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Simple and Accurate Instrumentation Device to Detect Loose-End Defective Cigarettes

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***Abstract*— Loose-end defect on the tip of the cigarette is a common problem found on production lines. Large companies use computerized sophisticated machines to detect and reject it automatically. However, the same solution can not be implemented in small or home industries because the investment cost is too high. This paper presents the development of simple electronic instrumentation to detect loose-end defects in cigarettes. It relies on the signal acquisition of a photoelectric transceiver mechanism that is converted and processed digitally to relatively quantify the difference between the good and defect. Motor-driven cigarette rotator device was built specially to test the performance of the instrumentation system. Loose-end defects are made artificially by removing 0.2 gr tobacco from the tip of a normal cigarette. The average quantifying relative value was found above 58.5%, this indicates that the system has good contrast properties. At the speed of 10,000 cigarettes/min, the average accuracy is 90.5%, and at 17,500 cigarettes/min, the average accuracy is 65.3%.**

***Index Terms*— cigarette quality; loose-end defective cigarette; photoelectric device.**

I. INTRODUCTION

The Indonesian cigarette industry has experienced significant growth over the past few decades [1], [2]. One of the factors contributing to this growth is the implementation of machine processes in the production of cigarettes [3]. These machines have revolutionized the way cigarettes are manufactured, providing numerous benefits to both the industry and consumers. However, one persistent issue that continues to plague the industry is the occurrence of loose-end defects [4]. This defect refers to the presence of unfinished or loose tobacco at the end of a cigarette, resulting in a subpar smoking experience for consumers. The loose-end defect can arise due to several reasons during the manufacturing process. Improper cutting of the tobacco, inadequate application of adhesive, or faulty machinery can all contribute to this defect. When a consumer lights a cigarette with a loose-end, they may experience a faster burn rate, uneven draw, and increased tobacco wastage. These issues not only affect the smoking experience but also lead to dissatisfaction among consumers. Smokers expect a consistent and enjoyable smoking experience from the cigarettes they purchase. The loose-end defect directly undermines this expectation. When a cigarette burns too quickly or unevenly, it affects the taste and overall satisfaction of the smoker. Consumers may also feel cheated as they are paying for tobacco that ends up being wasted due to loose-ends.

One way to tackle the loose-end defect is by implementing improved manufacturing techniques. Cigarette manufacturers can invest in state-of-the-art machinery that ensures precise and consistent packing of tobacco and paper. By using advanced automation and quality control measures [5], the likelihood of loose-ends can be significantly reduced. These techniques can help create cigarettes with tightly packed tobacco that stays intact throughout the smoking process. However, the same solution can not be implemented in small or home industries because the investment cost is too high. Loose-end defect detection based on photoelectric devices is a common method used in several patent sources [6]–[12]. A machine vision-based method for detecting the loose-end defect of a cigarette was also employed [13]–[15].

This paper presents the development of simple and low-cost electronic instrumentation to detect loose-end defects in cigarettes. It relies on a photoelectric infrared transmitter and phototransistor receiver. One of the key advantages of this photoelectric device is its simplicity and low cost. The phototransistor receiver is placed at the tip of the device and emits a beam of light. When a cigarette is inserted, the beam is interrupted. The microcontroller analyzes the interruption pattern to determine whether the cigarette has a loose-end defect. Motor-driven cigarette rotator device was built specially to test the performance of the proposed instrumentation system. There are two parameter qualifiers to indicate its performance: contrast properties of the measured signal and the accuracy of detection capability, both are normalized in percentage.

II. METHODS

A. *Hardware Block Diagram*

The instrumentation system mainly relies on infrared light transmission through the tip of the cigarette and its intensity was received by the photodiode to produce a small equivalent voltage. This voltage was amplified by a signal conditioner to a reasonable value before it was converted to a digital value and calculated by a microcontroller to relatively quantify the value of the good and defective cigarettes. Figure 1 shows the flow of signal on the main hardware of the instrumentation system.

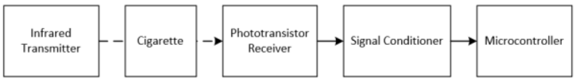

Figure 1. Main Hardware Block Diagram

B. *Photoelectric Components Arrangement*

Infrared transmitter and phototransistor receiver were placed at certain gaps to ensure physical non-contact with cigarettes so it can move freely between them. Figure 2 shows the arrangement of photoelectric components: infrared transmitter (1), cigarettes (3), and PT334-6B phototransistor receiver (2). It uses three infrared transmitters to improve light intensity reception on the receiver.

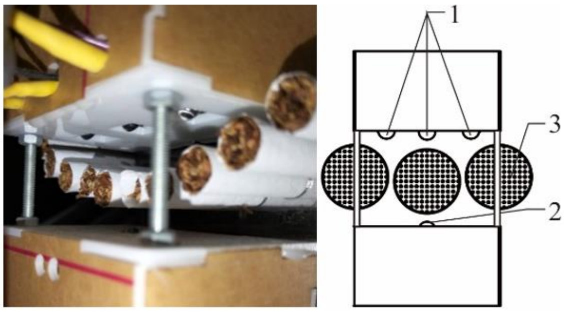

Figure 2. The Arrangement of Photoelectric Components

Figure 3 shows a single infrared transmitter based on High Power LED (HPL) with 3 Watts power consumption and emits a 940 nm wavelength of infrared light. These LED are designed to provide a higher output of infrared radiation compared to standard infrared LED. With advancements in technology, high power infrared LEDs have become more efficient, compact, and capable of emitting light in a narrower wavelength range.

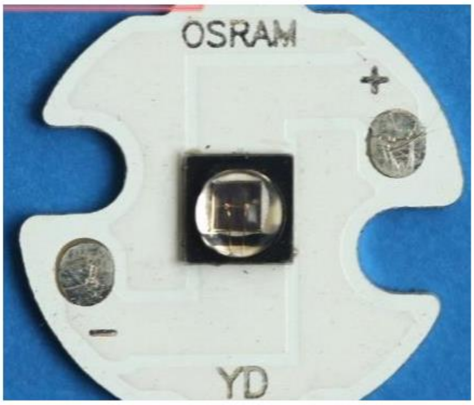

Figure 3. 3 Watts 940nm Infrared HPL

Figure 4 shows a typical 5mm generic phototransistor infrared receiver. Infrared phototransistors offer several advantages over other types of infrared detectors, such as infrared photodiodes. One of the key advantages is their ability to amplify the current, which allows for greater sensitivity and detection range. Another advantage is their response time. Infrared phototransistors can detect and amplify infrared light signals at a faster rate compared to other infrared detectors.

Figure 4. A Typical 5mm Infrared Phototransistor

C. *Signal Conditioner Circuit*

Figure 5 shows the electronic circuit for a signal conditioner that utilizes an operational amplifier as a non-inverting voltage amplifier with a gain of 3. The non-inverting amplifier is a type of operational amplifier (op-amp) configuration that amplifies an input signal while maintaining the same polarity. It is widely used due to its high input impedance, low output impedance, and excellent gain accuracy. The basic non-inverting amplifier circuit consists of an op-amp, two resistors, and an input and output terminal. The input signal is applied to the non-inverting terminal of the op-amp, while the inverting terminal is connected to ground. The output signal is taken from the junction between the resistor connected to the inverting terminal and the op-amp's output.

The non-inverting amplifier operates based on the principle of negative feedback. When an input signal is applied to the non-inverting terminal, the op-amp amplifies it and produces an output signal. This output signal is fed back to the inverting terminal through the resistor connected between the output and inverting terminal.

The feedback loop creates a voltage divider between the input and output resistors, which determines the gain of the amplifier. The gain of the non-inverting amplifier is given by the formula:

$$Gain(A) = 1 + \frac{R_F}{R_{in}} \qquad (1)$$

where R_F is the feedback resistor and R_{in} is the input resistor. The gain is always greater than 1, making the non-inverting amplifier an amplification device. The output voltage is connected to the Analog to Digital Converter (ADC) pin of a microcontroller. The analog voltage is then converted to an equivalent digital value to indicate infrared light intensity received by the phototransistor. The ADC is a 10-bit successive approximation type. It has a resolution of 1024, which means it can divide the input voltage range into 1024 discrete steps. The ADC operates based on the principle of comparing the input voltage with a known reference voltage. It generates a digital value proportional to the input voltage within the 0-1023 range.

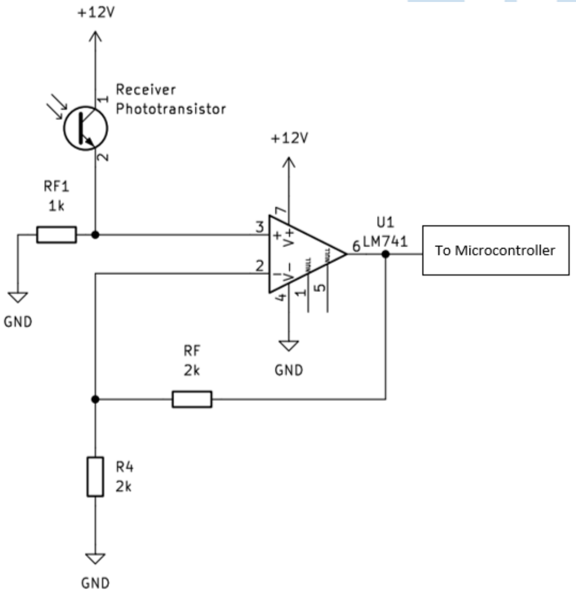

Figure 5. Non-inverting Amplifier Circuit Diagram

D. Mechanical Motor Driven Cigarette Rotator

A mechanical rotator device was specially built to test the performance of the instrumentation system. It can mount up to 50 cigarettes. The rotator is motor driven and its speed can be adjusted by a dedicated controller up to 17,500 cigarettes/min. Figure 6 shows the isometric view of the rotator and Figure 7 shows its side view, showing its motor and encoder. The mechanical rotator has built from five main parts: skid and frame (1), rotator wheel (2), human-machine interface (3), DC motor and speed controller (4), and encoder (5). Figure 8 shows the actual build of the mechanical rotator showing its cigarette wheel holder.

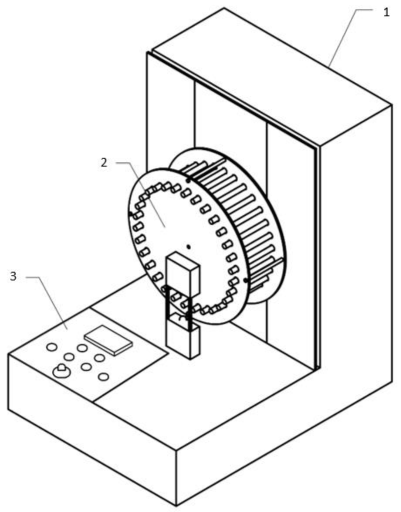

Figure 6. 3D Isometric View of Mechanical Cigarette Rotator

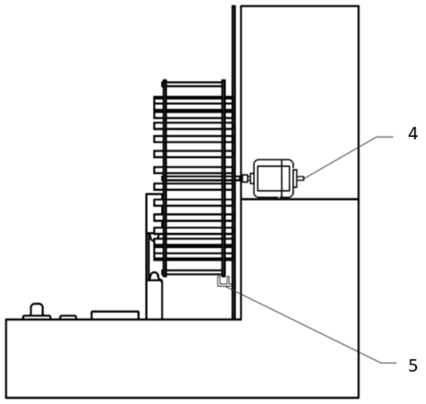

Figure 7. Side View of Mechanical Cigarette Rotator

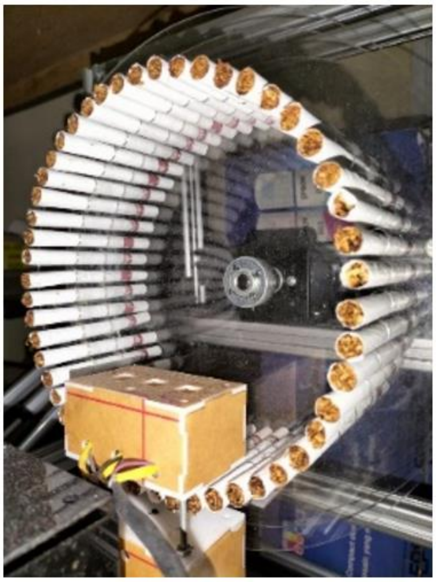

Figure 8. Actual Cigarette Rotator With Capacity of 50 Cigarettes

III. RESULTS AND DISCUSSION

The experiment was conducted to obtain two performance parameters of an instrumentation system that has been tested on simulated environment conditions using a mechanical rotator:

- Contrast properties of the measured signal

This parameter indicates a relative range of light intensity that is able to be received by the instrumentation system. A larger value is good, it means the system has a reasonable range to easily distinguish a normal cigarette from a defective cigarette.

- Accuracy of detection

This parameter indicates the system's ability to detect defective cigarettes. The test was conducted in two configurations: altering rotator speed and altering the amount of artificially loose-end defective cigarettes which are placed randomly on the rotator wheel.

The artificial loose-end defective cigarettes were made by removing 0.2 gr tobacco from the tip of a single normal cigarette as shown in Figure 9.

Figure 9. Normal and Artificially Loose-End Defective Cigarette

Figure 10 shows a series of digital values obtained from the calibration batch using a 40/50 configuration (40 normal cigarettes, 10 loose-end defective cigarettes, and 50 total cigarettes). This data is used to define a loose-end range of digital value and a range of normal cigarette's digital value. The relative difference between them is defined as the contrast properties of the measured signal and calculated using Equation 2.

Figure 11 shows the example of collected data from test batch 40/50 at a speed of 10,000 cigarettes/min, where the actual speed employed at the production level was around 8000 cigarettes/min. Figure 12 shows the data at a speed of 17,500 cigarettes/min. Actually, there are digital values greater than the upper limit of defined loose-end digital value. They were produced by light transmission through the gap between adjacent cigarettes on the mechanical rotator, as shown in Figure 13. Those values are excluded from the calculation.

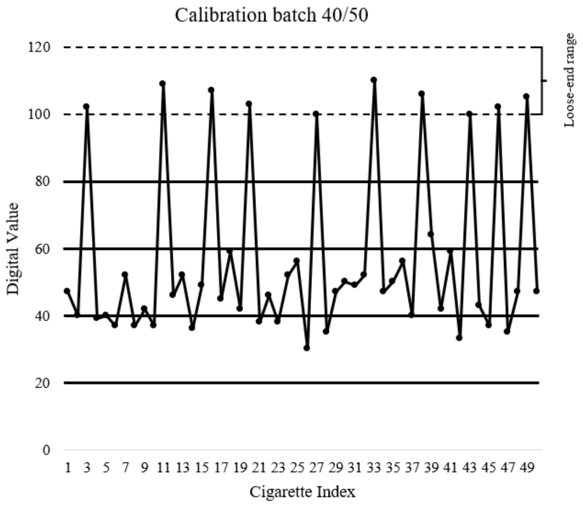

Figure 10. A Series of Digital Values Obtained From Calibration Batch

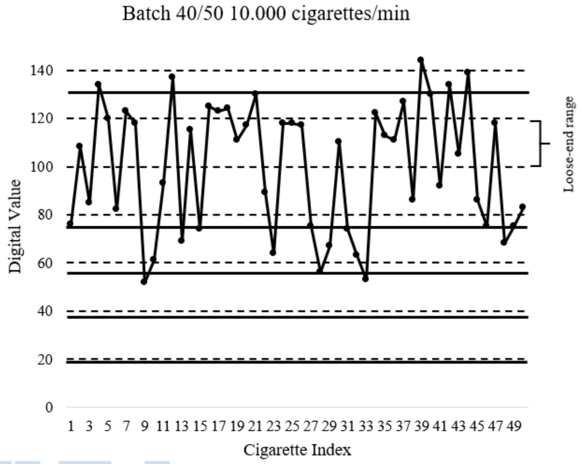

Figure 11. Example of Digital Value Obtained From Batch 40/50 10,000 cigarettes/min

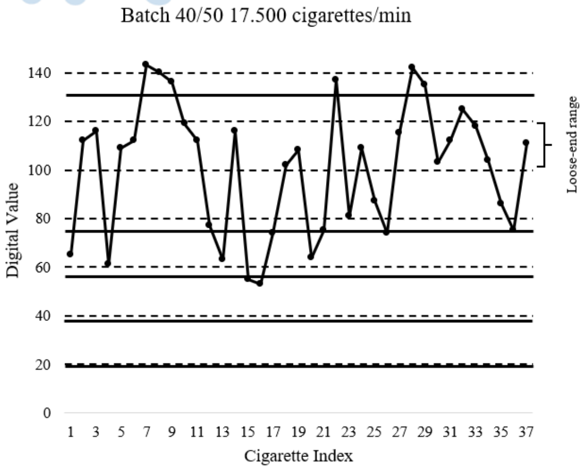

Figure 12. Example of Digital Value Obtained From Batch 40/50 17,500 cigarettes/min

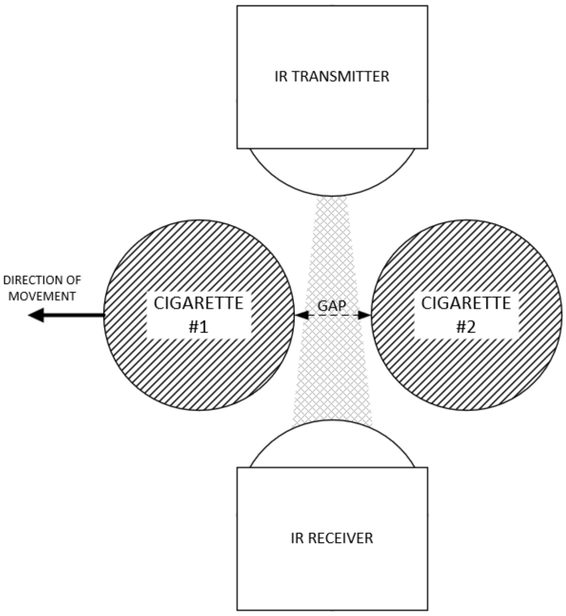

Figure 13. Illustration of Gap Between Cigarettes On Mechanical Rotator

Equation 2 is use to calculate the contrast properties of the measured signal.

$$CP = \frac{\overline{TP}-\bar{P}}{\bar{P}} \times 100\% \qquad (2)$$

where,

CP = Contrast Properties Value (%)

$\overline{TP}$ = Average digital value of loose-end defective cigarette per batch

$\bar{P}$ = Average digital value of normal cigarette per batch

TABLE I. CONTRAST PROPERTIES AND ACCURACY VALUE OBTAINED FROM SEVERAL TEST BATCHES

No	Test Batches	Rotator Speed (cigarettes /min)	Contrast Properties (%)	Actual Loose-end Detected	Accuracy (%)
1.	49/50	10.000	76	1	100
2.	45/50	10.000	57	5	100
3.	40/50	10.000	55	14	71,4
4.	49/50	17.500	58	3	33,3
5.	45/50	17.500	48	5	100
6.	40/50	17.500	57	16	62,5

Table I shows the test results from several test batches. The average value of the contrast properties parameter is 58.5%, evenly distributed across test batches. The average value of the accuracy parameter is 90.5% at 10,000 cigarettes/min and 65.3% at 17,500 cigarettes/min, it has a tendency to decrease at faster speed and at larger amounts of loose-end defective cigarettes. Signal noise due to electromagnetic radiation generated by a motor controller seems to contribute to this.

IV. CONCLUSIONS

The proposed instrumentation system to detect loose-end defective cigarettes was successfully designed and tested using a specially built apparatus. Low-cost components and simple design were evidently effective and practical to obtain good performance parameters. This will give an opportunity to development of a complete fully automated detection and rejection of loose-end defective cigarettes machine at a much lower cost compared to existing expensive machines. This could be an alternative solution to help the small and home local industries in Indonesia to improve their cigarette product quality.

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