Automatic Wire Length Measurement Using Webcam in Wiring Harness Production

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Measuring excess cable length in wire harness production is typically done manually using measuring tools, which can lead to measurement errors, longer inspection times, and inconsistent results. This study aims to develop an automated cable length measurement system using a webcam and computer vision technology. The system is designed to detect the cable's position, calculate the distance in pixels, and convert it to millimeters through a calibration process. The research methods include image acquisition, image processing, and performance evaluation using accuracy and error analysis. Experimental results on 20 cable samples showed an average error of 1,28% and an accuracy of 98,72% compared to manual measurements. These findings indicate that the proposed system can provide fast, accurate, and consistent measurements, making it a practical solution for improving the efficiency of quality control in the cable harness production process.

Keywords: Measuring excess, Wire harness, Cable length.

I. INTRODUCTION

WIRING HARNESS plays a vital role in automotive electrical systems by distributing electrical current and signals between various electronic components. The quality of the wiring harness assembly process directly affects vehicle performance, safety, and reliability. One of the common quality issues encountered during production is excess wire, where the cable length exceeds the specified requirement. This condition may complicate cable routing, increase assembly time, reduce production efficiency, and affect the quality of the final product. Currently, excess wire measurement is still performed manually using measuring tools and visual inspection. Although widely applied in industry, this method is prone to human error, inconsistent measurement results, low repeatability, and long inspection times, indicating the need for a more reliable and efficient measurement approach.

A wire is an electrical conductor used to transmit electrical power and signals between components in an automotive wiring harness. In automotive applications, wires generally consist of a copper conductor covered by an insulating material that provides electrical protection and mechanical durability. Wire characteristics such as conductor size, insulation thickness, flexibility, and heat resistance are selected according to the electrical and environmental requirements of the vehicle. In this study, several low-voltage automotive wire types were used as test samples, including AVSS, AVSSC, AVSSH, HDAV, and AESSX. These wire types differ in insulation thickness, flexibility, and heat resistance but serve the same function as electrical conductors. Since this research focuses on measuring excess wire length, the differences in wire type are not analyzed further and are only used to evaluate the performance of the proposed measurement system.

TABLE 1. WIRE TYPE

Wire Type	Description	Characteristic
AVSS (Auto Vinyl Super Thin Type)	Super Thin Vinyl Wire	Thin Insulation
AVSSC (Auto Vinyl Super Thin Type Flexible)	Flexible Super Thin Vinyl Wire	High Flexibelity
AVSSH (Auto Vinyl Super Thin Type Heat Resistant)	Heat-Resistant Wire	Heat Resistant
HDAV (Thicker skin Auto Mobil Vinyl)	Thick Vinyl Wire	Thick Insulation
AESSX	Automative Electrical Wire	Label-based size identification

The objective of this study is to evaluate the performance of the proposed measurement system by comparing the automatic measurement results with manual measurements using error and accuracy analysis. Furthermore, Fishbone Diagram and Failure Mode and Effects Analysis (FMEA) are applied to identify the factors affecting system performance and determine improvement priorities. The proposed system is expected to improve measurement consistency, reduce manual inspection errors, increase production efficiency, and provide a practical computer vision solution for quality control in wiring harness manufacturing.

II. METHOD

To analyze a process that occurs in a system, a flowchart is needed to support the workflow to be carried out, and help in understanding, designing, and communicating work procedures properly and correctly.

A. Process Flow

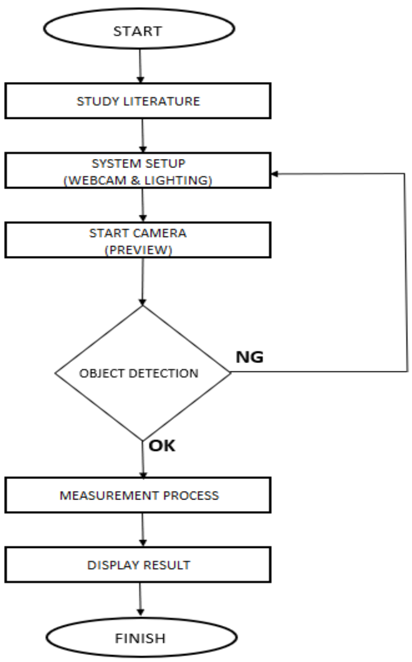

Figure 1. Flow chart

The research process begins with a literature study to understand the concepts of computer vision, digital image processing, and previous studies related to automatic measurement systems. The information obtained from the literature serves as the foundation for designing the proposed measurement system. After the literature review, the hardware configuration is prepared by setting up the webcam, tripod, lighting conditions, and measurement area. Proper camera positioning and stable illumination are essential to ensure consistent image quality throughout the measurement process. The webcam is then activated to provide a live preview, allowing the operator to verify that the object is correctly positioned within the camera's field of view. Once the setup is confirmed, an image of the wiring harness is captured and used as the input for the measurement system. The captured image undergoes an image processing stage to improve object visibility and prepare the image for analysis. Subsequently, the system detects the reference objects, namely the spot tape and marking points, which are used as measurement references. After these reference points are identified, the distance between them is calculated in pixel units. To obtain the actual measurement, the pixel distance is converted into millimeters using a predefined calibration factor. Finally, the measurement result is displayed on the user interface, enabling operators to obtain the excess wire length automatically. The process is then completed, and the system is ready to perform the next measurement.

B. Methode Fishbone

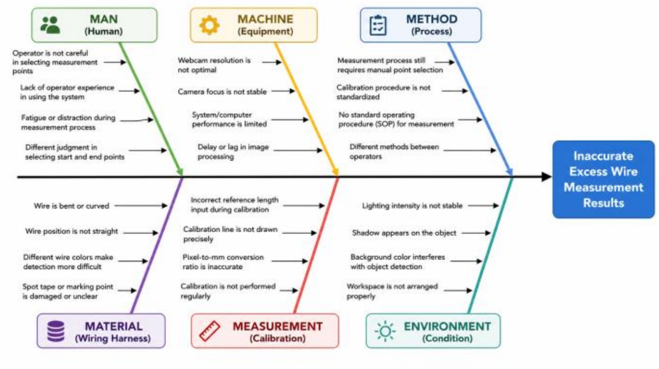

Figure 2. Fishbone Diagram

Fishbone Diagram was employed to identify the root causes affecting the accuracy of excess wire measurement in the proposed computer vision-based measurement system. The analysis categorized potential causes into six main factors, namely Man**,** Machine**,** Method**,** Material**,** Measurement**, and** Environment**.** Human-related factors include operator inexperience, inaccurate selection of measurement points, and inconsistency during the measurement process. Machine-related factors involve webcam resolution, camera focus stability, computer performance, and image processing delays. Method-related factors include the absence of standardized operating procedures, non-standardized calibration procedures, and variations in measurement practices among operators.

In addition, material-related factors such as bent wires, unclear spot tape or marking points, and different wire colors may reduce object detection performance. Measurement-related factors are associated with calibration inaccuracies, including incorrect reference length input and pixel-to-millimeter conversion errors. Environmental factors, including unstable lighting intensity, shadows, background interference, and workspace arrangement, also influence image quality and measurement consistency. The Fishbone analysis indicates that lighting conditions, calibration accuracy, and object positioning are the dominant factors affecting measurement performance, providing the basis for further risk prioritization using Failure Mode and Effects Analysis (FMEA)

C. Methode FMEA

Failure Mode and Effects Analysis (FMEA) was conducted to evaluate the potential failure modes that may affect the accuracy of the proposed excess wire measurement system. Each identified failure mode was assessed based on three evaluation parameters, namely Severity (S), Occurrence (O), and Detection (D). The Risk Priority Number (RPN) was then calculated by multiplying these three parameters (RPN = S × O × D). The resulting RPN values were used to determine the priority level of each failure mode and to identify areas requiring corrective actions.

The FMEA results indicate that several factors have a significant impact on measurement accuracy. Among the identified failure modes, unstable lighting conditions obtained the highest RPN value, indicating that variations in illumination greatly influence image quality and the system's ability to detect the reference points accurately. Other high-priority failure modes include incorrect calibration, camera focus instability, and unclear spot tape or marking points, which can reduce measurement consistency and increase the possibility of inaccurate results.

Based on the FMEA analysis, improvement efforts should be focused on the failure modes with the highest RPN values. Recommended corrective actions include providing stable and uniform lighting, implementing a standardized calibration procedure, ensuring proper camera positioning and focus before image acquisition, and maintaining the quality of spot tape and marking points. These improvements are expected to minimize measurement errors, enhance system reliability, and improve the overall performance of the automatic excess wire measurement system.

The explanation of S, O, D, and RPN is as follows:

1. (S) as the symbol for Severity. Severity assesses how severe the impact would be if a Failure Mode occurred (For example: safety, major malfunction, product damage). The S value focuses on consequences rather than how often or how easily they are detected. The higher the S value, the higher the priority of mitigation actions for that failure.

TABLE 2. FMEA SEVERITY INDIKATOR

Impact	Detailed Explanation Impact	Rank
Extremly Hazard	Measurement errors result in incorrect wire tuning decisions and may cause major product redesign	10
Critical	Measurement results are highly inaccurate, making the data unusable for analysis	9
Major	Measurement errors lead to incorrect wire tuning decisions and require extensive rework	8
Significant	Inconsistent measurement results significantly affect excess wire analysis.	7
Moderate	Measurement errors require repeated measurements on several samples.	6
Medium	System accuracy decreases but measurements can still be verified manually.	5
Low	Minor measurement deviations occur without affecting wire tuning decisions.	4
Minor	Errors affect only a small portion of the measurement data.	3
Very Minor	Errors have almost no impact on the research results	2
Negligible	No impact on measurement results or analysis	1

2. (O) as a symbol for Occurance. (O) is the symbol for Occurrence in the FMEA (Failure Mode and Effect Analysis) method. Occurrence is used to assess the likelihood of a cause of failure occurring in the production process. The Occurrence value describes: 1. How likely is it that failure will recur 2. Based on historical data, field statistics, and current process control performance Key principles of AIAG–VDA: Occurrence does not assess the failure mode itself, but rather assesses the frequency of the cause that triggers the failure mode. The more often a cause occurs under the current control conditions, the higher the Occurrence value assigned.

TABLE 3. FMEA OCCURANCES RATING SCALE

Frequency of Occurance	Occurance Criteria	Rank
Very Frequent	Failure occurs in almost every measurement process (>90%).	10
Very High	Failure occurs in most measurement processes (80– 90%)	9
High	Failure occurs frequently during measurements (70– 80%)	8
Moderately High	Failure occurs regularly during measurements (60– 70%)	7
Moderate	Failure occurs in approximately half of the measurements (40–60%)samples.	6
Medium	Failure occasionally occurs during measurements (30–40%)	5
Low	Failure rarely occurs (20–30%)wire tuning decisions.	4
Very Low	Failure occurs only occasionally (10–20%)	3
Almost Never	Failure is unlikely to occur (<10%)	2
Never	Failure is practically never observed during testing	1

3. (D) as symbol for Detection. (D) is the symbol for Detection in the FMEA (Failure Mode and Effect Analysis) method. Detection measures the ability of existing controls to detect causes or failures before their effects reach the customer. Based on the results of root cause identification using a Fishbone diagram, a Failure Mode and Effects Analysis (FMEA) was then conducted to evaluate the risk level of each potential failure that occurred in the excess wire measurement process.

TABLE 4. DETECTION CAPABILITY

Detection Capability	Detection Capability Criteria	Rank
Extremly Difficult	Measurement errors cannot be detected before being used in the analysis.	10
Very Difficult	Errors are only discovered after significant discrepancies appear	9
Highly Limited	Errors require detailed manual inspection to be identified	8
Limited	Errors can occasionally be detected through visual inspection	7
Moderately Difficult	Errors can be identified only after manual verification	6
Medium	Most errors can be detected through data comparison	5
Fairly Easy	The system provides indicators that help identify errors	4
Easy	Most errors are immediately visible during testing	3
Very Easy	Errors can be detected quickly through system validation.	2
Certain Detection	All errors can be detected before the measurement data is used.	1

D. Camera Image Processing

1. Hardware setup

This analysis method helps identify critical problems in the measurement process and supports the improvement of system performance during implementation.

Figure 3. Webcam setup

Image acquisition and processing process using a webcam during the excess wire measurement process. The webcam captures the image of the wire, spot tape, and marking point in real time. The captured image is then processed to identify the object position and calculate the measurement distance automatically. This process supports a more consistent and efficient measurement process compared to manual measurement methods.

2. Software Interface

The measurement system acquires real-time images using a webcam and processes them to detect the designated measurement points. Based on the detected points, the system automatically calculates and displays the wire length. The application interface is intentionally designed to be simple and intuitive, enabling operators to perform measurements efficiently with minimal user interaction.

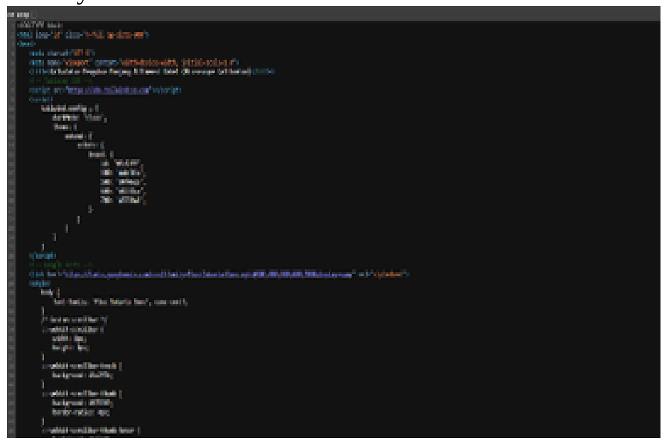

Figure 4. Coding of System

The system will show the measurement results immediately after the object detection process is successfully completed. This approach improves measurement consistency, reduces the possibility of human error associated with manual calculations, and supports a more efficient inspection process in wiring harness production.

3. Algorithm System

Algorithm 1 describes the workflow of the automatic wire length measurement system developed in this research. The algorithm explains the sequence of processes executed by the system, starting from camera initialization until the measurement result is displayed. The objective of the algorithm is to ensure that every measurement is performed under controlled conditions to improve accuracy and consistency

Algorithm 1 Automatic Wire Length Measurement Using Webcam

input: wiring harness object, webcam, lighting setup, calibration object with known length L_{cal}
initialize webcam and camera parameters
configure system setup (camera position and lighting)
start camera preview
while object is not detected **do**
    adjust camera position or lighting
    restart camera preview
end while
capture image
select measurement points P_1 and P_2
read pixel coordinates (x_1, y_1) and (x_2, y_2)
compute pixel distance $d_{px} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$
convert pixel distance to millimeter $L_{mm} = \frac{d_{px}}{k}$
display measurement result
output: wire length L_{mm} (mm)

Figure 5. Algorithm System

The algorithm begins by receiving the required inputs, namely the wiring harness object, a webcam as the image acquisition device, a controlled lighting setup, and a calibration factor obtained from a reference object with a known length. The calibration factor is essential because the captured image is represented in pixels, while the desired measurement result must be expressed in millimeters. In the initialization stage, the webcam and camera parameters are activated so that the camera can capture images continuously.

III. RESULT AND DISCUSSION

A. Measurement Result Comparison

The measurement system was tested using 20 wiring harness samples with different cable lengths and wire colors. The purpose of this testing was to evaluate the performance and accuracy of the computer vision-based measurement system by comparing the automatic measurement results with manual measurements performed using a manual measurement.

TABLE 4. MEASUREMENT RESULT COMPARISON

No.	Wire Type	Wire colour	Wire Size (mm)	Manual Measurement (mm)	Automatic Measurement (mm)	Difference (mm)	Error (%)
1.	AVSS	V	0,30	145	143	2	1,38
2.	AVSS	W	0,30	160	158	2	1,25
3.	AVSS	W-B	0,30	170	173	3	1,76
4.	AVSS	B-Y	0,30	168	170	2	1,19
5.	AVSS	B-W	0,30	169	170	1	0,59
6.	AVSS	R-G	0,30	190	193	3	1,58
7.	AVSS	R	0,30	155	157	2	1,29
8.	AVSS	G	0,30	144	147	3	2,08
9.	AVSS	R	0,30	172	170	2	1,16
10.	AVSS	B	0,30	177	178	1	0,56
11.	AVSS	L	0,30	156	155	1	0,64
12.	AVSS	G	0,30	140	142	2	1,43
13.	AVSS	GR	0,30	138	139	1	0,72
14.	AVSS	W	0,30	150	153	3	2,00
15.	AVSS	Y	0,30	159	162	3	1,89
16.	AVSS	B	0,30	165	166	1	0,61
17.	AVSS	G	0,30	170	168	2	1,18
18.	AVSS	GR	0,30	164	162	2	1,22
19.	AVSS	W	0,30	133	136	3	2,26
20.	AVSS	R	0,30	131	132	1	0,76

Remarks :
1. V = Violet
2. W = White
3. W-B = White-Back
4. B-Y = Black-Yelow
5. B-W = Black-White
6. R-G = Red-Green
7. R = Red
8. G = Green
9. B = Black
10. L = Blue
11. GR = Grey
12. Y = Yellow

B. Error Calculation

The measurement error was calculated by comparing the automatic measurement results with manual measurements used as reference values.

The percentage error was calculated using :

$$Error\ (\%) = \frac{|Manual - Automatic|}{Manual} \text{ x } 100 \qquad (1)$$

For **example**, Sample No. 1 :
Manual Measurement = 145 mm
Automatic Measurement = 143 mm

$$Error\ (\%) = \frac{|145 - 143|}{145} \text{ x } 100 = 1{,}38\%$$

The same calculation was applied to all measurement samples.

C. Average Error Analysis

The average error of the system was calculated by summing all individual measurement errors and dividing the result by the total number of samples.
The average error equation is shown in Equation :

$$Average\ Error = \frac{\sum Error}{n} \qquad (2)$$

where:

- ΣError = total measurement error
- n = number of samples

$$\sum Error = 1{,}38 + 1{,}25 + 1{,}76 + \ldots + 0{,}76$$
$$\sum Error = 25{,}55$$

$$Average\ Error = \frac{25{,}5}{20}$$
$$Average\ Error = 1{,}277 = 1{,}28\%$$

D. Accuracy Analysis

System accuracy was determined using the inverse relationship between measurement error and measurement accuracy.

The accuracy equation is presented in Equation :

$$Accuracy = 100\% - Average\ Error \qquad (3)$$

Substituting the calculated average error:

$$Accuracy = 100\% - 1{,}28$$
$$Accuracy = 98{,}72\%$$

Therefore, the developed computer vision measurement system achieved an accuracy of approximately 98,72%. This result indicates that the automatic measurement system produces measurements that are highly consistent with manual measurements and can be considered reliable for excess wire inspection applications.

Based on the testing results, the computer vision-based measurement system demonstrated several advantages compared to conventional manual measurement methods. The developed system achieved an accuracy of 98,72% with an average error of only 1,28%, indicating a high level of consistency with manual measurements.Manual measurements are highly dependent on operator skill, reading accuracy, and measurement consistency. In contrast, the computer vision system utilizes image processing algorithms and calibrated pixel-to-millimeter conversion, reducing the influence of human error.In addition, the developed system provides faster measurement results, better repeatability, and digital data storage capability, making it more suitable for quality inspection processes in manufacturing environments.

Future research should improve both the hardware and software of the proposed excess wire measurement system to enhance its accuracy and reliability. Using a higher-resolution camera and standardized lighting can improve image quality and reduce illumination effects. Furthermore, automatic detection of measurement points can eliminate manual selection, improving both efficiency and consistency.

IV. CONCLUSION

This study successfully designed and implemented an excess wire measurement system based on Computer Vision using Webcam. By utilizing a webcam and conversion method, the system is able to measure excess wire length automatically from captured images, providing a faster and more efficient alternative to conventional manual measurements. The developed application can accurately identify the start and end points of the wire, enabling consistent digital measurement to support the wiring harness inspection process.

Furthermore, the Fishbone analysis identified that measurement accuracy is influenced by several factors, including human, machine, method, material, measurement, and environmental aspects. The FMEA results indicate that unstable lighting, poor image quality, and object displacement during image acquisition are the most critical risks affecting system performance. Therefore, improvements should prioritize controlling these factors to enhance measurement reliability. Overall, the proposed computer vision-based system demonstrates good potential to improve the effectiveness, consistency, and accuracy of excess wire measurement while minimizing human error in industrial inspection processes.

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