Designing a Safety Condition Monitoring System for Body Harness Installation Using the Decision Tree Method

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***Abstract*—Work safety in high-altitude activities remains a major issue, particularly due to body harness installation errors such as hooks not being attached to anchor points or excessive tension on safety ropes. This study aims to develop a sensor-based body harness safety system and Decision Tree algorithm for real-time automatic monitoring. The system uses inductive proximity sensors to detect hook attachment and MPX5010 pressure sensors to measure excessive pressure on the harness rope. Sensor data is processed by a Decision Tree algorithm embedded in an Arduino Uno microcontroller to classify safe and unsafe conditions. In unsafe conditions, the system sends an emergency notification in the form of a misscall via the SIM800L GSM module. Sensor testing results show a 100% success rate for proximity and pressure sensors. Overall system testing using a confusion matrix results in 88% classification accuracy without false negatives. The proximity sensor functions as hook attachment verification, while the pressure sensor is the main parameter with a threshold of 3.425 kPa. The results of the study show that the system is capable of improving work safety at heights through effective early warning.**

***Keywords*— Body Harness, Mpx 5010, Proximity, GSM, Decision Tree, Microcontroller.**

I. INTRODUCTION

Work safety in activities at heights remains a serious problem in the industrial and construction sectors. Falls from heights are still among the leading causes of workplace accidents, even though the use of personal protective equipment (PPE) in the form of body harnesses is mandatory. These accidents are generally caused by incorrect installation of body harnesses, such as hooks that are not connected to anchor points or straps that are not tightened according to standards. Previous research has shown that improper installation of body harnesses is a dominant factor in fall accidents, so supervision that relies solely on manual inspection and worker discipline is considered suboptimal [1].

In an effort to improve work safety, a microcontroller-based body harness safety monitoring system has been developed that is capable of working automatically and in real-time. This system utilizes inductive proximity sensors to detect the attachment of hooks to metal anchor points [3] and MPX5010 pressure sensors to identify changes in pressure on the harness straps that indicate excessive pulling [4], [5]. Data from both sensors is processed using the Decision Tree method, which has a simple and efficient logical structure for application in embedded systems [6], [7]. If unsafe conditions are detected, the system sends an emergency warning via the SIM800L GSM module in the form of a missed call to safety officers [8], [9].

II. METHOD

A. Machine Learning

Machine learning is a branch of artificial intelligence that enables systems to learn patterns from data and make decisions without requiring explicit programming of rules. This approach works by utilizing training data to build models capable of classifying or predicting new data. In the context of occupational safety systems, machine learning can be used to classify body harness usage conditions based on sensor data, such as proximity sensors and MPX5010 pressure sensors. The use of simple and efficient algorithms allows this method to be implemented in microcontroller-based embedded systems and supports real-time data processing.

B. Decision Tree

A decision tree is a classification method used to aid decision making by utilizing a tree-like structure. This structure consists of a root node, decision nodes, branches, and leaf nodes that represent the classification results. At each decision node, a test is performed on a specific attribute, while the branches show the results of the test. The simple structure of a decision tree makes this method easy to understand and suitable for implementation in embedded systems with limited resources.

In this study, Decision Tree is used to classify the condition of body harness installation into two classes, namely Safe and Unsafe. The classification process is carried out based on two main parameters, namely the presence of a hook at the anchor point detected by an inductive proximity sensor and the pressure value on the harness strap measured using an MPX5010 sensor. Data from both sensors are processed using the Decision Tree logic flow so that the system is able to make decisions automatically.

Decision Tree testing was conducted using manual data without sensors, with 10 samples covering proximity and

MPX5010 pressure (kPa) parameters, categorized as Safe or Unsafe. The first step was to calculate the entropy of the initial dataset to measure uncertainty. Of the 10 samples, there were 6 Safe and 4 Unsafe, so the initial entropy was calculated as:

$$Entropy(S) = -\sum_{i=1}^{n} p_i \log_2 p_i$$

$$Entropy(S) = -\left(\frac{6}{10}\log_2\frac{6}{10} + \frac{4}{10}\log_2\frac{4}{10}\right) = 0{,}971$$

Next, the dataset is divided based on a pressure threshold of 3.425 kPa. Samples with pressure ≤ 3.425 kPa are all included in the Safe category, so branch entropy = 0. Samples with pressure > 3.425 kPa are all included in the Unsafe category, so branch entropy = 0. Based on this, the Information Gain of the Pressure attribute is calculated as the difference between the initial entropy and the average branch entropy:

$$Gain(S, Tekanan)$$

$$= 0{,}971 - \left(\frac{6}{10}\cdot 0 + \frac{4}{10}\cdot 0\right) = 0{,}971$$

To ensure balanced data distribution, the Gain Ratio is also calculated, which is the ratio between Information Gain and Split Information:

$$SplitInfo(S, Tekanan)$$

$$= -\left(\frac{6}{10}\log_2\frac{6}{10} + \frac{4}{10}\log_2\frac{4}{10}\right) = 0{,}971$$

$$GainRatio(S, Tekanan) = \frac{0{,}971}{0{,}971} = 1$$

These results show that the MPX5010 Pressure attribute is highly effective as the main node in the Decision Tree. Each sample with pressure > 3.425 kPa is classified as Unsafe, while pressure ≤ 3.425 kPa is categorized as Safe. This calculation proves that the Decision Tree is capable of replicating learning results with manual data, in accordance with revisions that emphasize testing without sensors, and supports the implementation of real-time systems for monitoring body harness conditions.

C. Tiny Decision Tree Classifer

Tiny Decision Tree Classifier is a lightweight C/C++-based library designed to implement decision tree algorithms directly on microcontrollers such as Arduino. This library is self-contained and requires only standard libraries, making it suitable for use in systems with limited memory and computing power. The algorithm used is based on C4.5 and can handle numerical attributes. With this library, the classification process can be performed in real-time without relying on external processing, thereby improving the responsiveness of occupational safety monitoring systems.

D. Skicit-Learn

Scikit-Learn is a Python-based machine learning library that provides various supervised and unsupervised learning algorithms, including Decision Tree. In Scikit-Learn, attribute selection at each node is performed using impurity measures such as Gini Impurity or Entropy to obtain the best data separation. The tree formation process is performed recursively until the data is classified or the depth limit is reached. In this study, Scikit-Learn was used as a reference in the design and learning process of the Decision Tree model before it was implemented in an embedded system.

III. RESULTS AND DISCUSSION

A. Research Design

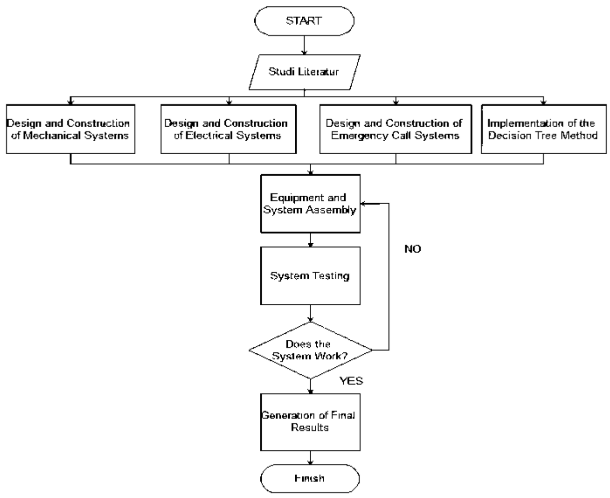

Figure 1. Research Implementation Stage Flowchart

This research (Figure 1) began with a literature study related to automatic body harness monitoring systems, MPX5010 pressure sensors, Decision Tree algorithms, and emergency communication systems. The next stage was system design, which included the mechanical design of sensor placement, the design of electronic circuits that integrate sensors, Arduino Uno microcontrollers, and communication modules, as well as the design of a call-based emergency warning system. The Decision Tree algorithm was applied to evaluate the body harness attachment condition based on sensor data. The system was then assembled and functionally tested to ensure its ability to detect safe and unsafe conditions and send emergency alerts. If any discrepancies were found, repairs and retesting were carried out. The final stage of the research was the documentation and analysis of the test results as the basis for the report.

B. Work System Design

The system is designed to automatically verify the attachment of body harnesses in order to minimize the risk of workplace accidents. A proximity sensor detects the hook attachment at the anchor point. If the hook is not detected, the system classifies the condition as an emergency. If detected, the MPX5010 pressure sensor is used to detect excessive pressure on the harness strap. The sensor data is processed by Arduino Uno using a Decision Tree algorithm to determine whether the condition is safe or an emergency. In an emergency, the system automatically sends a real-time misscall notification, as shown in Fig 2.

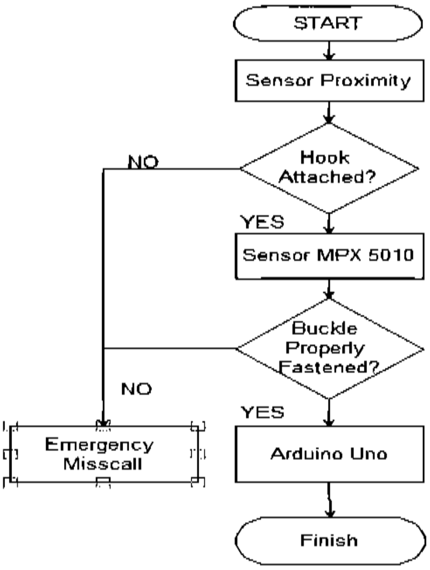

Figure 2. Work System Design Flowchart

C. Program Design

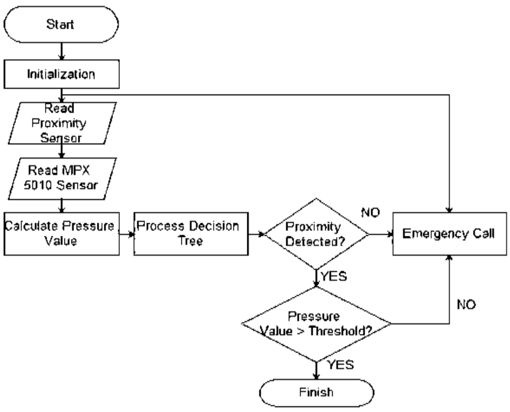

Figure 3. Program Design Flowchart

Figure 3 shows the workflow of the body harness monitoring system program, which begins with the system initialization process. Next, the system reads the proximity sensor data to detect the attachment of the hook to the anchor point and the MPX5010 pressure sensor to obtain the pressure value on the harness strap. The sensor data is then processed using the Decision Tree method to determine the harness attachment condition. If the hook is not detected or the pressure value exceeds the safety limit, the system sends an emergency call. Conversely, if the hook is detected and the pressure is within the safety limit, the system determines that the condition is safe and the process ends.

D. Mechanical Design

The mechanical system is designed with ergonomics in mind so as not to interfere with user mobility. A proximity sensor is placed on the hook area of the body harness to detect connection with the anchor point, while an MPX5010 pressure sensor is installed on the chest strap as an indicator of excessive pressure due to strong pulling, not to determine the correctness of the strap attachment. Arduino Uno and GSM modules are integrated to ensure reliable processing and emergency communication. All components and cable routes are neatly designed to minimize the risk of interference and damage during use, as shown in Fig. 4.

Figure 4. Mechanical Design

E. Electrical Design

The electrical system design includes the integration of proximity sensors, MPX5010 pressure sensors, Arduino Uno microcontrollers, and GSM communication modules for real-time monitoring of the body harness. The Arduino Uno functions as a control center that processes proximity sensor data to detect hook attachment at anchor points and MPX5010 sensor data as an indicator of excessive pressure due to strong pulling, not to determine the correctness of harness attachment. Sensor data is processed using the Decision Tree method to classify safe or emergency conditions. In unsafe conditions, the Arduino Uno activates the GSM module to send an emergency notification in the form of a missed call to the supervisor, with the system designed to be compact and energy-efficient, as shown in Fig 5.

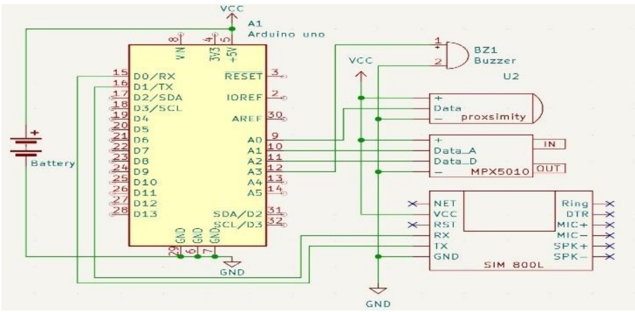

Figure 5. Electrical Design

F. Sensor Testing Against Microcontrollers and Decision Tree Method Integration

System testing was conducted to evaluate the performance of the proximity sensor and MPX5010 pressure sensor in transmitting data to the Arduino Uno microcontroller. The testing was conducted by simulating various hook attachment conditions at anchor points and variations in pressure on the harness strap. Sensor data was processed using a Decision Tree algorithm to classify conditions as safe or unsafe. The system's decisions were compared with actual conditions to assess the accuracy and responsiveness of the system in supporting automatic work safety monitoring, as shown in Table I.

TABLE I
SENSOR TESTING AGAINST MICROCONTROLLERS AND DECISION TREE METHOD INTEGRATION

No	Testing Procedure	Tested Condition	Expected Output	Actual Result	Compliant / Non-Compliant
1	System Initialization	Arduino Powered On, Sensors Activated	Sensor Ready for Detection	P	Compliant
2	Read Proximity Sensor (Hook Not Installed)	Hook Not Installed	Not Detected	O	Compliant
3	Read Proximity Sensor (Hook Installed)	Hook Installed	Detected	P	Compliant
4	Read Pressure Sensor (Pressure < Threshold)	Low Pressure (Loose Hook)	Low Pressure Value	P	Compliant
5	Read Pressure Sensor (Pressure ≥ Threshold)	High Pressure (Hook Securely Locked)	High Pressure Value	P	Compliant
6	Decision Tree Processes Data	Combination of Proximity and Pressure Data	Classification: Safe / Unsafe	P	Compliant
7	Proximity Not Detected	No Attachment Detected	Emergency Call Activated	P	Compliant
8	Proximity Detected, Pressure < Threshold	Attachment Not Securely Locked	No Warning	P	Compliant
9	Proximity Detected, Pressure ≥ Threshold	Attachment Properly Installed	Emergency Call Activated	P	Compliant
10	System Response	System Response Time < 1 Second	Fast and Consistent Response	P	Compliant
11	Noise / Interference Testing	Arduino Powered On, Sensors Activated	Sensor Ready for Detection	P	Compliant

G. *Proximity Sensor Testing*

Before being integrated into the body harness system, the proximity sensor was tested separately to evaluate its ability to detect metal objects as indicators of hook attachment at the anchor point. The test was conducted under several conditions, namely when metal objects were brought closer to and moved away from the sensor. The test results in Table 2 show that the sensor responds actively when an object is detected and remains inactive when the object is moved away. Based on a comparison between the number of successful tests and the total number of tests, the proximity sensor showed a success rate of 100%, indicating that it functioned properly before being implemented in the system, as shown in Table II.

TABLE II
PROXIMITY SENSOR TEST RESULTS

No	Test Condition	Metal Object Treatment	Output	Sensor Respond	Compliance
1	Initial Condition	No Metal Object in Front of the Sensor	0	Inactive	Compliant
2	Metal Object Brought Closer	Metal Object Brought Closer to the Sensor	1	Active	Compliant
3	Metal Object Remains in Place	Metal Object Remains Near the Sensor	1	Active	Compliant
4	Metal Object Moved Away	Metal Object Moved Away from the Sensor	0	Inactive	Compliant
5	Metal Object Brought Closer Again	Metal Object Brought Closer Again	1	Active	Compliant
6	Metal Object Remains in Place	Metal Object Remains Near the Sensor	1	Active	Compliant
7	Metal Object Moved Away	Metal Object Moved Away Again	0	Inactive	Compliant
8	Metal Object Brought Closer	Metal Object Brought Closer to the Sensor	1	Active	Compliant
9	Metal Object Remains in Place	Metal Object Remains Near the Sensor	1	Active	Compliant
10	Metal Object Moved Away	Metal Object Moved Away from the Sensor	0	Inactive	Compliant

H. *MPX 5010 Sensor Testing*

Before being integrated into the body harness system, the MPX5010 pressure sensor was tested separately to evaluate its response to pressure changes. The test was conducted by applying gradual pressure variations from no pressure to the sensor's maximum pressure, with readings taken by Arduino Uno in kilopascals (kPa). The test results in Table 5 show that the sensor is able to respond to pressure changes gradually and stably, with values increasing as the pressure increases. Based on all test data, the MPX5010 sensor shows a success rate of 100% and is declared suitable for use in body harness monitoring systems, as shown in Table III.

TABLE III
MPX 5010 SENSOR TEST RESULTS

No	Pressure Condition	Measured Pressure (kPa)	Pressure Variation	Remarks
1	No Pressure	0,07	—	Initial Condition
2	Light Pressure	0,23	Increasing	Good Response
3	Light Pressure	0,27	Stable	Consistent
4	Moderate Pressure	1,3	Increasing	Good Response
5	Moderate Pressure	1,9	Stable	Consistent
6	High Pressure	2,9	Increasing	Good Response
7	High Pressure	3,5	Stable	Consistent
8	Very High Pressure	4,71	Increasing	High Response
9	Very High Pressure	5,91	Significant Increase	Extreme Response
10	Maximum Threshold	6,7	Maximum Increase	Sensor Threshold

IV. RESULTS AND ANALYSIS

A. Body Harness Test Dataset Results

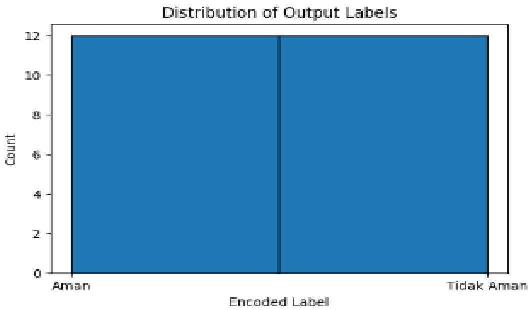

Figure 5. Machine Learning Dataset Visualization

The figure 5 shows a visualization of the dataset distribution used in the Decision Tree algorithm formation process in the body harness monitoring system. The dataset consists of a combination of proximity sensor and MPX5010 pressure sensor values labeled into two classes, namely safe and unsafe. This visualization provides an initial overview of the data characteristics, where the amount of data in both classes is relatively balanced, thereby reducing potential bias in the Decision Tree classification process.

The research dataset is shown in Table IV, which contains proximity and pressure (kPa) feature values along with their class labels. The data is arranged based on predetermined work condition scenarios and entered into the system as training and test data. This labeled dataset is used to evaluate the Decision Tree algorithm's ability to objectively determine the safety conditions of body harness installation.

TABLE IV
BODY HARNESS SAFETY SYSTEM TEST RESULTS DATASET

No	Proximity	Pressure (kPa)	Label
1	1	0,85	Safe
2	1	1,5	Safe
3	1	2,2	Safe
4	1	1,32	Safe
5	1	0,8	Safe
6	1	2,8	Safe
7	1	3	Safe
8	1	3,5	Safe
9	1	0,2	Safe
10	1	0,7	Safe
11	1	2,65	Safe
12	1	3,35	Safe
13	0	2,8	Unsafe
14	0	3,5	Unsafe
15	1	5	Unsafe
16	0	6,2	Unsafe
17	1	5,5	Unsafe
18	1	3,7	Unsafe
19	0	8	Unsafe
20	0	9	Unsafe
21	1	5	Unsafe
22	0	6	Unsafe
23	1	5,1	Unsafe
24	0	4,5	Unsafe

Based on the test results dataset and the Decision Tree algorithm learning process, a decision tree structure was obtained which shows that the MPX5010 pressure sensor is the main parameter in determining the safety condition of the body harness. The learning results set a pressure threshold value of 3.425 kPa as the risk condition limit. Pressure exceeding this threshold is immediately classified as an Unsafe condition because it indicates excessive tensile force on the harness straps, as shown in Fig. 6.

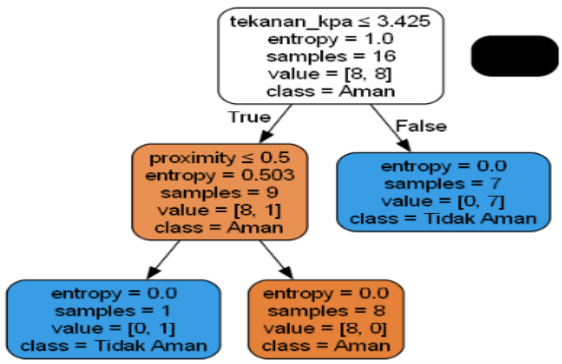

Figure 6. Decision Tree

Under pressure conditions that are still within safe limits, the system performs further evaluation using proximity sensors to verify the hook's attachment to the anchor point. If the hook is not detected, the condition is still classified as Unsafe, even if the pressure value is normal. Conversely, if the pressure is within safe limits and the hook is detected, the system sets the condition to Safe. These results show that the pressure sensor acts as an early indicator of an emergency condition, while the proximity sensor serves to validate the harness attachment, so that the combination of the two enables accurate real-time decision making.

B. *Actual Test Results*

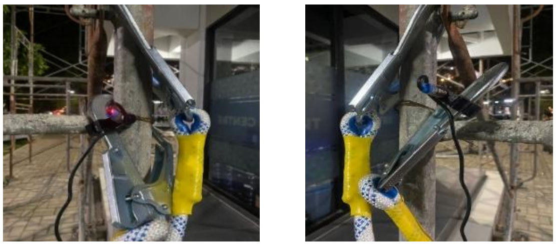

Figure 7. Safe and Unsafe Hook Positions

The Figure 7 shows a comparison between safe and unsafe hook installation conditions. In safe conditions, the hook is correctly installed on the anchor point so that the proximity sensor successfully detects the presence of the hook, as indicated by the indicator light turning on and the sensor output value of 1, which is classified as safe. Conversely, in the unsafe condition, the hook is only clamped onto the scaffolding pipe and is not properly attached to the anchor point, so that the proximity sensor cannot identify the hook. This condition is indicated by the indicator light not turning on and a sensor output value of 0, which indicates an unsafe condition. In this situation, the system automatically activates the GSM module to send an emergency call as a safety warning.

Figure 8. Safe and Unsafe Buckle Strap Positions

The image 8 shows the readings from the MPX5010 pressure sensor on the body harness strap in safe and unsafe conditions. Under normal use, the detected pressure value is below the system threshold, so it is classified as a safe condition and the system does not activate an emergency warning. Conversely, under conditions of excessive pressure, the measured pressure value exceeds the specified threshold and is therefore classified as unsafe. In this condition, the system automatically activates the GSM module to make an emergency call as a safety warning. The Table V presents the results of system testing based on a combination of proximity sensor and MPX5010 pressure sensor readings under various conditions of use.

TABLE V
SYSTEM TEST RESULTS BASED ON USAGE

No	Fiture		Prediction		Actual
	Proximity	Mpx 5010	Safe	Unsafe	
1	1	0,25	✓		Safe
2	1	3,7		×	Unsafe
3	1	3,65		×	Unsafe
4	1	1,14	✓		Safe
5	1	4,7		×	Unsafe
6	1	0,17	✓		Safe
7	1	1,09	✓		Safe
8	1	1,23	✓		Safe
9	1	1,34	✓		Safe
10	1	1,4	✓		Safe
11	1	1,82	✓		Safe
12	1	2,13	✓		Safe
13	1	1,22	✓		Safe
14	0	2,68		×	Unsafe
15	0	3,12		×	Unsafe
16	0	1,8		×	Unsafe
17	0	5,7		×	Unsafe
18	0	1,51		×	Unsafe
19	0	0,58		×	Unsafe
20	0	0,68		×	Unsafe

Data readings from the proximity sensor and MPX5010 pressure sensor are processed using a Decision Tree algorithm to determine the safety conditions for body harness installation. The proximity sensor functions as an initial check to detect the presence of a hook at the anchor point. If the proximity sensor value is 0, indicating that the hook is not detected, the system immediately classifies the condition as Unsafe because the harness is not properly connected and could potentially cause an accident. If the hook is detected (proximity value is 1), the system then evaluates the pressure value from the MPX5010 sensor. Pressure at or below the threshold of 3.425 kPa is classified as Safe, while pressure exceeding this threshold is categorized as Unsafe because it indicates excessive tension due to hazardous conditions.

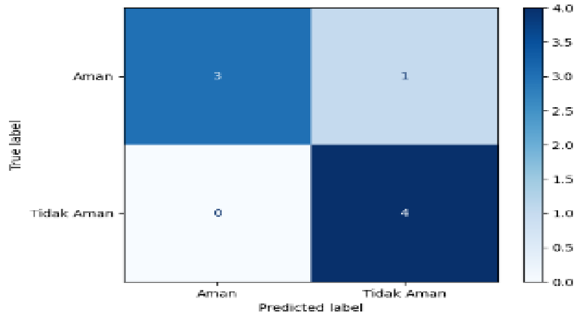

Figure 9. Confusion Matrix

Test results show (Figure 9) that the system is capable of classifying body harness attachment conditions consistently and in accordance with actual conditions in the field. The combination of a proximity sensor to detect hook attachment and an MPX5010 pressure sensor to indicate excessive tension enables the system to make automatic, real-time work safety decisions. System performance was evaluated using a confusion matrix, which showed that all unsafe conditions were successfully detected without any false negatives. The test data yielded an accuracy rate of 88%, indicating that most conditions were classified correctly. Although there was one misclassification in a safe condition, the system still prioritized safety by minimizing the risk of failure to detect dangerous conditions.

IV. CONCLUSION

Based on the results of the design, implementation, and testing, the safety harness system based on inductive proximity sensors and MPX5010 pressure sensors functioned according to the research objectives. Separate tests showed that the proximity sensors were able to detect the attachment of the hook to the anchor point with 100% success, while the MPX5010 pressure sensors provided a consistent response to pressure changes with 100% success. The application of the Decision Tree algorithm in the classification process resulted in an accuracy rate of 88% in determining the condition of the body harness attachment into the Safe and Unsafe categories. The integration of both sensors with the classification algorithm allows the system to operate in real-time and provide early warnings through a misscall mechanism, proving the system to be effective in improving work safety at heights.

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