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Design and Implementation of a Low-Cost Quality Control System for Card Clothing (Carding Rope/Wire)

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***Abstract*— Quality control of card clothing (carding rope/wire) is a critical requirement in textile industries, as uneven tooth height directly affects fiber alignment and sliver quality. Conventional inspection systems are mainly manual lacks consistency, accuracy and reliability. And modern inspection systems are largely vision-based, which are very expensive, complex, and difficult to maintain for small/medium-scale industries. This paper presents the design and implementation of a low-cost, contact-based, closed-loop quality control system for real-time monitoring of card clothing tooth height. The proposed system uses a Bluetooth-enabled dial gauge for displacement measurement, specially designed & developed gauge mounting fixture/mechanism for tooth projection pick up. The system is integrated with a PLC and HMI for continuous monitoring, alarm generation, and machine interlocking. The system ensures that production is machine is stopped when measured values exceed predefined tolerance limits and prevents restart until the acceptable limit is restored. Experimental implementation on an actual production line demonstrates the reliable & real-time performance, improved quality assurance, and significant cost reduction compared to vision-based solutions.**

***Index Terms*— Card clothing, Quality control, Dial gauge, PLC, HMI, Closed-loop monitoring, Textile automation.**

I. INTRODUCTION

Carding is a fundamental process in textile manufacturing, where fibres are disentangled, cleaned, and aligned using carding machines equipped with metallic card clothing wires [1]. There are various parameters associated with card clothing wires like pitch, teeth angle and the height of teeth affecting fibre quality. However, the most significant and dominant parameter is tooth height uniformity, it plays a crucial role in determining the quality of the produced sliver. Even minor deviations in tooth height can result in uneven fibre processing, reduced yarn quality, and increased waste. Traditional inspection methods are either manual or based on camera and vision systems [2,3]. Manual inspection lacks consistency and traceability, while vision-based systems involve high capital cost, complex image processing algorithms, and frequent maintenance requirements. These limitations create a need for a simple, affordable, and reliable quality monitoring solution [4] suitable for continuous industrial operation.

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This work focuses on developing a low-cost, real-time quality control system capable of measuring the vertical displacement/projection [5,3] of each tooth on the carding rope and enabling automatic machine interlocking [6] whenever deviations exceed acceptable limits.
Note: The research and references for the said application and work are very limited. And this is the first kind of implementation for such application (Problem Statement), along with quality assurance it is greatly advantageous to industries in terms of cost-reliability and other long-term benefits [7].

A. Problem identification

Uneven tooth height in card clothing wires significantly affects sliver quality and machine efficiency. Existing quality control System is fully manual and fail to provide continuous and real-time measurement across the entire length of the wire rope. In existing method, wire rope is unwounded from one drum and winded in other drum through motorized mechanism. This process varies from 2 hours to 8 hours; it is batch process. During this transfer process, after every 15 minutes machine is stopped for nearly 10 to 15 minutes for quality inspection and available part (Approx. 1 mtr) is inspected manually with scale, vernier and gauges. So, for 2-hour batch, there are only 8 inspections and only 8 mtr wire rope is checked. However, large amount of wire remains unchecked, this is the most concerning as well as alarming issue for quality assurance. Quantitative Calculations for one such batch are as under, product look like this,

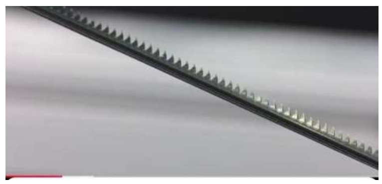

Figure 1: Carding Wire (Actual photograph)

For Batch of 2 Hour, consider line speed 6 meters/minutes with tooth pitch 5 mm. So, total length of wire and total number of teeth are as calculated below,
Total Length: 6 X 60 X 2 = 720 mtrs = 720000 mm
Total Teeth: 720000/5 = 144000
It is very evident from above calculations that with manual inspection, teeth across the length of only 8 mtrs (Total Teeth 1600 max) being checked and balance rope 712 mtrs (Total Teeth 142400) remained unchecked.
To take care of this above issue and to check/inspect the 100% wire rope, the system is designed using instruments and sensors.
Objectives
The primary objectives of this project are:

- To develop a closed-loop quality monitoring system for card clothing wires.
- To provide real-time measurement of tooth height using a low-cost contact-based sensor.
- To enable operator-programmable setpoints and tolerance limits.
- To implement automatic machine stopping when limits are exceeds.
- To ensure machine restart is permitted only after values return within acceptable range.
- To generate/record batch-wise quality records with specific interval (Generally 5 to 10 minutes interval acceptable) for process capability analysis (Cp and Cpk).

B. Geometry of the product

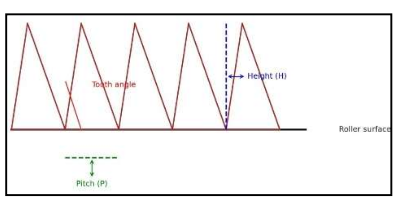

Figure 2: Teeth Structure

OPERATION:
Normally, line speed varies from 2 meters/minutes to 10 meters/minutes.
Normally, product height varies from 2mm to 10.5 mm

Normally, Pitch varies from 3 mm to 12 mm.
Consider following example for teeth calculations,
It was also considered in above problem identification, now it is explained in view of system design and development,
Line Speed = 6 mitres/Min,
= 6000mm/min
= 6000/60 = 100mm/sec
Pitch = 5 mm.
Teeth Calculation per second): Line Speed/Pitch = 100/5 = 20 teeth/sec.
So, the above results are demanding high speed measurement and decision making.
As per our system design, we can handle/measure maximum 20 teeth per second with maximum sampling time of 50 mS. All the practical combinations for above parameter ranges covered under this sampling rate.

II. System architecture

The proposed system consists of a Bluetooth-based dial gauge for measuring vertical displacement/projection, a PLC for decision-making and interlocking logic, and an HMI for local visualization (Dashboard). The dial gauge transmits measurement data to a gauge controller, which communicates with the PLC via RS485 serial communication. The PLC continuously compares real-time values with predefined limits and controls machine operation accordingly.
Note: Most important part of the system is the use of industrial digital dial gauge. Manufacturer has track record of providing these gauges to industries from more than 25 years. They issue calibration certificate with validity of one year from the date of use. Excellent accuracy (3 microns), least count (1 micron) and repeatability (1.2 microns) give more values to the measurements.
For scalability, the local PLC is capable of communicating with a master PLC over TCP/IP, enabling centralized monitoring through a LAN/WAN-based dashboard and connecting to reporting server.

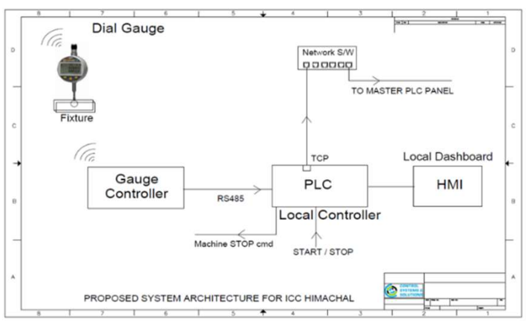

Figure 3: System Architecture

D. Phase wise Implementation

PHASE 1- Design and development of the system
Involved the development of a prototype of closed-loop monitoring system and validation of communication between the dial gauge, PLC, and HMI.
Basic PLC panel and dial Set up communication testing

Figure 4: Basic PLC panel and dial Set up (Actual Photograph)

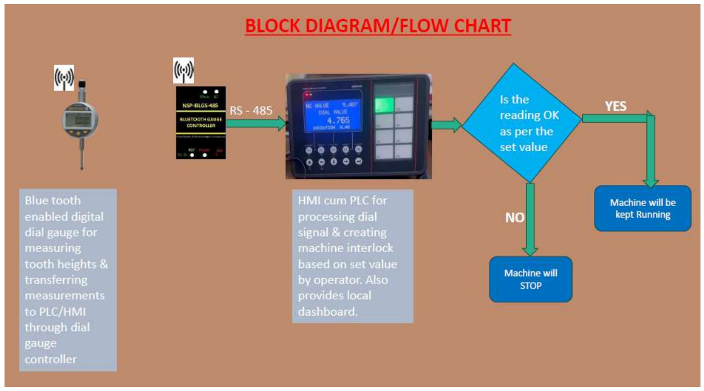

Figure 5: FLOW CHART (Block Diagram/Flow Chart for Log and Decision Making)

PHASE 2 - Functionality Checking and Validation

- A Bluetooth based dial gauge is used to measure the vertical displacement (height).
- The gauge controller collects this measurement data and sends the data to the PLC through RS485 communication (Serial Port).
- The PLC acts as the local controller. It continuously checks if the displacement is within the desired range set by the operator.
- The status is shown on the HMI (local dashboard), so the operator can clearly see the machine condition.
- If the measured value goes beyond the set value, the PLC automatically sends a STOP command to the machine.
- The machine will not restart until the displacement value comes back within the acceptable range.
- The local PLC can also communicate with the master PLC panel through TCP/IP for centralized monitoring via LAN/WAN.
- Machine/Station (VP-01) data is hooked up with master PLC and master PLC connected to reporting server for data recording.
- Sample auto-generated Data collection log/recording sheet as under.

TABLE I: AUTO-GENERATED DATA COLLECTION LOG/RECORDING SHEET OF MACHINE (VP-01)

Sr. No.	ICC Himachal Pradesh		VP-1	Report from 06-08-2025 – 18:30 HRS to 07-08-2025 – 19:40 HRS					
	Timestamp	Batch Number	DIAL_ VALUE	SET_ POINT	Minimum	Maximum	DEVIATION	NG_ VALUE	OK/NOK_ STATUS
1	13-08-2025 18:30	12345678	5.155	5.00	4.600	5.400	0.4	0	OK
2	13-08-2025 18:35	12345678	5.155	5.00	4.600	5.400	0.4	0	OK
3	13-08-2025 18:40	12345678	5.14	5.00	4.600	5.400	0.4	0	OK
4	13-08-2025 18:45	12345678	5.16	5.00	4.600	5.400	0.4	0	OK
5	13-08-2025 18:50	12345678	5.155	5.00	4.600	5.400	0.4	0	OK
6	13-08-2025 18:55	12345678	5.235	5.00	4.600	5.400	0.4	0	OK
7	13-08-2025 19:00	12345678	5.245	5.00	4.600	5.400	0.4	0	OK
8	13-08-2025 19:05	12345678	5.015	5.00	4.600	5.400	0.4	0	OK
9	13-08-2025 19:10	12345678	5.195	5.00	4.600	5.400	0.4	0	OK
10	13-08-2025 19:15	12345678	5.315	5.00	4.600	5.400	0.4	0	OK
11	13-08-2025 19:20	12345678	5.46	5.00	4.600	5.400	0.4	5.46	NOT OK
12	13-08-2025 19:25	12345678	5.155	5.00	4.600	5.400	0.4	0	OK
13	13-08-2025 19:30	12345678	5.155	5.00	4.600	5.400	0.4	0	OK
14	13-08-2025 19:35	12345678	4.45	5.00	4.600	5.400	0.4	4.45	NOT OK
15	13-08-2025 19:40	12345678	4.785	5.00	4.600	5.400	0.4	0	OK

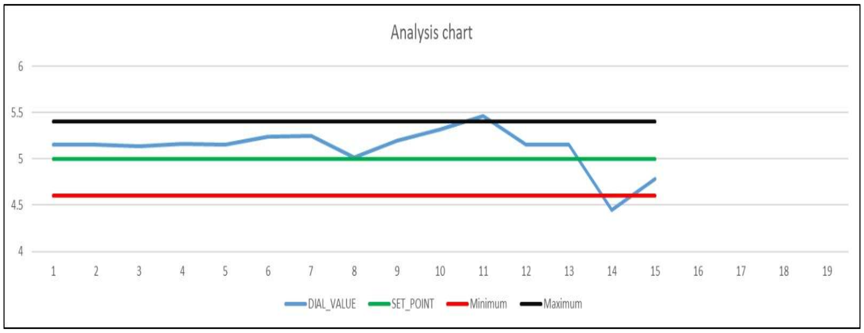

Figure 6: Analysis Graph chart

III. Research Gap and Comparison of Two Systems

TABLE II: RESEARCH GAP BETWEEN VISION BASED SYSTEM AND PROPOSED SYSTEM

Pointers	Vision Based System	Proposed System	Gap
Technology Used	Relies on camera-based monitoring and image-processing software. This requires high-resolution cameras, industrial PCs, and specialized vision algorithms, which makes it very expensive.	Uses direct dial gauge-based measurement of displacement and PLC/HMI-based control. This removes the need for high-cost cameras and complex software.	Present Vision based solution is *over-engineered* for the said requirement, whereas there is a lack of low-cost, direct measurement-based solutions.
Accuracy vs. Practical Need	Provides very high accuracy and detailed visualization of displacement, but at the cost of complexity and high expenses.	Provides sufficient accuracy for industrial operation through continuous real-time measurement and alarms, which is practically enough.	No focus on *cost-effectiveness, only focus on visualization & accuracy.*
Complexity & Maintenance	Needs regular calibration, software updates, lighting adjustments for cameras. Very trained and highly qualified staff for troubleshooting is required.	Simpler Dial-HMI-PLC integration with minimal maintenance and easy troubleshooting.	Vision based system needs heavy maintenance, while a simpler approach is missing.
Cost and Scalability	High initial/capital cost and higher running/maintenance cost. Not feasible for smaller plants or cost-sensitive applications.	Low-cost, easily replicable, and scalable to multiple machines.	Lack of affordable monitoring solutions for small/medium plants.

IV. Result and Discussions

The implemented system reliably detected out-of-range tooth heights and triggered immediate machine stoppages. Operators could monitor real-time displacement values on the HMI, while batch-wise data enables calculations of Cp and Cpk indices. The system proved effective for continuous/online quality monitoring with minimal maintenance requirements.

V. Conclusion

This paper presents a practical and low-cost solution for real-time quality control of card clothing wires in textile industries. Against the option of expensive vision-based systems, the proposed contact-based dial gauge integrated with PLC and HMI achieves reliable performance, improved quality assurance, and significant cost savings through capital investment (nearly 10 times lower). The system is scalable, easy to maintain, and well-suited for small and medium-scale textile manufacturing units, who do not afford to install vision based costly system.

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