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Design and Implementation of an Arduino Based Visitor Counting and Capacity Control System Using US-015 Sensor

(Rancang Bangun Sistem Penghitung dan Pengendali Kapasitas Pengunjung Berbasis Arduino Uno dan Sensor US-015)

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ABSTRACT

Visitor capacity management in libraries requires accurate monitoring to ensure comfort and safety. This study designed a people counter simulator and automatic access controller at the Darul Ulum Amban Mosque Library Building. The system uses an Arduino Uno microcontroller as the control center and two US-015 ultrasonic sensors installed sequentially at the entrance and exit to detect visitor movement direction. The visitor count is displayed in real-time via a 16x2 LCD with a maximum capacity limit of 15 people. When capacity is reached, the system provides a multi-modal response by automatically closing the portal using a servo motor, activating a buzzer, and turning on an LED as a warning indicator. Test results show that the ultrasonic sensors work optimally within a range of 1 cm to 65 cm with adequate accuracy. Electrical power measurements show very efficient system consumption of 2.29 Watts. With a total manufacturing cost of approximately IDR 499,000, this system proves to be an economical, accurate, and effective solution for replacing manual counting and preventing room overcrowding.

ABSTRAK

Pengelolaan kapasitas pengunjung perpustakaan memerlukan monitoring akurat demi kenyamanan dan keamanan. Penelitian ini merancang simulator penghitung orang dan pengendali akses otomatis di Gedung Perpustakaan Masjid Darul Ulum Amban. Sistem menggunakan mikrokontroler Arduino Uno sebagai pusat kendali dan dua sensor ultrasonik US-015 yang dipasang berurutan di pintu masuk dan keluar untuk mendeteksi arah pergerakan pengunjung. Jumlah pengunjung ditampilkan secara real-time melalui LCD 16x2 dengan batas maksimum kapasitas 15 orang. Apabila kapasitas terpenuhi, sistem memberikan respons multi-modal berupa penutupan portal otomatis menggunakan motor servo, aktifnya buzzer, dan nyala LED sebagai indikator peringatan. Hasil pengujian menunjukkan sensor ultrasonik bekerja optimal pada rentang jarak 1 cm hingga 65 cm dengan tingkat akurasi memadai. Pengukuran daya listrik menunjukkan konsumsi sistem sangat efisien, yakni 2,29 Watt. Dengan total biaya pembuatan sekitar IDR 499.000, sistem ini terbukti menjadi solusi ekonomis, akurat, dan efektif dalam menggantikan penghitungan manual serta mencegah kelebihan kapasitas ruangan.

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1. INTRODUCTION

Visitor capacity management in public facilities is a crucial aspect directly related to the comfort, safety, and operational efficiency of a building [1]. Limiting the number of people in a room is not only a preventive measure to reduce congestion but also a safety standard that must be met, especially in the post-pandemic era where physical distancing protocols remain a primary public concern. Public facilities such as libraries, exhibition halls, and multipurpose buildings often experience significant fluctuations in visitor numbers, thus requiring a reliable and real-time monitoring system. Without a measurable capacity management system, the risk of overcapacity can degrade service quality, increase noise levels, and even endanger visitor safety in emergency situations.

The Darul Ulum Amban Mosque Library Building, located within the University of Papua campus, is one of the main literacy centers serving as a primary reference for students in supporting their academic activities[2]. Based on field observations, this library has a relatively limited room area with an ideal maximum capacity of 15 people, yet it frequently experiences congestion due to high student enthusiasm, particularly during exam periods and final project work. Currently, visitor counting is still carried out manually by staff, a method prone to recording errors (human error), inefficient, and requiring additional human resources. This situation is exacerbated by the lack of an early warning system when the room capacity reaches its maximum limit, causing arriving visitors to often remain uninformed and forced to wait in uncontrolled queues.

Various previous studies have attempted to address similar problems through automated technology approaches. Ahmad [3] designed a people-counting device for building entrance and exit doors; however, the system did not integrate ultrasonic sensors or adequate audio warning features (buzzers). Another study conducted by Putri et al. [4] utilized Infrared (IR) sensors to detect visitor movement; however, IR sensors have limited short-range detection and are highly susceptible to ambient light interference, making them less optimal for applications on doors of certain widths. Meanwhile, Lale et al.[5] developed an automatic bus passenger counting system using an IR FC-15 sensor combined with a smart card, an approach that is relatively complex and costly to implement in small to medium-scale buildings.

Based on the identification of gaps in previous studies, this research proposes an innovative solution in the form of an Arduino Uno microcontroller-based visitor counting and capacity control simulator integrated with a US-015 ultrasonic sensor. The selection of the ultrasonic sensor is based on its advantageous characteristics, including a wide detection range (2 cm to 450 cm), high accuracy, and resistance to light and environmental interference compared to IR sensors. The Arduino Uno was chosen as the control center due to its open-source nature, economic value, ease of programming, and extensive library ecosystem, allowing for flexible integration with various supporting modules such as LCDs, servo motors, LEDs, and buzzers [6], [7], [8], [9].

Furthermore, the design of this automated system strongly emphasizes the principle of optimal energy conservation. It is crucial to recognize that electrical energy generation is not free; it involves significant economic costs[10], [11], resource consumption[12], [13], power loses[14], [15], and environmental impacts[16], [17]. Therefore, developing an embedded system that operates with minimal power consumption is not merely a technical preference, but an economic and environmental necessity[18], [19], [20], [21]. By utilizing an Arduino Uno microcontroller and US-015 ultrasonic sensors, the proposed system is inherently designed to be highly energy-efficient[22], [23], [24]. Unlike conventional commercial monitoring systems that rely on power-hungry computers or continuous CCTV surveillance, this microcontroller-based approach consumes only a fraction of the energy. This ensures that the operational electricity costs remain negligible over the system's lifespan, proving that effective facility management can be achieved without contributing to unnecessary energy waste [25].

The novelty of this research lies in the integration of a bidirectional counting system with a physical access control mechanism and multi-modal warnings within a single compact platform. The system is designed not only as a passive counter but also to actively control the portal using a servo motor, provide visual warnings via LEDs and an LCD, and deliver audio warnings through a buzzer when the room capacity reaches its maximum limit. The hysteresis logic implemented in the programming is designed to prevent double counting errors, which frequently occur in similar systems. Furthermore, the use of a miniature building as a simulation medium allows for measurable system testing before implementation on an actual building scale, thereby reducing the risk of failure and development costs.

Along with the rapid development of Internet of Things (IoT) technology, microcontroller-based visitor counting systems have significant potential to be developed into smarter and connected solutions in the future. Integrating IoT modules such as ESP8266 or ESP32 into this system will enable the real-time transmission of visitor count data to cloud platforms via MQTT or HTTP protocols, allowing building managers to monitor room capacity from anywhere via smartphones or web dashboards[6], [26], [27]. IoT technology also opens opportunities for implementing automatic notifications, historical visitor data analysis,

and even integration with smart building management systems. Although IoT implementation has not been carried out in this study, the designed system architecture has considered compatibility with such developments as a direction for future research relevant to Industry 4.0 trends and the Smart Campus concept.

Based on this background and development opportunities, this research aims to design, build, and test the performance of a visitor counting and capacity control simulator for the entrance and exit doors of the Darul Ulum Amban Mosque Library Building, based on the Arduino Uno and US-015 ultrasonic sensor. This research is expected to provide a practical, economical, and energy-efficient solution to the problems at the study location, while also serving as an academic reference for the future development of more advanced and IoT-connected room capacity monitoring systems.

2. METHODS

This research employs an experimental method with an embedded system design approach. The research stages include a literature review, hardware and software design, the development of a miniature building as a simulation medium, and the testing and calibration of the device.

2.1. System Architecture

This visitor counting and capacity control system is designed using an Input–Process–Output paradigm integrated into a single microcontroller-based embedded platform. The overall system architecture is designed to detect human movement direction, process visitor count data in real-time, and provide an automated access control response when the room capacity limit is reached as given in Figure 1.

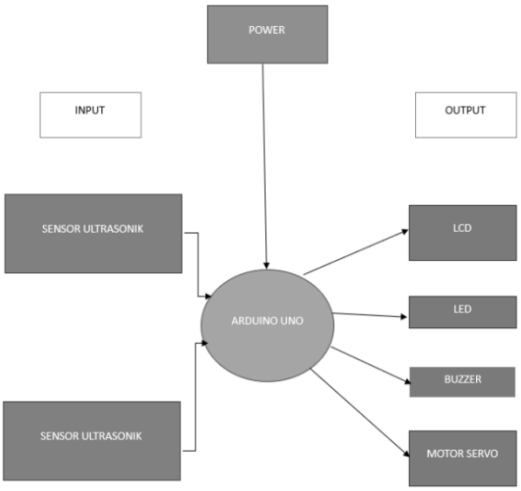


Figure 1. Block Diagram of the Visitor Counting and Capacity Control System Architecture

The system's input block consists of two US-015 ultrasonic sensors positioned sequentially at the entrance and exit pathways. The placement of these two sensors is a key strategy for bidirectional movement detection. When a visitor passes through, the sensor emits a 40 kHz ultrasonic wave and receives its reflection. The activation sequence between the first and second sensors determines whether the movement is categorized as "entering" or "exiting," thereby preventing the miscounting errors commonly found in single-sensor systems.

The process block serves as the system's control center, utilizing an Arduino Uno microcontroller based on the ATmega328P chip. This microcontroller is responsible for reading the digital signal from the ultrasonic sensor's Echo pin, calculating the pulse duration to convert it into a distance value, and executing the counting logic. The programming logic implements a hysteresis algorithm with trigger distance and stabilization margin parameters to filter noise and prevent double counting when a visitor pauses briefly in the detection area. The microcontroller also manages state variables to track the number of active visitors in the room (visitorCount), total entries (entryCount), and total exits (exitCount).

The output block consists of four actuator and display components that work synchronously based on the logic decisions of the Arduino Uno:

a) 16x2 LCD with I2C module: Serves as the primary visual interface to display real-time data on the number of visitors entering, exiting, and the total number currently in the room. The I2C protocol was chosen to conserve the microcontroller's digital pins. SG90 Servo Motor: Acts as the mechanical

actuator for the door portal. Under normal conditions, the servo is at a 0° position (open). When capacity reaches the maximum limit (15 people), the microcontroller sends a PWM signal to rotate the servo to a 90° position, physically closing the entry pathway.

b) Indicator LED: Functions as a visual warning. The LED will automatically illuminate when the room capacity is full, providing a clear visual signal to visitors at the door.

c) Passive Buzzer: Functions as an audio warning (alarm). The buzzer is activated simultaneously with the servo and LED when the capacity limit is reached, reinforcing the multi-modal warning system so it is not overlooked by visitors or staff.

The integration of these components is designed to operate in a responsive, continuous loop. Any status change in the input block is immediately processed within milliseconds by the process block, which is then directly translated into action by the output block. This architecture ensures that the system functions not merely as a passive monitoring tool, but as an active access control system capable of independently and reliably enforcing room capacity restriction protocols.

2.2. Hardware and Software

The system design is carried out through a hardware–software co-design approach, which aligns the selection of physical components with the programming logic structure so that all counting and capacity control functions can operate in an integrated manner. This approach is crucial because detection accuracy is determined not only by the sensor's characteristics but also by how the microcontroller interprets the received signals. Therefore, the design is divided into two interrelated aspects: the hardware aspect, which covers component selection, pin configuration, and electrical schematics; and the software aspect, which encompasses program structure, direction detection algorithms, and actuator control logic.

2.2.1. Hardware

The system's control center utilizes an Arduino Uno board based on the Atmel AVR (ATmega328P) microcontroller, operating at 5 V, where figured in Figure 2. The Arduino Uno was chosen because it is an open-source platform equipped with a bootloader, allowing programs to be uploaded directly via a computer without external programmer devices. In terms of interface capacity, this board provides sufficient digital pins to accommodate two ultrasonic sensors, one servo, one buzzer, and one LED, while communication with the LCD is routed through the I2C bus to ensure efficient pin usage. Support for external interrupt features on pins 2 and 3, along with PWM outputs on several digital pins, also provides flexibility in developing detection logic and servo control [7], [22].

The primary detection components are two US-015 ultrasonic sensors, each placed on the entrance and exit pathways. Each sensor has a Trigger (TRIG) and Echo (ECHO) pin, where the TRIG pin is used to emit a 40 kHz ultrasonic pulse, and the ECHO pin receives the reflected signal from the object. The distance is calculated by the microcontroller based on the time interval between pulse transmission and reflection reception. The sequential placement of the two sensors forms the basis of the bidirectional detection logic, as the activation sequence of both sensors determines whether a movement is categorized as an entry or an exit activity.

The system's output devices consist of four complementary components. A 16x2 LCD module with an I2C interface at address 0x27 is used to display real-time visitor count data; using I2C via the SDA and SCL lines saves the four to six digital pins that would otherwise be required for a parallel connection. The servo motor functions as the portal actuator with a movement range of 0° (open) to 90° (closed), controlled via a PWM signal. The buzzer serves as an audio warning and the LED as a visual warning, both of which are activated simultaneously when the room capacity is reached. All components are connected via a breadboard and jumper wires, with resistors acting as current limiters in the indicator circuits.

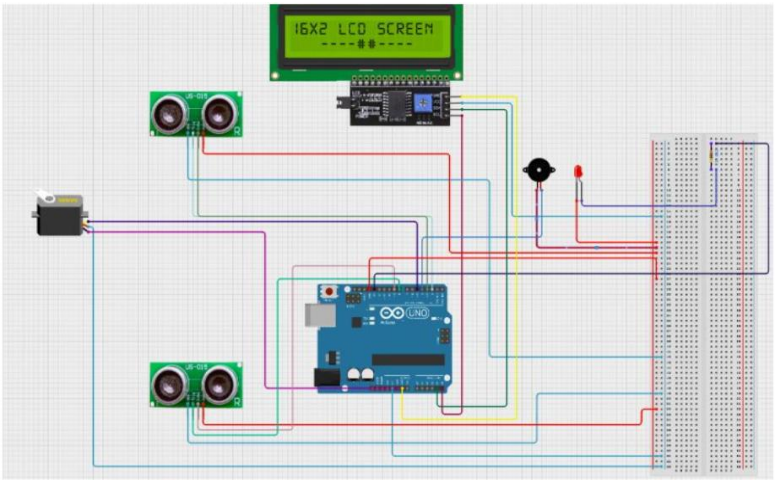


Figure 2. Hardware Circuit Schematic

Table 1. Arduino Uno Pin Configuration

Component	Function	Pin Configuration
Entrance ultrasonic sensor	Detect entering visitors	TRIG → D2, ECHO → D3
Exit ultrasonic sensor	Detect exiting visitors	TRIG → D8, ECHO → D9
Buzzer	Audio warning	D4
Servo motor	Portal actuator	D5
16x2 LCD (I2C, address 0x27)	Real-time data display	SDA → A4, SCL → A5
Indicator LED	Visual warning	D13
Power supply	System voltage source	5 V and GND

The system's power supply uses an AC/DC adapter that converts mains voltage into direct current for circuit requirements, with a nominal design voltage of 5 VDC, given in Table 1. During electrical verification, the adapter's input voltage was measured at 9.2 V, while the voltage at the Arduino output pin was measured at 4.6 V. These values remain within the safe operational range for the microcontroller and supporting components, simultaneously demonstrating that the voltage regulation on the Arduino board functions as intended. This power supply stability is a prerequisite for consistent sensor readings, given that voltage fluctuations can cause deviations in Echo pulse width measurements.

2.2.2. Software

The software was developed using the Arduino IDE with C/C++ based programming [6], [7], [8], [9]. The program structure follows the typical setup–loop paradigm of the Arduino ecosystem. The setup() function is used to initialize all devices: configuring input and output pin modes, initializing serial communication at a 9600 bps baud rate for debug monitoring, activating the LCD and its backlight, setting the initial servo position to 0°, and turning off the LED as the system's initial state. Once initialization is complete, the system sends the message "Visitor Counting System Ready!" via the Serial Monitor to indicate that the device is ready to operate.

The loop() function continuously executes the sensor reading and decision-making processes. Two UltrasonicSensor objects are instantiated for each door, allowing distance readings to be performed independently on the entrance and exit sensors. The reading results are then compared against two key parameters: TRIGGER_DISTANCE as the detection distance threshold and HYSTERESIS_MARGIN as the stabilization margin. The application of hysteresis aims to create two distinct threshold boundaries for the "object detected" and "object not detected" conditions, ensuring that minor fluctuations in distance readings are not immediately translated into new entry or exit events.

To maintain counting integrity, the system uses two boolean variables, inTriggered and outTriggered, as state flags for each sensor. The combination of these two flags determines the direction of movement: if the entrance sensor is triggered first followed by the exit sensor, the system records one entry event; conversely, if the exit sensor is triggered first, the system records one exit event. As long as the flag has not returned to its initial state, an event involving the same object will not be recounted. This mechanism effectively prevents double counting when a visitor pauses briefly in the detection area or moves back and forth in front of the sensor.

Counting data is managed through three separate variables: visitorCount for the number of active visitors in the room, entryCount for the accumulated number of entries, and exitCount for the accumulated

number of exits. Separating these three variables is crucial so that the system not only displays the current visitor balance but also provides a traceable traffic log. Every value change is immediately updated on the LCD display in the format M = entryCount, K = exitCount, Total = visitorCount, allowing staff to verify the consistency between entry data, exit data, and the actual number of people in the room.

At the control layer, the microcontroller compares the visitorCount value with the maximum capacity limit of 15 people. As long as the value remains below the limit, the servo is maintained at the 0° position, the LED remains off, and the buzzer is silent. When the limit is reached, the program simultaneously changes the servo position to 90°, turns on the LED, and activates the buzzer. When visitors exit, bringing the capacity back below the limit, the system returns all actuators to their normal state. This flow is comprehensively illustrated in the system flowchart in Figure 3, which serves as the primary reference during the debugging and logic validation processes.

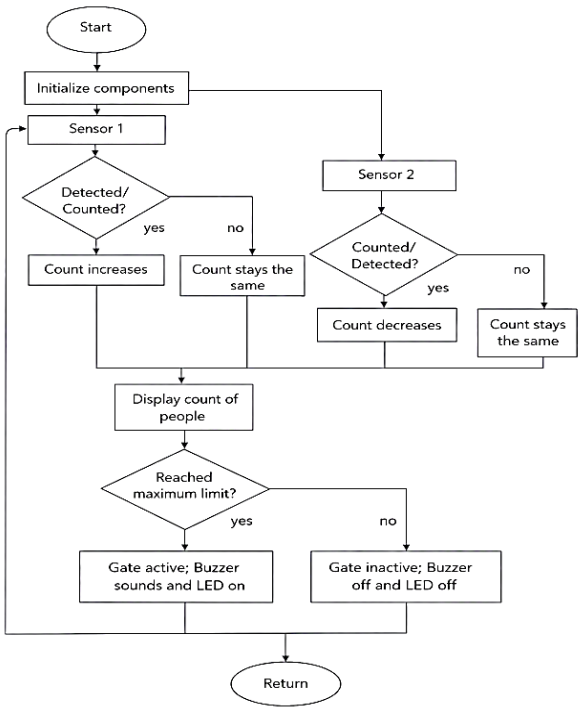


Figure 3. Flowchart of Bidirectional Counting Logic and Capacity Control

The integration of this hardware and software results in a system capable not only of acquiring data but also of making decisions and executing physical actions autonomously. The structured pin configuration facilitates circuit reproduction by other researchers, while the separation between the sensor reading module, hysteresis logic, and actuator management makes the program modular and easy to expand. This characteristic forms the basis for the system's feasibility to be integrated with additional connectivity modules in future research, without requiring a major architectural overhaul.

3. RESULTS AND DISCUSSION

3.1. Ultrasonic Sensor Performance Testing

The performance testing of the US-015 ultrasonic sensor is a critical stage in system evaluation, considering that this sensor serves as the main component for detecting visitor movement at the entrance and exit doors. The testing was conducted to measure the accuracy, consistency, and effective detection range limit of the sensor against human objects under operational conditions that resemble real scenarios. The testing method applied was repeated measurement of 20 times for each distance variation, with a total of 16 test distance points ranging from 1 cm to 75 cm with 5 cm intervals. This repetition approach was chosen to minimize the influence of random errors and ensure that the obtained data has a high level of reliability. During testing, the test object was positioned perpendicular to the sensor's emission plane, and the sensor response was recorded in two categories: "Counted" (✔) if the sensor successfully detected the object, and "Not Counted" (✘) if the sensor failed to provide a response.

Testing on the entrance door ultrasonic sensor showed very consistent results in the near to medium distance range. Based on the test data (Table 2), the sensor successfully detected objects with 100% accuracy

(20 out of 20 trials successful) at distances from 1 cm to 65 cm. In this range, the 40 kHz ultrasonic waves emitted by the transmitter successfully reflected back to the receiver with sufficient intensity to be processed by the Arduino Uno microcontroller. The stable sensor response in this distance range indicates that the US-015 has very adequate performance for human detection applications at standard-width entrances. This data also shows that although the sensor's technical specifications mention a maximum range of up to 450 cm, optimal performance in the context of human object detection in this system is achieved at much shorter distances.

Table 2. Recapitulation of US-015 Sensor Testing

No	Test Distance (cm)	Number of Trials	Successfully Detected	Failed to Detect	Success Rate
1–14	1 – 65	20 × 14 = 280	280	0	100%
15	70	20	0	20	0%
16	75	20	0	20	0%

Testing on the exit door ultrasonic sensor produced performance very consistent with the entrance door sensor. At distances from 1 cm to 65 cm, the exit sensor also showed a 100% detection success rate from a total of 280 trials. This consistency confirms that both US-015 sensor units used have uniform technical characteristics, thus not causing bias in the bidirectional counting logic. The uniformity of performance between these two sensors is an important prerequisite for the system, because differences in sensitivity between sensors can cause errors in determining the direction of visitor movement, which ultimately implies errors in counting the number of visitors in the room.

However, at test distances of 70 cm and 75 cm, both sensors showed total detection failure (0% success from 40 trials). This phenomenon is interesting to analyze further, considering that the US-015 technical specifications mention a maximum range of up to 450 cm. Several technical factors are suspected to be the cause of this limitation. First, at greater distances, the intensity of ultrasonic waves reflected by human objects experiences significant attenuation (weakening) due to absorption by air and scattering by particles in the environment. Second, the shape and surface material of the test object (human body with cloth clothing) tends to absorb ultrasonic waves rather than reflect them specularly, unlike hard and flat objects like walls commonly used in manufacturer specification testing. Third, testing environmental conditions such as temperature, humidity, and ambient acoustic noise also affect sensor performance at long distances.

The finding regarding the optimal detection limit at 65 cm has very important practical implications for system configuration. Based on the test results, the TRIGGER_DISTANCE value in Arduino programming was set below 65 cm (considering HYSTERESIS_MARGIN to prevent double counting). Setting this threshold ensures that the system only responds to objects within the sensor's effective detection zone, thus avoiding detection errors due to weak reflected signals or environmental noise at greater distances. In other words, although the sensor is technically capable of "seeing" up to a certain distance, the system is logically designed to only operate in zones that have been tested for accuracy, namely below 65 cm. This calibration strategy is a form of implementing the fail-safe principle in embedded system design, where system reliability is prioritized over maximum detection range.

Overall, the performance testing of the US-015 ultrasonic sensor proves that this sensor works very reliably in the distance range of 1 cm to 65 cm, both at the entrance and exit doors, with a 100% detection success rate from a total of 560 trials. Detection limitations at distances above 65 cm have been anticipated through proper TRIGGER_DISTANCE configuration in programming, so it does not affect overall system performance. These test results provide a strong empirical foundation for the next testing stages, namely integrated system testing and overall testing, where the sensor will be operated in more complex and dynamic visitor counting scenarios.

3.2. Overall System Testing and Capacity Control

Overall system testing is the final evaluation stage aimed at validating the integrated performance of all system components in operational scenarios that resemble real conditions at the Darul Ulum Amban Mosque Library Building. This testing was conducted using a miniature building as a simulation medium, with a maximum capacity limit set at 15 people according to the characteristics of the original room. The testing scenarios were divided into three main conditions: (1) normal condition when the number of visitors is below maximum capacity, (2) critical condition when the number of visitors reaches the maximum limit, and (3) recovery condition when visitors start leaving the room. Each scenario was tested repeatedly to ensure consistency of system response, including the behavior of the servo motor as portal actuator, visual indicator status (LED and LCD), and audio indicators (buzzer). This testing approach allows comprehensive evaluation of the capacity control logic that has been programmed on the Arduino Uno microcontroller.

In normal conditions, when the number of visitors is in the range of 1 to 14 people, the system shows very stable performance and in accordance with the initial design. Based on the test data (Table 3), every visitor detected by the entrance door ultrasonic sensor will be immediately counted by the microcontroller and displayed in real-time on the 16x2 LCD screen in the format "M=X, K=Y, Jumlah=Z", where M is the number of visitors entering, K is the number of visitors exiting, and Z is the number of active visitors in the room. In this condition, the servo motor remains at position 0° (portal open), the LED is off, and the buzzer produces no sound. The fast and accurate system response in this normal condition indicates that the bidirectional counting logic implemented through the hysteresis algorithm works well, without any double counting or missed counting errors occurring.

Table 3. Recapitulation of Overall System Testing Results

No	Number of Visitors	Portal Status (Servo)	LED Status	Buzzer Status	LCD Display
1–14	1 – 14 people	Open (0°)	Off	Silent	M=X, K=0, Jumlah=X
15	15 people (full)	Closed (90°)	On	Sounding	M=15, K=0, Jumlah=15

In critical conditions, when the 15th visitor is detected entering, the system provides a multi-modal response that is the hallmark (novelty) of this research. The Arduino Uno microcontroller simultaneously activates three output devices: the servo motor rotates to position 90° to physically close the portal, the LED turns on as a visual indicator, and the buzzer produces a warning sound as an audio indicator. At the same time, the LCD screen updates its display to "M=15, K=0, Jumlah=15" which indicates that the room capacity has reached the maximum limit. This simultaneous response occurs in less than one second after the sensor detects the object, a very adequate performance for access control applications in public facilities. This portal locking mechanism effectively prevents additional visitors from entering, so that capacity restriction protocols can be enforced automatically without requiring officer intervention.



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Figure 5. System Display in Full Capacity

In recovery conditions, when visitors start leaving the room, the system shows very good adaptation capability. Based on the test data (Table 4), when the first visitor leaves and is detected by the exit door ultrasonic sensor, the servo motor immediately returns to position 0° (portal open), the LED turns off, and the buzzer stops sounding. The number of active visitors in the room automatically decreases to 14 people, and the LCD display is updated to "M=15, K=1, Jumlah=14". This recovery process continues consistently every time a visitor leaves, with the number of active visitors gradually decreasing until it reaches zero. The consistency of the system response in this recovery condition proves that the capacity reduction logic works reliably, and the system does not experience a stuck state after passing through the full capacity phase.

Table 4. Recapitulation of Overall System Testing

No	Exiting Visitor	Number of Active Visitors	Portal Status	Alarm Status	LCD Display
1	1	14	Open	Off	M=15, K=1, Jumlah=14
2	2	13	Open	Off	M=15, K=2, Jumlah=13
3	3	12	Open	Off	M=15, K=3, Jumlah=12
4	4	11	Open	Off	M=15, K=4, Jumlah=11
5	5	10	Open	Off	M=15, K=5, Jumlah=10

No	Exiting Visitor	Number of Active Visitors	Portal Status	Alarm Status	LCD Display
6	6	9	Open	Off	M=15, K=6, Jumlah=9
7	7	8	Open	Off	M=15, K=7, Jumlah=8
8	8	7	Open	Off	M=15, K=8, Jumlah=7
9	9	6	Open	Off	M=15, K=9, Jumlah=6
10	10	5	Open	Off	M=15, K=10, Jumlah=5
11	11	4	Open	Off	M=15, K=11, Jumlah=4
12	12	3	Open	Off	M=15, K=12, Jumlah=3
13	13	2	Open	Off	M=15, K=13, Jumlah=2
14	14	1	Open	Off	M=15, K=14, Jumlah=1
15	15	0	Open	Off	M=15, K=15, Jumlah=0

Overall, system testing proves that the visitor counting and capacity control simulator based on Arduino Uno and US-015 ultrasonic sensor has successfully worked according to design specifications. The system is capable of accurately counting visitors entering and exiting, displaying data in real-time on the LCD, and providing appropriate access control responses when room capacity reaches the maximum limit. 100% counting accuracy was achieved in all testing scenarios (15 times entering and 15 times exiting), without any detection errors or data loss. This success is inseparable from the application of hysteresis logic in programming that has been calibrated based on sensor performance test results in sub-chapter 3.1, as well as the selection of actuator components (SG90 servo motor) that have fast response and adequate angular precision for the portal mechanism. From a practical application perspective, this system proves capable of replacing manual counting methods that are prone to human error, while providing an economical and automatic capacity control solution for managers of the Darul Ulum Amban Mosque Library Building.

3.3. Power Consumption and Cost Analysis

System performance evaluation is not limited to functional aspects and detection accuracy, but also includes analysis of electrical power consumption and economic studies as indicators of system implementation feasibility in the long term, where the measurement results are given in Table 5. Power consumption measurement was conducted using a digital Watt Meter connected in series on the main power supply line of the simulator, with the aim of obtaining real data regarding the system's energy needs during operation in both normal and full capacity conditions. This analysis is important to conduct considering that the system is designed to operate continuously during library operating hours (8–10 hours per day), so energy efficiency becomes a determining factor in reducing operational costs. In addition, economic studies were conducted through the preparation of a Bill of Quantities (BoQ) to calculate the total investment required to build the system prototype, which was then compared to the benefits obtained from implementing the system.

Power consumption measurement on the simulator showed very efficient results, as presented in Table 5. The system operates with a power consumption of 2.29 Watts at an input voltage of 8.8 Volts and an electric current of 0.011 Amperes. This power consumption value is classified as very low when compared to commercial visitor counting systems based on computers or CCTV cameras which generally consume tens to hundreds of Watts. The low power consumption is inseparable from the selection of efficient components, especially the use of the Arduino Uno microcontroller which only requires a current of around 50 mA, as well as the US-015 ultrasonic sensor which is only active in emitting ultrasonic waves for several microseconds in each measurement cycle. With a power consumption of 2.29 Watts, if the system is operated for 10 hours per day for 30 days, then the total energy consumed is only 0.687 kWh per month, which is equivalent to an electricity cost of less than IDR 1,500 per month, based on an average electricity tariff of IDR 2,200/kWh. This proves that this system is very environmentally friendly and economical from an operational perspective.

Table 5. System Power Consumption and Voltage Measurement

No	Measurement Parameter	Value	Description
1	Input Voltage (Adapter)	9.2 V	Main power source
2	Output Voltage (Arduino Pin)	4.6 V	Component power supply
3	System Operating Voltage	8.8 V	Measured on Watt Meter
4	Electric Current	0.011 A	11 mA
5	Electric Power	2.29 W	Total system consumption

In addition to power measurement, input and output voltage testing was also conducted to ensure the stability of the power supply supplied to all system components. Based on the measurement results (Table 5),

the input voltage from the AC-DC adapter was measured at 9.2 Volts, which was then regulated by the Arduino Uno to an output voltage of 4.6 Volts at the output pins. This output voltage value is within a safe tolerance range to operate all sensor and actuator modules (LCD, LED, buzzer, and servo motor), while also ensuring the safety of the microcontroller from overvoltage risks. This voltage stability also indicates that the adapter used has adequate quality in providing clean power without significant fluctuations, so that system performance remains consistent even when operated for long durations.

From an economic perspective, the preparation of the Bill of Quantities (BoQ) shows that the total investment required to build this simulator prototype is only IDR 499,000, given in Table 6. This cost breakdown includes main electronic components (Arduino Uno, ultrasonic sensors, LCD, LED, buzzer, servo motor, and adapter) of IDR 219,000, as well as supporting components and physical materials of IDR 280,000, such as: jumper cables, plywood, popsicle sticks, glue, and auxiliary tools. When compared to commercial visitor counting systems available on the market with prices ranging from IDR5–15 million, the designed prototype has a much higher economic value, with costs of only about 3–10% of the price of commercial systems. This proves that the open-source approach based on Arduino Uno applied in this research is very effective in reducing production costs without sacrificing system functionality.

Table 6. Recapitulation of Simulator Bill of Quantities (BoQ)

Component Category	Number of Items	Total Cost (Rp)	Percentage
Main Electronic Components (Arduino, Sensors, LCD, Servo, LED, Buzzer, Adapter)	8	219,000	43.9%
Supporting Components (Jumper Cables, Resistors)	2	55,000	11.0%
Physical Materials & Auxiliary Tools (Plywood, Popsicle Sticks, Glue, Ruler, Solder)	5	225,000	45.1%
Total	15	499,000	100%

Cost-benefit analysis shows that this investment of IDR 499,000 will provide a very fast return on investment if implemented on an actual building scale. The economic benefits obtained include: (1) elimination of manual counting officer labor costs which average IDR 1.5–2 million per month, (2) reduction of loss risks due to overcapacity which can cause fines or sanctions from building safety authorities, (3) increased operational efficiency that allows library officers to focus on core services rather than recording administrative tasks, and (4) extended lifespan of equipment in the room (such as computers and books) due to a more controlled and less crowded environment. Assuming labor cost savings alone, this system will reach the break-even point in less than one month after implementation.

Overall, power consumption analysis and economic studies prove that this Arduino Uno-based visitor counting and capacity control simulator not only excels in terms of technical performance, but is also very economically feasible and energy efficient. The very low power consumption (2.29 Watts) makes this system environmentally friendly and saves operational costs, while the total investment of only IDR 499,000 makes it a very affordable solution for managers of small to medium-scale public facilities, including the Darul Ulum Amban Mosque Library Building. The combination of reliable technical performance, energy efficiency, and high economic value becomes the main strength of the designed system, while also making it a very competitive alternative compared to commercial solutions available on the market.

4. CONCLUSSION

This research has successfully designed, implemented, and tested the performance of a visitor counting and capacity control system based on Arduino Uno microcontroller and US-015 ultrasonic sensor, validated using a miniature building as a simulation medium. The test results demonstrate that the ultrasonic sensor operates optimally within a distance range of 1 cm to 65 cm with a 100% detection success rate from a total of 560 trials. The system successfully limits the maximum room capacity to 15 people through rapid and precise multi-modal responses, namely physical portal closure by servo motor, audio warning activation through buzzer, and visual indicators through LED and 16x2 LCD. Furthermore, the system proves to be highly efficient with power consumption of only 2.29 Watts and possesses high economic value, with a total prototype manufacturing cost reaching IDR 499,000—significantly more affordable compared to commercial solutions available on the market.

The implementation of this system provides significant practical contributions in managing small to medium-scale public facilities, particularly in replacing manual counting methods that are prone to human error and improving operational efficiency for staff. The portal locking mechanism and multi-modal warnings when capacity is full also play a crucial role in maintaining visitor comfort and safety standards.

For future development, it is recommended that the system be equipped with Internet of Things (IoT) modules such as ESP8266 or ESP32 so that room capacity data can be monitored remotely and in real-time through mobile applications or web dashboards. Additionally, the addition of a backup battery and an indoor LCD module is recommended to enhance system reliability during power outages and provide direct visual information to visitors inside the building.

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