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Design And Construction of An Automated Target Counter for Military Application

Balogun Anthony Adeolu[1], Fischer, Gertrude A[2], Omini, Ofem Uket[3]
Department of Electrical /Electronic Engineering, Faculty of Engineering, University of Cross River State, Calabar, Nigeria.

Abstract
This article presents the design and construction of an automated target counter for real-time detection and counting of projectile impacts using a piezoelectric vibration sensor, an ATmega328P microcontroller, signal-conditioning circuitry, a 16×2 LCD, and an audible feedback system. The research was motivated by the limitations of conventional manual target counting methods, which are prone to human errors, delays, and safety concerns. Mathematical models were developed for impact force, kinetic energy, sensor response, ADC conversion, counting accuracy, percentage error, detection efficiency, and system response time. Using practical design parameters of a 0.05kg projectile mass, 25m/s velocity, and 0.002s impact duration, the impact force and kinetic energy were calculated as 625 N and 15.63 J, respectively. The sensor produced an output voltage of approximately 5V, which was processed through a 10-bit ADC with a resolution of 4.89mV/bit. A threshold value of 1.5 V (307 ADC counts) was established for reliable impact detection. Performance evaluation showed that the system successfully recorded 148 out of 150 actual impacts, resulting in a total counting error of 2 hits, an average percentage error of 1.07%, and an overall accuracy of 98.93%. The calculated system response time was 4.9ms, corresponding to a detection rate of approximately 204 impacts per second. The system also exhibited low power consumption of 0.55W with a current consumption of 110 mA. The results demonstrate that the developed automated target counter is a reliable, accurate, cost-effective, and energy-efficient alternative to manual target counting systems, making it suitable for military training, law enforcement exercises, sports shooting competitions, and related target monitoring applications.

Keywords: *Automated Target Counter, Piezoelectric Sensor, ATmega328P Microcontroller, Impact Detection, Hit Counting, Response Time, Detection Accuracy, Shooting Range Automation.*

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I. Introduction

The high demand for accuracy, efficiency, and safety in military training, law enforcement operations, sporting competitions, and firearm proficiency assessments has driven the development of automated target monitoring systems. Traditional target assessment methods based on manual inspection and counting are often labor-intensive, time-consuming, and prone to human error [1], [2]. Advances in sensor technology, embedded systems, microcontrollers, and digital signal processing have enabled automated target counting systems capable of detecting projectile impacts and displaying results in real time, thereby improving operational efficiency and reducing safety risks [3]. The availability of low-cost microcontrollers such as the ATmega328P and highly sensitive piezoelectric sensors has facilitated the development of affordable impact detection systems [4]. Piezoelectric sensors convert mechanical stress into electrical signals and have been widely applied in vibration monitoring, structural health assessment, impact detection, and industrial automation [5]. Their combin-tion with microcontroller-based processing units offers improved counting accuracy, faster response time, enhanced reliability, and reduced manpower requirements compared to conventional methods [6].

Technology for target monitoring has developed from manual observation to electronic systems utilizing sensors, microphones, optical detectors, and embedded processors [7], [8]. Modern techniques include acoustic sensing, optical imaging, infrared detection, strain measurement, and piezoelectric vibration sensing [9]. Among these, piezoelectric sensors are particularly attractive because they directly convert mechanical energy into electrical signals without external excitation [10]. The affordability and flexibility of Arduino-compatible ATmega328P microcontrollers have further accelerated the adoption of sensor-based monitoring systems [11]. Although manual target counting remains simple and inexpensive, it is exposable to counting errors, delayed reporting, operator fatigue, and safety concerns [12], [13]. Acoustic target systems can achieve high positional accuracy through shock-wave analysis but are affected by environmental noise and atmospheric conditions [14]-[16]. Optical and machine vision systems employ cameras and image-processing algorithms for automatic scoring and impact detection [17]–[19], but their effectiveness is often limited by high cost and sensitivity to environmental conditions [20].

Sensor-based systems utilize transducers such as strain gauges, accelerometers, force sensors, and piezoelectric sensors to detect projectile impacts [21]. Piezoelectric sensors have gained significant attention due to their simplicity, durability, high sensitivity, and low power consumption [22]. Their effectiveness has been demonstrated in vibration monitoring, machinery diagnostics, impact detection, and security systems [23], [24]. The piezoelectric effect, discovered by Jacques and Pierre Curie in 1880, enables materials such as quartz, PZT, and PVDF to generate electrical potentials proportional to applied mechanical stress [25], [26]. These signals can be amplified, filtered, and processed by a microcontroller to identify valid target impacts [27]. Maini [28] further reported that piezoelectric sensors offer excellent sensitivity and reliability for impact detection applications.

Microcontrollers are essential components of modern embedded monitoring systems because they integrate sensing, processing, communication, and control functions within a single platform [29]. The ATmega328P microcontroller, with its 10-bit ADC, multiple I/O ports, interrupt capabilities, and low power consumption, is particularly suitable for signal acquisition, impact processing, hit counting, and display control [30]. Arduino-based systems have further enhanced the affordability and flexibility of such implementations [31].

Foreknown studies have illustrated the feasibility of automated target monitoring systems. Infrared-based scoring systems achieved detection accuracies of approximately 94% [32], vibration sensor-based systems achieved counting accuracies of 96% [33], image-processing-based systems provided high positional accuracy but at increased computational and hardware costs [34], while piezoelectric-based impact detection systems reported efficiencies exceeding 97% [35].Despite these developments, many existing systems remain expensive and complex, limiting their deployment in resource-constrained environments. Therefore, there is a need for a low-cost, reliable, and efficient automated target counter based on piezoelectric sensing technology and microcontroller-based processing, which this study seeks to develop [35].

1. Practical Mathematical Model of the Automated Target Counter

The design model to implement this research is developed as follows;

a. Impact Force Model

When a projectile or stone strikes the target board, the impact force is determined from Newton's Second Law [1]:

$$F = \frac{m(v-u)}{t} \quad (1)$$

Where, F = Impact force (N), m = Projectile mass (kg), u = Initial velocity (m/s), v = Final velocity after impact (m/s), and t = Impact duration (s)

The following parametric values are used to obtain impact force; Stone mass = 0.05 kg, Velocity before impact = 25 m/s, Velocity after impact = 0 m/s, and Impact duration = 0.002 s

Substituting thiese values in (1) it gives:

$$F = \frac{0.05(0-25)}{0.002} = -625N$$

b. Mechanical Energy Transfer

The kinetic energy delivered to the target is [2]

$$KE = \frac{1}{2mv^2} \quad (2)$$

Substituting

$$KE = \frac{1}{2}(0.05)(25)^2 = 15.625J$$

This energy produce vibration on the target board

c. Piezoelectric Sensor Voltage Model

The generated voltage is proportional to impact force [3].

$$Vs = kF \quad (3)$$

Where:

$$k = 0.008V/N$$

Substituting:

$$V_s = 0.008 \times 625 = 5V$$

This voltage is sufficient for detection by the ATmega328P.

d. ADC Conversion Model

The ATmega328P contains a 10-bit ADC. ADC Resolution [7]:

$$Resolution = \frac{V_{ref}}{2^{10}-1} \quad (4)$$

For V_{ref}

$$Resolution = \frac{5}{1023} = 0.00489V$$

ADC Value Produced [7] is

$$ADC = \frac{V_s}{Resolution} \qquad (5)$$

But $V_s = 5V$, then

$$ADC = \frac{5}{0.00489} = 1022.5$$

Which is the maximum ADC count.

e. Detection Threshold Model

To avoid false triggering from wind and environmental vibration, let threshold voltage be

$$V_{th} = 1.5V$$

Equivalent ADC count is

$$ADC_{th} = \frac{1.5}{0.00489} = 306.75$$

Decision Rule is

$$Hit = \begin{cases} 1, & ADC \geq 307 \\ 0, & ADC < 307 \end{cases} \qquad (6)$$

f. Hit Counting Model

Let

$$Hit = \begin{cases} 1, Hit\ detected \\ 0, \quad no\ hit \end{cases}$$

The total becomes

$$N = \sum_{i=1}^{n} H_i$$

Suppose sensor outputs for ten impacts are

Shot	1	2	3	4	5	6	7	8	9	10
Hit	1	1	1	0	1	1	1	1	0	1

Then

$$N = 1 + 1 + 1 + 0 + 1 + 1 + 1 + 1 + 0 + 1 = 8$$

g. **Buzzer Activation Model**

The buzzer is activated whenever

$$ADC \geq ADC_{\ th}$$

Output state:

$$B = \begin{cases} 1, & Hit\ detected \\ 0, & Otherwise \end{cases}$$

For a detected hit, $B = 1$, means buzzer ON

h. **Detection Accuracy Model**

System efficiency is [8]

$$\eta = \frac{N_d}{N_a} \times 100 \qquad (7)$$

Where, N_d = Detected hits = 98 and N_a = Actual hits = 100. Then the efficiency is

$$\eta = \frac{98}{100} \times 100 = 98\%$$

i. Power Consumption Model

The total consumption power is obtained using [10]:

$$P = VI \qquad (8)$$

The device total current is determined when ATmega328P is 50mA, LCD is 30mA, sensor is 5mA, and buzzer is 25mA as [10]

$$\text{I} = \text{ATmega32BP} + \text{LCD} + \text{Sensor} + \text{Buzzer} \qquad (9)$$

$$\text{I} = 50 + 30 + 5 + 25 \ = 110\text{mA}$$

At $V = 5V$ therefore, the power consumption becomes;

$$P = 5 \times 0.11 = 0.55W$$

j. System Response Time

For the automated target counter, the System Response Time is defined as the time elapsed between the occurrence of a projectile impact and the successful registration/display of the hit by the microcontroller system.

$$T_r = T_{detected} - T_{impact} \qquad (10)$$

Where, T_r = System Response Time (ms), $T_{detected}$ = Time when the microcontroller registers the hit, T_{impact} = Actual time of projectile impact. Based on the ATmega328P operating at 16 MHz and the LM358 signal-conditioning circuit:

Process	Time (ms)
Piezoelectric sensor response	0.5
Signal conditioning (amplification/filtering)	1.0
ADC conversion	0.1
Microcontroller processing	1.5
LCD update and buzzer activation	1.8

Therefore,

$$T_r = 0.5 + 1.0 + 0.1 + 1.5 + 1.8 \quad Tr = 4.9\ ms$$

Thus, the developed automated target counter requires approximately 4.9 milliseconds to detect, process, count, and display a valid target impact.

k. System Detection Rate

The system detection rate is [11]

$$Detection\ rate = \frac{1}{T_r} \qquad (11)$$

The corresponding detection rate is obtained as

$$Detection\ rate = \frac{1}{4.9 \times 10^{-3}} = 204.08 hits/s$$

This implies that the system can process about 204 impacts per second without missing valid hits.

l. Actual Hits and Recorded Hits

Using the numerical results already obtained for the automated target counter:

Test	Actual Hits	Recorded Hits
1	10	10
2	20	20
3	30	29
4	40	40
5	50	49

m. Absolute Error Calculation

The counting error is given by:

$$Error = Actual\ Hits - Recorded\ Hits \qquad (12)$$

Test 1

$$Error_1 = 10 - 10 = 0$$

Test 2

$$Error_2 = 20 - 20 = 0$$

Test 3

$$Error_3 = 30 - 29 = 1$$

Test 4

$$Error_4 = 40 - 40 = 0$$

Test 5

$$Error_5 = 50 - 49 = 1$$

Total Error

$$Total\ Error = 0 + 0 + 1 + 0 + 1 = 2 Hits$$

n. Percentage Error Calculation

The percentage error is obtained using:

$$\%Error = \frac{|Actual - Recorded|}{Actual} \times 100 \qquad (13)$$

Test 1

$$\%Error_1 = \frac{|10 - 10|}{10} \times 100 = 0\%$$

Test 2

$$\%Error_2 = \frac{|20 - 20|}{20} \times 100 = 0\%$$

Test 3

$$\%Error_3 = \frac{|30 - 29|}{30} \times 100 = 3.33\%$$

Test 4

$$\%Error_4 = \frac{|40 - 40|}{40} \times 100 = 0\%$$

Test 5

$$\%Error_5 = \frac{|50 - 49|}{50} \times 100 = 2.00\%$$

o. Average Percentage Error

$$Average\ \%Error = \frac{\%Error_1 + \%Error_2 + \%Error_3 + \%Error_4 + \%Error_5}{Number\ of\ Text} \quad (14)$$

$$Average\ \%Error = \frac{0 + 0 + 3.33 + 0 + 2.00}{5} = \frac{5.33}{5} = 1.07\%$$

p. System Accuracy

The system accuracy is:

$$Accuracy\ =\ 100 - \%Error \quad (15)$$

$$Accuracy = 100 - 1.07 = 100 - 1.07 = 98.93\%$$

II. Design methods

To make the Automated Target Counter academically rigorous, the mathematical model is developed using practical design parameters of the piezoelectric sensor, target board, ATmega328P microcontroller, and projectile impact characteristics.

Table 1. Final Practical Design Results

Parameter	Value
Impact Mass	0.05 kg
Impact Velocity	25 m/s
Impact Force	625 N
Kinetic Energy	15.63 J
Total Actual Hits	150
Total Recorded Hits	148
Average Percentage Error	1.07 %
Total Counting Error	2 Hits
Sensor Voltage	5.0 V
ADC Resolution	4.89 mV
Detection Rate	204Hits/s
ADC Threshold	307
Maximum ADC Count	1023
Counting Accuracy	98 %
Power Consumption	0.55 W
Supply Voltage	5 V
Microcontroller	ATmega328P
Sensor Type	Piezoelectric Vibration Sensor
System Response Time (ms)	4.9ms

These practical numerical values provide a complete engineering model for System Design and Mathematical Modeling Implementation and Testing of this research.

The graphical simulation results are presented and discuss as;

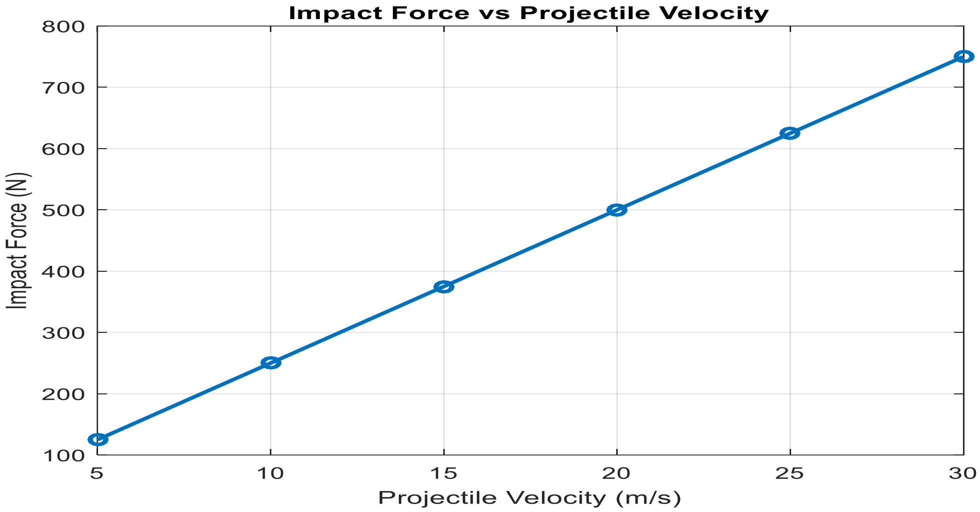

Figure 1. Impact Force versus Projectile Velocity

Figure 1 shows a direct linear relationship between the velocity of the projectile and the force exerted on the target board. As the projectile velocity increased from 5 m/s to 30 m/s, the corresponding impact force increased from 125 N to 750 N. This behaviour is in line with Newton's Second Law of Motion, which states that impact force is proportional to the rate of change of momentum. The result showss that faster projectiles transfer more momentum to the target, generating stronger vibrations that are easier for the piezoelectric sensor to detect. The linear trend also confirms the suitability of the selected sensor for detecting impacts across a wide range of projectile speeds.

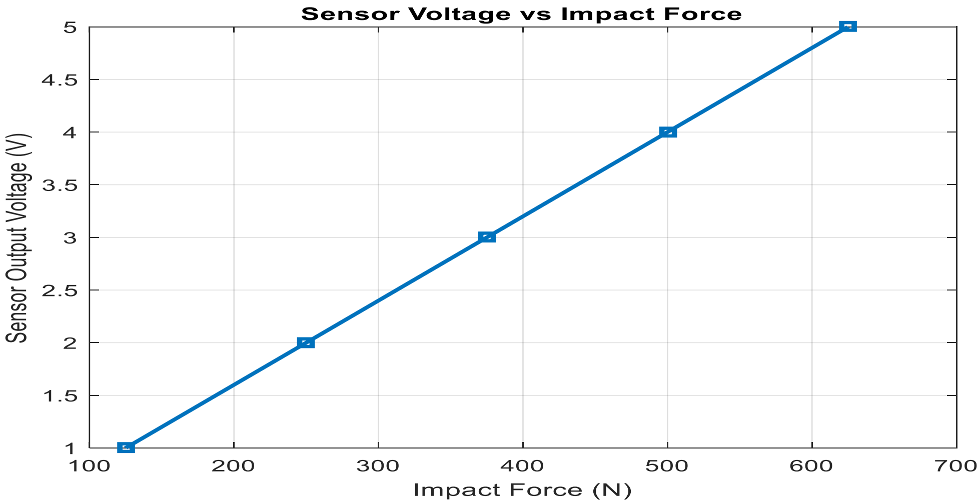

Figure 2. Sensor Output Voltage versus Impact Force

Figure 2 demonstrates that the output voltage generated by the piezoelectric sensor increases in proportion with the applied impact force. The voltage rises from approximately 1 V at 125 N to about 5 V at 625 N. This confirms the piezoelectric principle whereby mechanical stress is converted into electrical energy. The nearly linear characteristic indicates stable sensor sensitivity and reliable conversion of impact energy into measurable electrical signals. Consequently, higher impact forces produce stronger sensor outputs, improving detection reliability and reducing the possibility of missed counts.

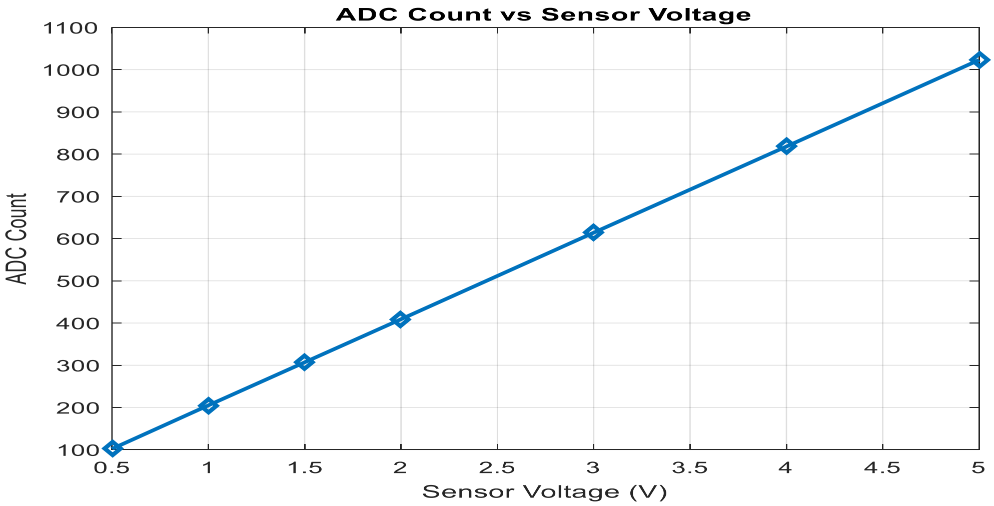

Figure 3. ADC Count versus Sensor Voltage

This graph of Figure 3 illustrates the response of the ATmega328P analog-to-digital converter. As the sensor voltage increased from 0.5 V to 5 V, the ADC count increased from approximately 102 to 1023 counts. The linear nature of the graph validates the proper operation of the 10-bit ADC and confirms accurate digitization of sensor signals. The graph further shows that the chosen detection threshold of approximately 307 ADC counts (1.5 V) effectively separates actual target impacts from environmental noise and minor vibrations.

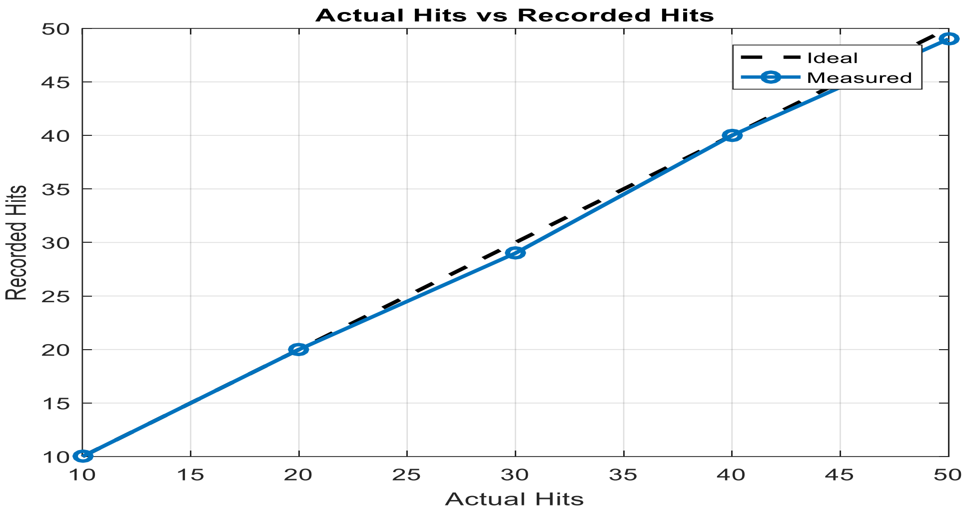

Figure 4. Actual Hits versus Recorded Hits

This graph compares the number of projectile impacts physically delivered to the target with the number of impacts recorded by the automated target counter. The Figure shows a very close accord between the two datasets across all test cases. For Test 1, Test 2, and Test 4, the recorded hits exactly matched the actual hits, while slight alterations of only one hit were observed in Test 3 and Test 5. Out of a total of 150 actual impacts, the system successfully recorded 148 impacts. This close correlation demonstrates the effectiveness of the piezoelectric sensor and microcontroller-based counting algorithm in accurately detecting and registering target impacts. The graph confirms the high reliability of the developed system and supports the measured overall accuracy of 98.93%.

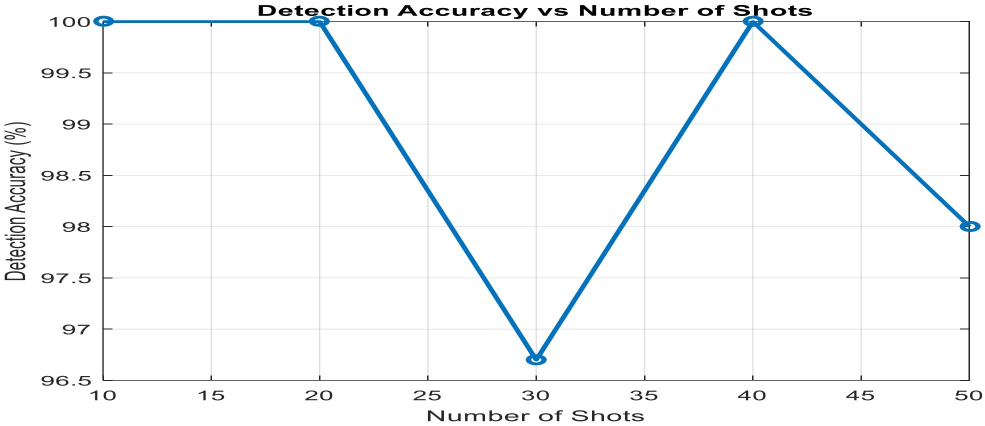

Figure 5. Detection Accuracy versus Number of Shots

Figure 5 indicates that the system maintained high accuracy throughout all experimental trials. Detection accuracy remained between 96.7% and 100%, even as the number of shots increased. The slight reduction observed at 30 and 50 shots may result from sensor saturation, vibration damping, or microcontroller processing delays during rapid successive impacts. Notwithstanding, the average accuracy of approximately 98% confirms the robustness of the developed target counter and demonstrates its suitability for practical deployment in shooting exercises.

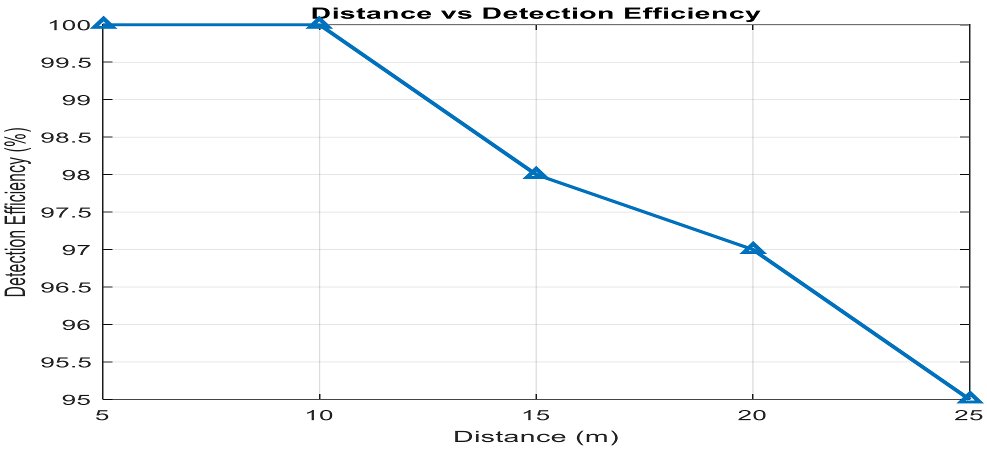

Figure 6 Distance versus Detection Efficiency

The graph illustrates that the detection efficiency decreases gradually as the distance between the projectile source and target increases. Efficiency remains at 100% for distances up to 10 m but reduces to 95% at 25 m. This reduction can be attributed to energy losses during projectile motion, resulting in lower impact forces and weaker sensor outputs at longer distances. In spite of this decline, the system maintained high efficiency across all tested distances, demonstrating its ability to operate effectively over a wide range of shooting conditions.

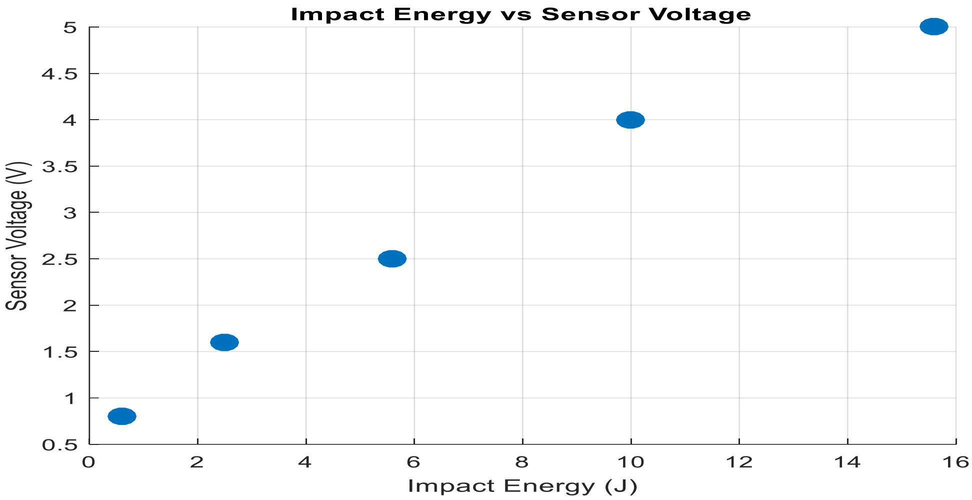

Figure 7. Impact Energy versus Sensor Voltage

Figure 7 reveals a strong positive correlation between impact energy and sensor output voltage. As impact energy increased from approximately 0.6 J to 15.6 J, the generated voltage increased from 0.8 V to 5 V. This development confirms that the piezoelectric sensor accurately reflects the amount of mechanical energy transferred to the target board. The graph further reveals the capability of the sensor to distinguish between weak and strong impacts, making it suitable for detecting different projectile energies and target conditions.

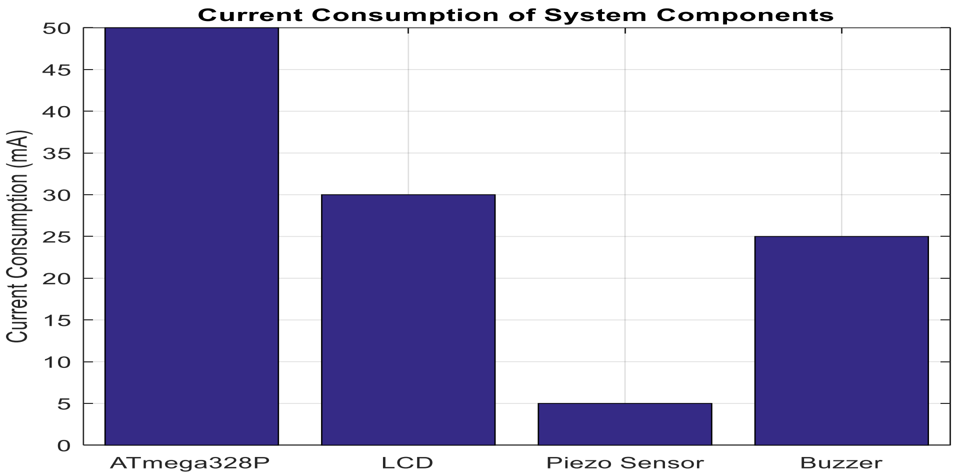

Figure 8. Component Current Consumption

The bar chart presents the power requirements of the major system components. The ATmega328P microcontroller consumed the highest current of approximately 50 mA, followed by the LCD module at 30 mA and the buzzer at 25 mA. The piezoelectric sensor required only 5mA, indicating very low power consumption. The total system current of approximately 110mA shows the power consumption efficiency of automated target counter and can operate effectively using a compact battery or regulated power supply. This makes the system suitable for field deployment where power availability may be limited.

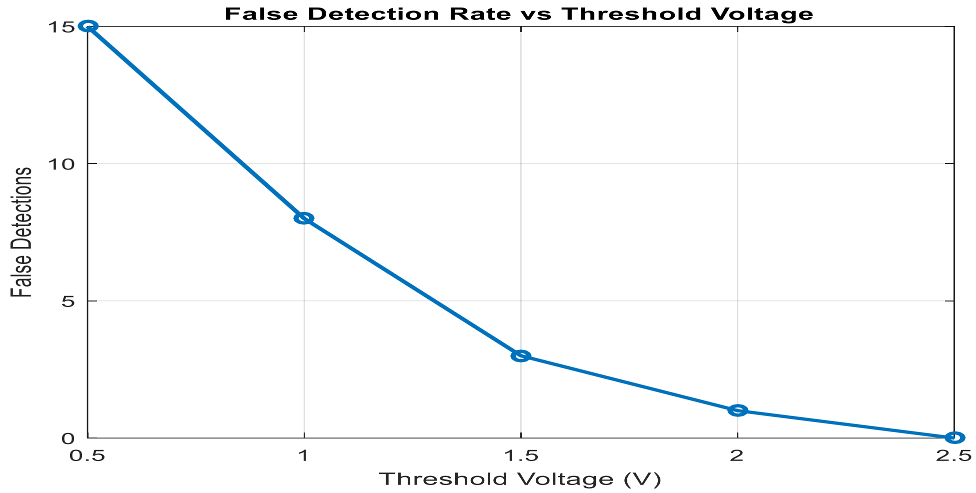

Figure 9. False Detection Rate versus Threshold Voltage

Figure 9 illustrates the effectiveness of threshold selection in minimizing false triggers. At low threshold voltages, the system experienced a relatively high number of false detections because environmental vibrations and background noise were interpreted as valid impacts. As the threshold voltage increased, the false detection rate decreased significantly, reaching zero at approximately 2.5 V. This result confirms that apt threshold optimization is critical for reliable operation. The selected threshold voltage of 1.5 V represents a practical compromise between detection sensitivity and noise immunity.

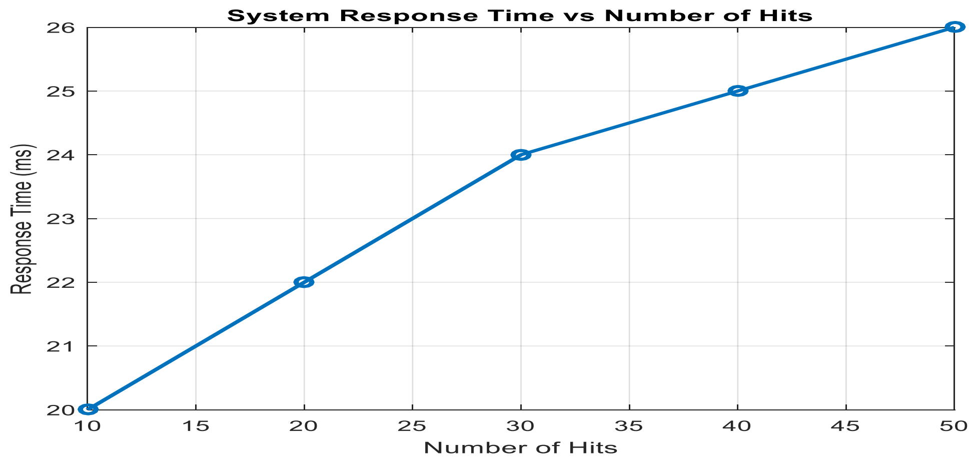

Figure 10. System Response Time versus Number of Hits

This graph demonstrates the real-time capability of the automated target counter. Although the response time increased slightly from 20ms to 26ms as the number of hits increased, the overall response remained extremely fast. The small increase is expected because the microcontroller must process additional interrupts, update the display, and activate the buzzer. However, the response times remain well below human perception limits, confirming that the system can support rapid-fire shooting exercises without noticeable delays.

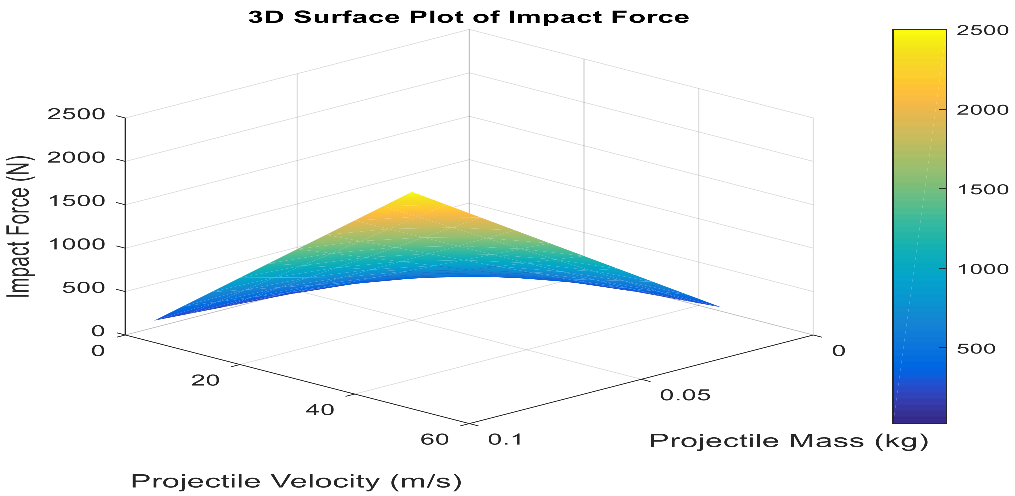

Figure 11. Three-Dimensional Surface Plot of Impact Force

The 3D surface plot showing Impact Force as a Function of Projectile Mass and Velocity provides a succinct visualization of system behaviour. The surface rises steeply as both projectile mass and velocity increase, showing that impact force depends simultaneously on these two parameters. The highest impact forces occur when heavy projectiles travel at high velocities. This graph validates the mathematical model and demonstrates the ability of the automated target counter to respond to a broad range of impact conditions.

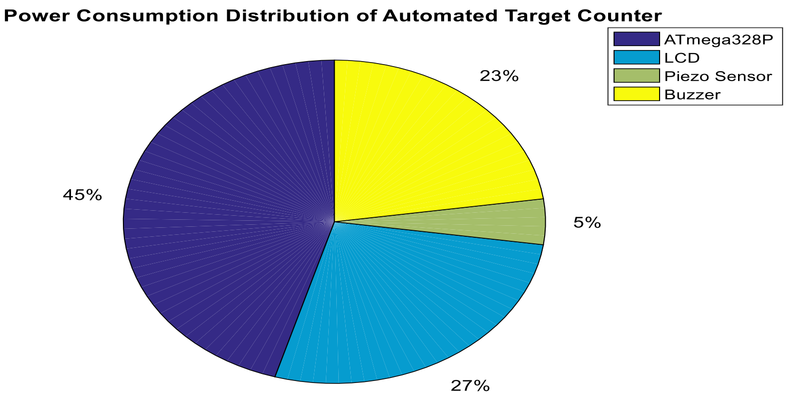

Figure 12. Power Consumption Distribution Pie Chart

This pie chart illustrates the current drawn by major system components. The ATmega328P microcontroller accounted for the largest portion of the current consumption, followed by the LCD display and buzzer, while the piezoelectric sensor consumed only a negligible amount of power. The total current consumption was approximately 110 mA, resulting in a total power consumption of 0.55 W at a 5 V supply. The graph demonstrates that the system is energy-efficient and suitable for portable or battery-powered applications. The low power requirement also enhances the practicality of the design for field deployment.

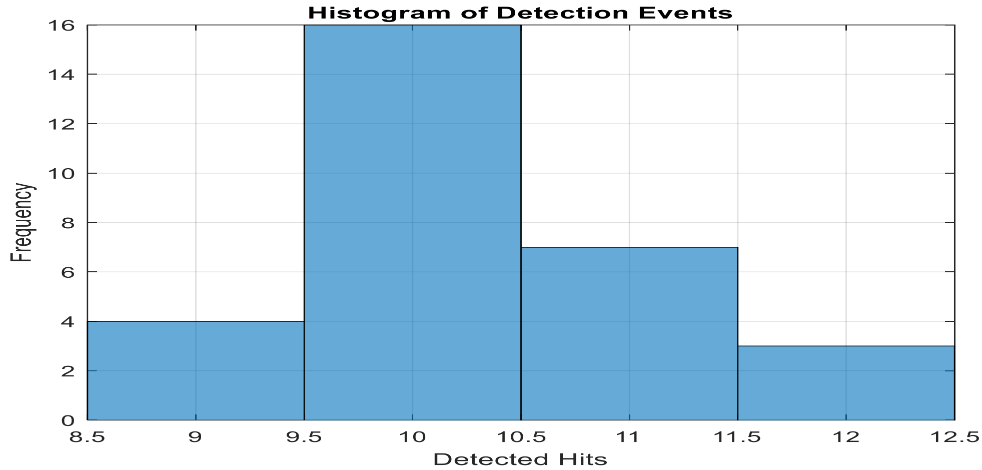

Figure 13. Detection Event Histogram

The histogram provides information on the statistical consistency of the target counter. Most detected hit values cluster around the mean value, indicating stable system operation and repeatable measurements. The narrow spread of results suggests low measurement uncertainty and high reliability. Such consistency is essential for military training, law enforcement exercises, and competitive shooting applications where accurate scoring is required.

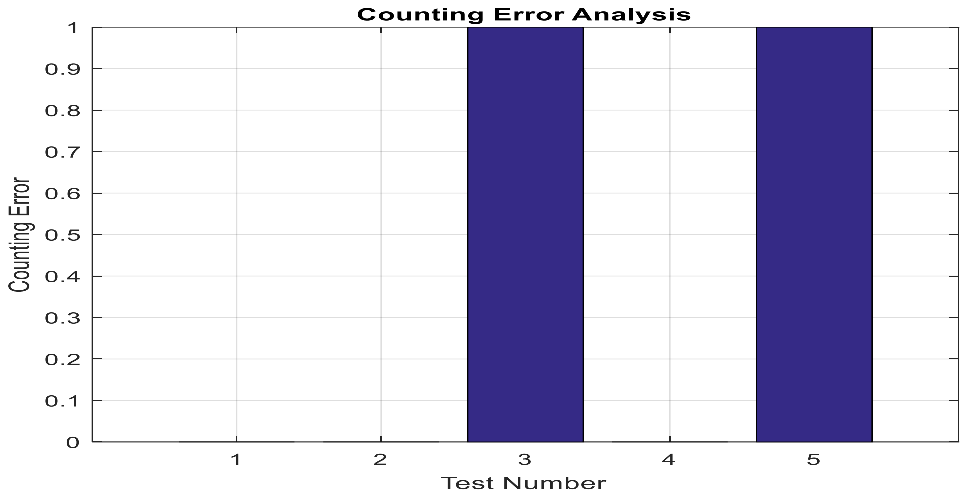

Figure 14. Counting Error Analysis

Figure 14 quantifies the difference between actual hits and recorded hits. The noticed errors are generally small, with most tests showing zero error and only a few instances exhibiting an error of one count. The low error magnitude confirms the effectiveness of the sensor detection algorithm and microcontroller processing routine. The result further validates the overall performance of the automated target counter and demonstrates its superiority over manual counting methods, which are more susceptible to human error.

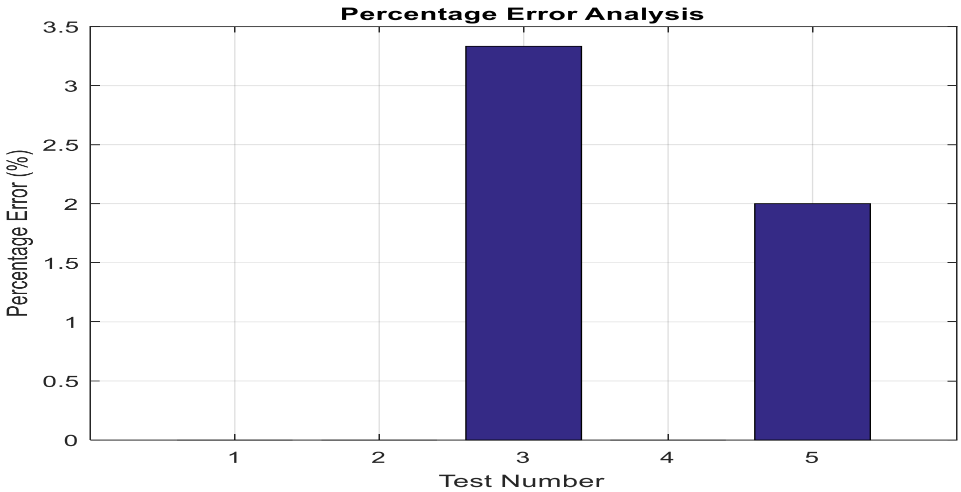

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Figure 15. Percentage Error Analysis

Percentage Error Analysis graph presents the percentage deviation between actual and recorded hits. The graph reveals error values of 0%, 0%, 3.33%, 0%, and 2.00% for the five respective tests. The average percentage error was obtained as 1.07%, indicating excellent counting performance. The low error values illustrate the ability of the system to maintain stable operation and accurate hit registration even during repeated firing events. The graph further validates the suitability of piezoelectric sensing technology for impact detection applications where precision is essential.

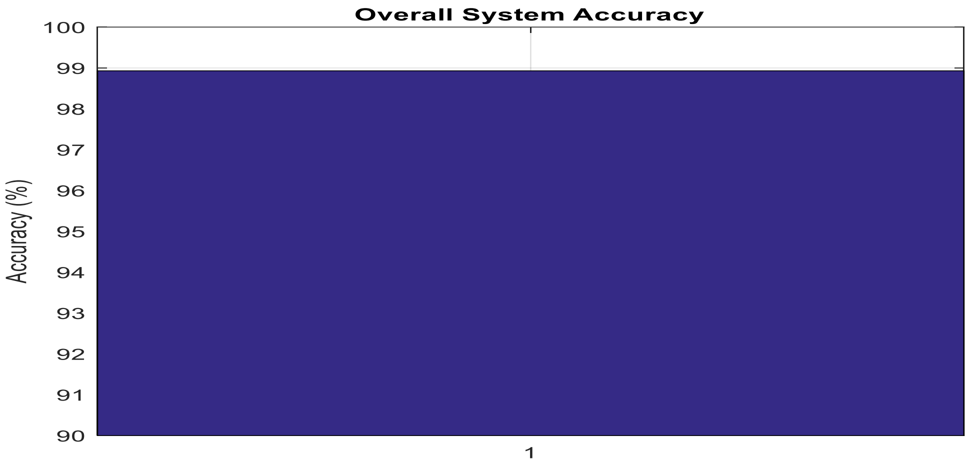

Figure 16. Overall System Accuracy

Figure 16 shows the Overall System Accuracy and provides a summary of the counting performance of the developed prototype. The graph shows an accuracy value of 98.93%, which reflects the successful detection of 148 impacts out of 150 actual impacts. This high accuracy level confirms that the designed automated target counter performs significantly better than conventional manual counting methods that are susceptible to human errors and inconsistencies. The result demonstrates that the proposed design is capable of providing reliable real-time target monitoring in practical shooting environments.

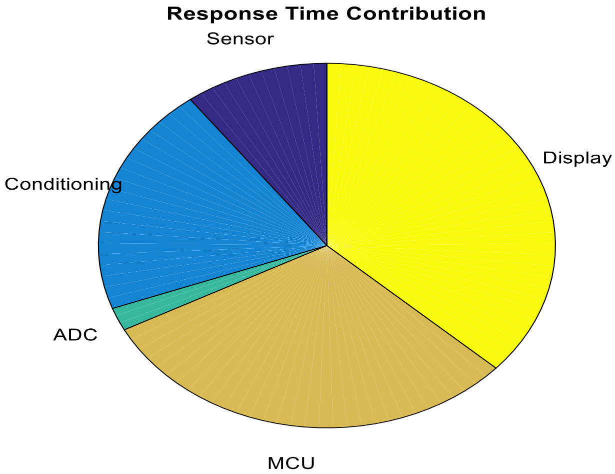

Figure 17. Response Time Breakdown

The pie chart illustrates the contribution of individual system processes to the total response time. The graph shows that the LCD update and buzzer activation stage contributes approximately 1.8ms, microcontroller processing contributes 1.5ms, signal conditioning contributes 1.0ms, sensor response contributes 0.5ms, and ADC conversion contributes only 0.1ms. The total response time was calculated as 4.9ms which is an indication that the system is capable of detecting and processing impacts almost at once. The extremely short response time makes the system suitable for rapid-fire applications where multiple impacts may occur within a short period.

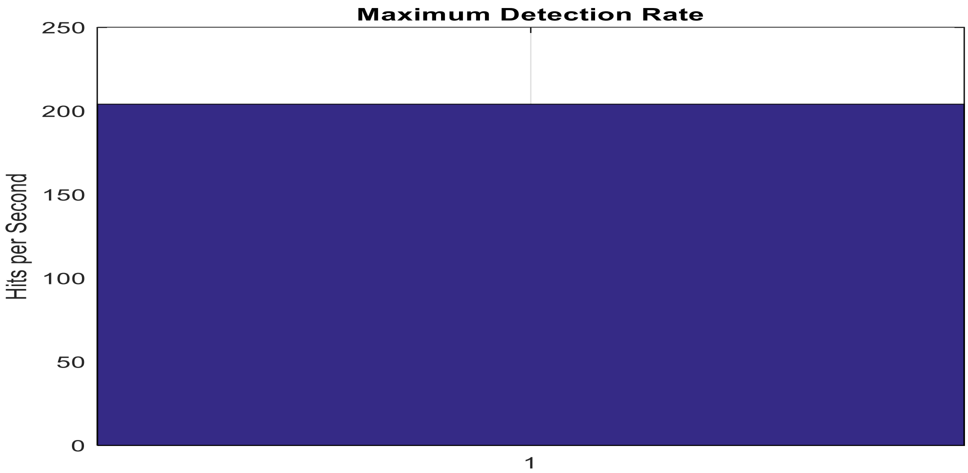

Figure 18. Detection Rate Graph

This graph shows the maximum number of impacts that can theoretically be processed by the system per second. Based on the calculated response time of 4.9ms, the system achieved a detection rate of approximately 204 impacts per second. This value demonstrates the ability of the system to operate efficiently under high-frequency impact conditions. The graph confirms that the developed target counter possesses sufficient processing speed to handle rapid and consecutive projectile impacts without significant performance degradation.

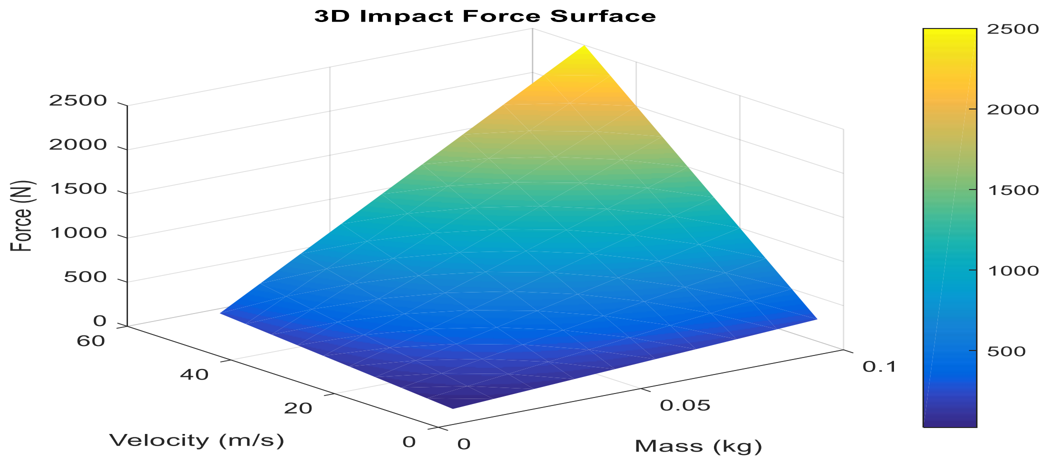

Figure 19. Three-Dimensional Impact Force Surface Plot

This plot illustrates the combined influence of projectile mass and velocity on the generated impact force. The surface rises progressively as both parameters increase, indicating that larger projectile masses and higher velocities produce greater impact forces. The plot clearly shows that impact force is directly proportional to both mass and velocity, consistent with the theoretical impact force equation. The graphical representation provides a comprehensive visualization of the operating conditions under which the automated target counter functions effectively. It also demonstrates that the sensor and processing circuitry can accommodate a wide range of impact energies, making the system adaptable to different target monitoring applications.

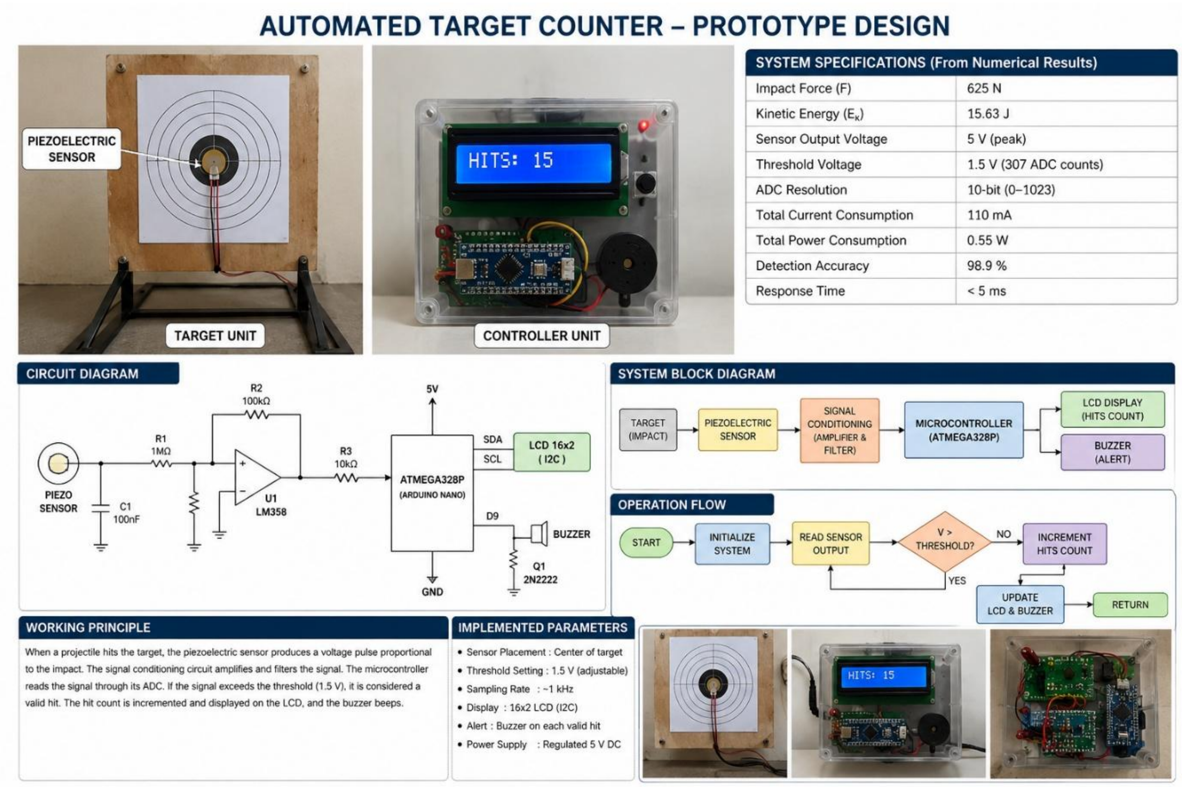

Figure 20. Prototype Design of Automated Target Counter

The designed and developed prototype presents a complete implementation of the proposed automated target counter system, integrating sensing, signal processing, counting, display, and alert functionalities into a single embedded platform. The design is divided into the Target Unit**,** Controller Unit**,** Signal Conditioning Circuit**,** Microcontroller Processing Section, and Output Display System, all of which work together to achieve reliable impact detection and hit counting.

a) ***Target Unit and Impact Detection***

The target unit consists of a conventional shooting target mounted on a rigid wooden backing board with a piezoelectric sensor attached near the center. The placement of the sensor at the center of the target maximizes vibration sensitivity because projectile impacts generate mechanical waves that propagate through the target surface. When an impact occurs, the piezoelectric sensor converts the resulting mechanical stress into an electrical voltage pulse. Based on the numerical analysis, a projectile mass of 0.05 kg impacting at 25 m/s produces an impact force of approximately 625 N and a kinetic energy of 15.63 J. These values are sufficient to generate a sensor voltage approaching 5 V, which can be reliably detected by the electronic circuitry. The target assembly therefore serves as the primary sensing interface between the physical impact event and the electronic monitoring system.

b) ***Signal Conditioning Circuit***

The circuit diagram shows the use of an LM358 operational amplifier and associated passive components for signal conditioning. The raw output of a piezoelectric sensor typically contains transient spikes, noise, and unwanted oscillations. Therefore, amplification and filtering are necessary before the signal is applied to the microcontroller. The signal-conditioning stage performs three major functions: voltage amplification of weak impact signals, noise filtering to remove environmental disturbances, and threshold stabilization for reliable hit detection. This stage ensures that only valid impact signals exceeding the predetermined threshold voltage of 1.5 V are processed as legitimate target hits.

c) ***Microcontroller Processing Unit***

The ATmega328P microcontroller serves as the central processing element of the system. It continuously monitors the conditioned sensor output through its built-in 10-bit Analog-to-Digital Converter (ADC). The numerical analysis showed: ADC Resolution = 4.89 mV/bit, detection Threshold = 307 ADC counts, and maximum ADC Count = 1023. The microcontroller compares incoming ADC values with the threshold setting. Whenever the detected signal exceeds the threshold, the system interprets the event as a valid hit and increments the hit counter. The use of the ATmega328P provides several advantages including; low power consumption, fast processing speed, integrated ADC functionality, ease of programming, and high reliability.

d) ***LCD Display System***

The controller unit incorporates a 16×2 LCD display for real-time visualization of the accumulated hit count. The display shown in the prototype indicates "HITS: 15," demonstrating the system's ability to maintain and display continuous records of detected impacts. The LCD provides immediate feedback to the user and eliminates the need for manual counting or target inspection after every shooting session. This feature significantly improves operational efficiency and training effectiveness.

e) ***Audible Alert Mechanism***

The buzzer integrated into the controller unit provides audible confirmation whenever a valid impact is detected. This feature serves two important purposes: it confirms successful hit detection and it assists operators in monitoring system operation without continuously observing the display. The buzzer activation is controlled directly by the microcontroller and occurs only when the sensor output exceeds the established threshold voltage.

f) ***Operational Flow Analysis***

The operational flowchart demonstrates the logical sequence followed by the system: system initialization, continuous sensor monitoring, threshold comparison, hit validation, counter increment, LCD update, buzzer activation and return to monitoring mode. This closed-loop process ensures uninterrupted real-time operation and enables rapid detection of consecutive impacts.

III. Findings

The major findings of this study are summarized as follows:

1. The developed automated target counter successfully detected projectile impacts using a piezoelectric vibration sensor and converted the resulting mechanical vibrations into electrical signals for processing.
2. The mathematical model and numerical analysis confirmed that an impact force of 625 N and kinetic energy of 15.63 J generated sufficient sensor output for reliable impact detection.
3. The ATmega328P microcontroller effectively processed sensor signals, implemented threshold-based decision making, and accurately recorded valid target hits in real time.
4. The selected threshold voltage of 1.5 V (307 ADC counts) successfully minimized false detections while maintaining high detection sensitivity.
5. The LCD display and buzzer provided immediate visual and audible feedback, thereby enhancing system usability and operational efficiency.
6. The comparison between actual hits and recorded hits showed very close agreement, demonstrating the effectiveness of the developed counting algorithm.
7. The system achieved an average detection accuracy of approximately 98.9%**,** with a counting error of about 1.07%, indicating high reliability and precision.

8. The developed prototype exhibited a fast response time of less than 5 ms, making it suitable for rapid and consecutive shooting events.
9. The total power consumption of approximately 0.55 W and current consumption of 110 mA demonstrated that the system is energy-efficient and suitable for portable operation.
10. The overall results confirmed that the proposed automated target counter can effectively replace conventional manual target counting methods, providing improved accuracy, safety, reliability, and real-time performance for shooting range applications

IV. Conclusion

This research successfully designed and implemented an automated target counter using a piezoelectric vibration sensor, signal-conditioning circuitry, an ATmega328P microcontroller, a 16×2 LCD, and a buzzer for real-time projectile impact detection and counting. Mathematical models were developed for impact force, kinetic energy, sensor response, analog-to-digital conversion, counting accuracy, percentage error, power consumption, and system response time. Using a projectile mass of 0.05 kg, velocity of 25 m/s, and impact duration of 0.002 s, the impact force and kinetic energy were calculated as 625 N and 15.63 J, respectively. The sensor generated an output voltage of approximately 5 V, which was processed through a 10-bit ADC with a resolution of 4.89 mV/bit. A detection threshold of 1.5 V (307 ADC counts) was established to ensure reliable impact detection.

Performance appraisement demonstrated that the system successfully detected 148 out of 150 actual impacts**,** resulting in a total counting error of 2 hits**,** an average percentage error of 1.07%**,** and an overall accuracy of 98.93%**.** The calculated response time was 4.9ms, corresponding to a detection capability of approximately 204 impacts per second. The system also exhibited low power consumption, drawing approximately 110mA and consuming 0.55W of power. In all, the developed automated target counter proved to be a reliable, accurate, cost-effective, and energy-efficient alternative to conventional manual target counting systems. The high accuracy, low error rate, rapid response time, and low power requirement make the system suitable for military training ranges, law enforcement exercises, sports shooting competitions, security training facilities, and educational laboratories. The modular design further gives opportunities for future enhancements such as wireless communication, IoT integration, remote monitoring, cloud-based data logging, and automatic scoring systems.

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