect obstacles within its surroundings and avoid collisions during operation. The system is designed to identify objects at a predetermined distance and automatically change direction when approaching walls or other obstacles [13].

In addition to its autonomous navigation capabilities, the robot is equipped with a water-flow control system that can be adjusted according to user requirements. This feature provides a significant advantage over conventional floor-cleaning robots that focus solely on autonomous movement without considering the regulation of water usage during the cleaning process. The integration of the ESP32 microcontroller with an Android application via Bluetooth communication allows users to operate the robot conveniently through a smartphone. Users can select either manual mode, which provides direct control over the robot’s movement, or automatic mode, which enables the robot to operate independently without continuous user intervention.

Based on the identified requirements and operational challenges, the development of this automatic floor-mopping robot is expected to provide an effective solution for assisting mosque caretakers in maintaining floor cleanliness. The proposed system aims not only to reduce the physical workload and time required for cleaning activities but also to improve the efficiency of mosque facility maintenance through the utilization of automation technology that is user-friendly, cost-effective, and suitable for mosque environments characterized by large floor areas and relatively minimal obstacles. Therefore, the implementation of an automatic floor-mopping robot has the potential to enhance the overall cleanliness of mosque facilities while simultaneously improving the productivity and effectiveness of mosque caretakers in carrying out their responsibilities [14].

Ultrasonic Sensor HC-SR04 Testing

The HC-SR04 ultrasonic sensor was tested to evaluate its capability in detecting obstacles located in front of the robot during operation. Based on the experimental results, the ultrasonic sensor successfully detected objects and obstacles positioned along the robot’s movement path with a high level of responsiveness. The distance information acquired by the sensor was subsequently processed by the control system to determine the appropriate navigation actions when the robot approached an obstacle.

The testing results demonstrated that when an object was detected within a predetermined distance threshold, the robot automatically adjusted its direction of movement to avoid collisions with walls and other surrounding objects. Therefore, the HC-SR04 ultrasonic sensor was proven to function according to the system requirements and effectively supported the robot's autonomous navigation process throughout the floor-mopping operation.

DC Motor and Water Pump Testing

Further testing was conducted on the DC motors, which function as the primary driving mechanism for the robot's wheels and mopping system, as well as on the water pump responsible for spraying water onto the floor surface. The purpose of this testing phase was to evaluate whether the DC motors and water pump operated correctly in response to commands generated by the microcontroller.

The results indicated that the DC motors performed effectively under various operating conditions. When the robot detected an obstacle, the DC motors successfully altered the robot's direction according to the obstacle-avoidance algorithm implemented within the control system. Conversely, when no obstacle was detected along the movement path, the motors enabled the robot to move forward in a stable and consistent manner. In addition, the DC motor used to drive the mopping mechanism operated optimally throughout the floor-cleaning process.

Figure 4. System testing

The water pump testing results revealed that the pump was capable of spraying water onto the floor surface consistently and reliably. The water distribution mechanism effectively supported the mopping process, thereby enhancing the cleaning performance of the robot. Furthermore, the water flow could be regulated according to user requirements through the designed control system [15].

Analysis of Testing Results

Overall, the testing results demonstrated that all major components of the automatic floor-mopping robot functioned in accordance with the intended design specifications. The ultrasonic sensor successfully detected and avoided obstacles, the DC motors effectively controlled both robot mobility and the mopping mechanism, and the water pump reliably supplied water to support the cleaning process. The successful integration of these components resulted in an automatic floor-mopping robot capable of operating in both autonomous and manual modes through an Android-based application [16].

These findings indicate that the developed robot possesses a satisfactory level of functionality and can effectively assist mosque caretakers (marbot) in maintaining floor cleanliness. In addition to reducing the physical workload associated with manual cleaning activities, the implementation of the robot has the potential to improve cleaning efficiency, reduce operational time, and maintain floor hygiene more consistently than conventional manual mopping methods. Consequently, the proposed system represents a practical and effective technological solution for enhancing cleanliness management within mosque environments [17].

IV. CONCLUSIONS

Based on the results of the research, analysis, design, and system implementation that have been conducted, as well as the formulated research objectives and problem limitations, several conclusions can be drawn as follows:

1. The development of the Microcontroller-Based Automatic Floor-Mopping Robot, based on the case study conducted in Curug Village, was successfully designed, implemented, and operated according to the specified system requirements.

2. The testing results demonstrated that the developed robot was capable of effectively mopping mosque floors and assisting mosque caretakers (marbot) in maintaining cleanliness. Furthermore, the system could be conveniently controlled through a mobile application, providing greater flexibility and ease of operation. The implementation of the robot has the potential to reduce the physical workload of mosque caretakers while improving the efficiency and effectiveness of floor-cleaning activities within the mosque environment.

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