# Dynamic Measurement for Detecting the Road of an Autonomous Vehicle Using the Proximity Sensor

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**Abstract.** The majority of sensors have played a vital role in the autonomous vehicle area. In this research, a dynamic model for measuring a characteristic of the analog sensor is developed, the shape of the output signal is a critical factor in road identification of autonomous vehicles. By hand-made testing system is built successfully, a number of alloys and non-magnetic metals (Aluminium and Copper) are considered in every aspect of them. In addition, the comparison experimental outcomes between various dynamic models prove that, with the same metal size (50 × 20), and sensing distance (6 mm), the shape of the output signal of measuring is similar. These results are distinguished clearly with alloys. Signal interference will also be minimized due to the control of the movement speed of the sensor. This is an integral element for approaching road of mobile devices with different obstacles.

**Keywords:** Dynamic performance · Analog proximity sensor
Autonomous vehicle · Identification · Sensing distance

## 1 Introduction

### 1.1 Proximity Sensor and Autonomous Vehicle

Proximity sensors are used for metal detection in long-term periods [1]. Whether to detect a stainless-steel object on a line or a copper tape on a machine, these sensors were one of the first implemented in the area and remain popular these days.

Ferrous and nonferrous metals influence on proximity sensors in different manners which are sensed by identifying their operation range depending on the object being detected. The standard sensing range of proximity sensors is determined by its response to a one-millimeter thick square piece of mild steel [2]. In fact, the sensors must be adjusted to the sensing distance per metal respectively. The more conductive the metal, the less the sensor's range.


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Conventional inductive proximity sensors are designed for non-contact detection of metal objects [3]. In addition, they also identify the properties of various metals. Generally, a sensor includes a coil and ferrite core arrangement, an oscillator and detector circuit, and a solid-state output as shown in Fig. 1. They operate with a high-frequency electromagnetic field created by LC-resonance circuit with a ferrite core and a single coil which is encircled the ferrite core [4]. When a metal object (target) gets into the high-frequency field, eddy currents are induced on the surface of the target resulting in a loss of energy in the oscillator and creating a signal which turns the solid-state output to 'ON' or 'OFF' [5]. When the target leaves the sensing area the oscillator regenerates, allowing the sensor to return to its original state.

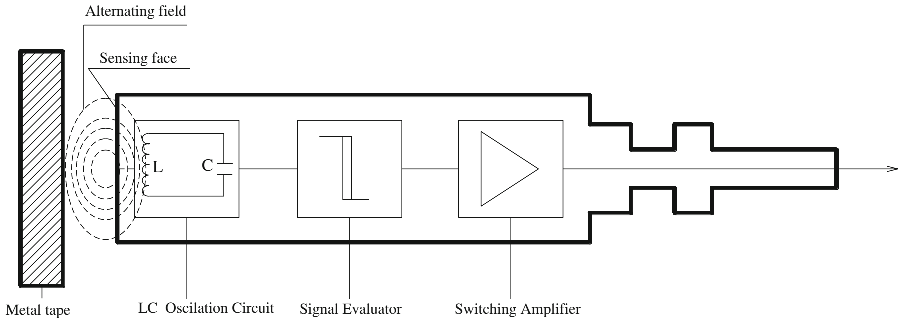
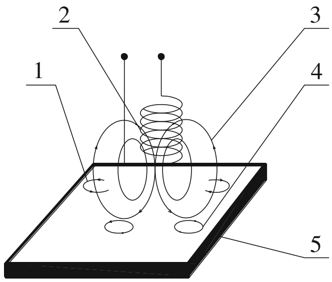



**Fig. 1.** Schematic of the analog proximity sensor

Cameras and sensors are highly important to the self-operation of autonomous vehicles. While cameras can be used for the purposes of navigation and object identification [6], processing the captured images is often difficult and time-consuming as it requires modern algorithms such as machine learning etc. Alternatively, proximity sensors can be utilized to facilitate cameras' tasks with simple and fast object identification. Therefore, this paper investigates how proximity sensors perform to identify objects, which in turn can be used to track the road for autonomous vehicles.

### 1.2 Principles of Operation of Eddy Current Testing

Eddy currents are a phenomenon generated by a changing magnetic flux intersecting a conductor wire [7]. Simultaneously, it also triggers a circulating stream of electrons or current within the conductor. In addition, the skin effect in conductors carrying alternating current is the outcome of establishing eddy current. Eddy currents move in a plane which is 3 parallel to the coil or metal surface and are reduced in phase with depth. The principles of electromagnetic induction may inspect eddy current working. And it is shown in Fig. 2.




1- Eddy current
2- Coil
3- Coil's magnetic field
4- Eddy current's magnetic field
5- Conductive material

**Fig. 2.** Eddy current in a metal tapes

Eddy currents can be used for measuring metals for the difference in composition, structure, hardness, and for detecting and testing surface [8]. They can also be applied to measuring changes in dimensions of rods and tubes and of the metal plate thickness and coatings of non-metallic on metal substrates or coatings of metal on non-metallic substrates.

In calculating, Z0 is the impedance parameter which characterizes every coil. This parameter is defined by the voltage-current ratio (V0/I0). The relationship between them has pointed out Eq. (1). Impedance Z0 has a magnitude |Z| and a phase $\varphi$:

$$Z_0 = \frac{V_0}{I_0} = R_0 + jX_0 = R_0 + j2\pi f\, L_0 = \sqrt{R_0^2 + X_0^2}_{\varphi = atan2\left(\frac{X_o}{R_0}\right)} = |Z|\varphi \qquad (1)$$

When an alternating current is generated within a coil, it also creates a time-varying magnetic field. The magnetic streams of flux tend to be focused on the center of the coil. Faraday's electromagnetic induction law inspects eddy current as shown in Eq. (2). Faraday found out that a time-varying magnetic induction flux density causes on currents in an electrical conductor. The electromotive force ε is proportional to the time-rate change of the magnetic induction flux density $\Phi_B$:

$$\varepsilon = -\frac{d\phi_B}{dt} \qquad (2)$$

In [9] proved that non-ferrous metal accuracy may be tested with results better than 1%, in the kHz or even MHz range. The measurement of the ferrous metal is more complex and challenging. Additionally, an extra problem to be solved is separating of an effect of the magnetic permeability and electrical conductivity of the metal under test onto the eddy current measurement outcomes. The technique for simultaneous distance and thickness testing of zinc-aluminum coating is shown in [10]. In order to enhance of this research direction, NASA Langley Research Center developed a flux-focusing eddy current probe by using a ferromagnetic material between the drive and pickup coils [11]. A range of non-ferrous metal is conductive materials. Therefore, eddy current testing uses the principle of electromagnetic induction to detect flaws has a critical role. For nonferrous materials such as aluminum and copper, eddy current electrical conductivity measurements are often used to verify metal performance [12]. For ferrous metal, the eddy current flow focused on extremely close to the surface, making sub-surface defects difficult to detect unlike non-ferrous material unless you strongly magnetize the materials or use special remote field probes.

# 2 Methodology

## 2.1 Experimental Set-up for an Analog Proximity Sensor

Schematic of the measurement set-up is shown in Fig. 3. A test panel (12) has a rectangular shape, which located on all laboratory instruments. Using rod (9) to fix analog proximity sensor (10). In the testing process, in order to change sensing distance between sensor and metal tape, stepper motor (4) is used. The smooth motion of the sensor is achieved by the lead screw (7). Using support (2) in order to fix this lead screw. In addition, to guide the straight motion of the screw, the navigation rod (3) is fixed. In order to observe the change of the output signal from the sensor, the sensor slider (11) will control the sensor along the test surface. The navigation rod will also be used in this case to facilitate the slide frame to straight.

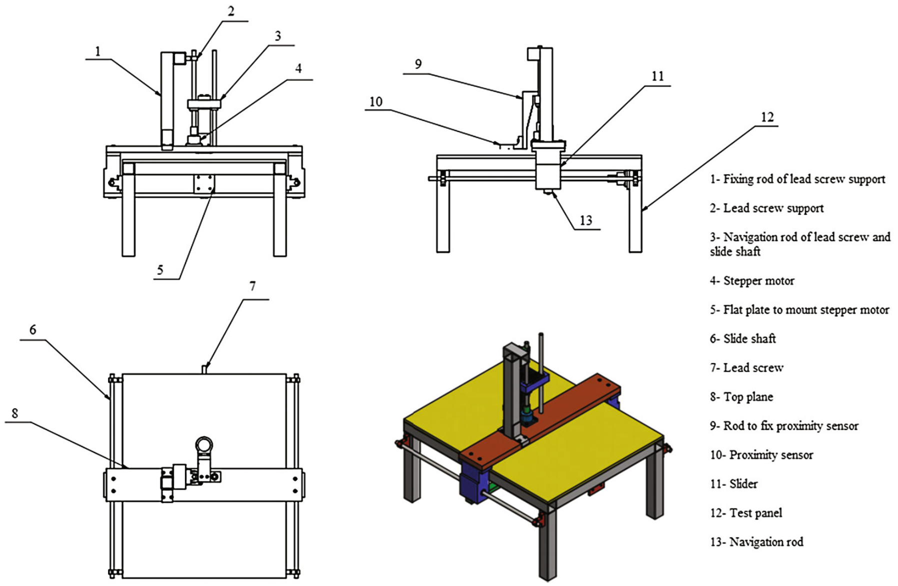



**Fig. 3.** Testing set-up of the measurement system

### 2.2 Diagram and Operating Principle of the Dynamic Measurement System

This is an analog proximity sensor which operates at 12.04 V used for identifying the metallic performance. It includes 4 wires consisting of red (positive wire), black (ground wire or negative wire), a white wire and blue wire. The out wire is the output of the sensor which is taken as the acquiring signal to the LabVIEW software by interfacing with MyRIO hardware. It is connected as the 4th pin to the Proximity Sensor with My-RIO Toolkit Using LabVIEW an analog output of the MyRIO hardware as the acquiring signal, which sends a signal to the program indicating the detection or non-detection of the type of metallic. Achievement results are shown in Fig. 4.

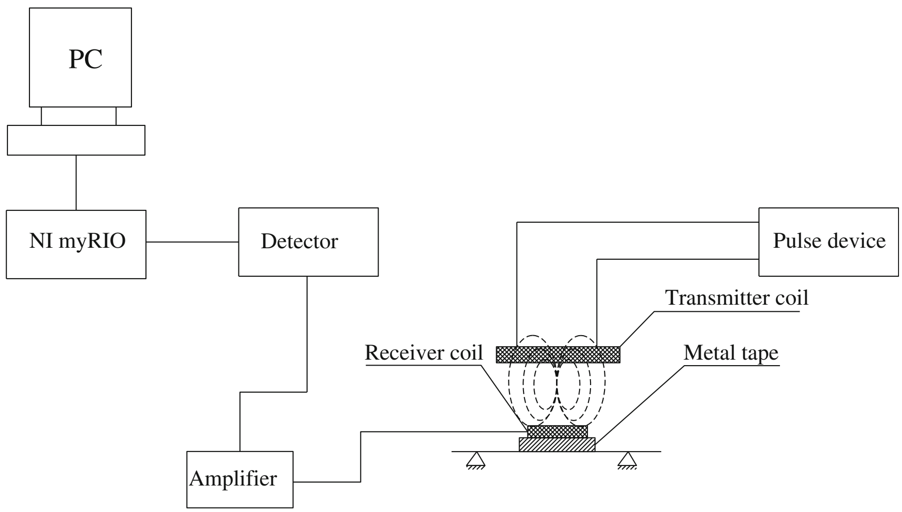
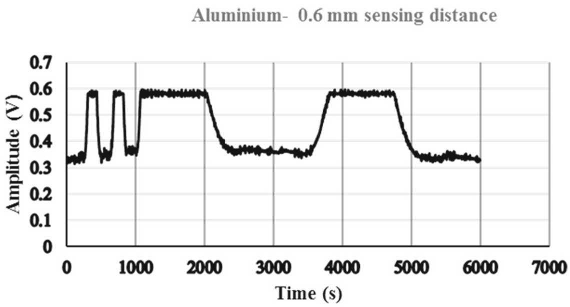



**Fig. 4.** Diagram of the measurement system of the analog proximity sensor

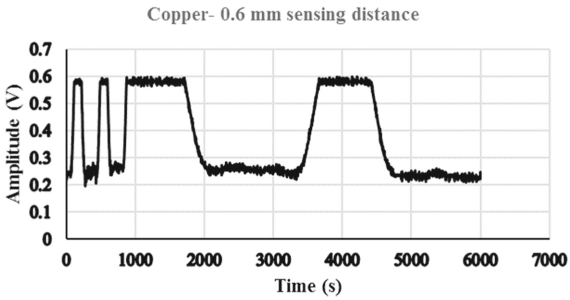
With this method of measurement, the analog sensor is mounted on a mobile device which may control the speed. Firstly, let it pass through each of the metal tapes of the same size (non-ferrous metals and alloys) on the flat table. Then, in turn, change the sensing distance to observe the signal received on the computer screen. Simultaneously, compare the results obtained with previous studies to draw conclusions.

Firstly, stick non-ferrous metals and an alloy have the same size on the test table surface, respectively. In addition, the stepper motor is controlled in order to the sensor passes through the center of the metal tape, the signal received on the computer screen specifies the difference in amplitude of the signal which is well illustrated in Fig. 5.

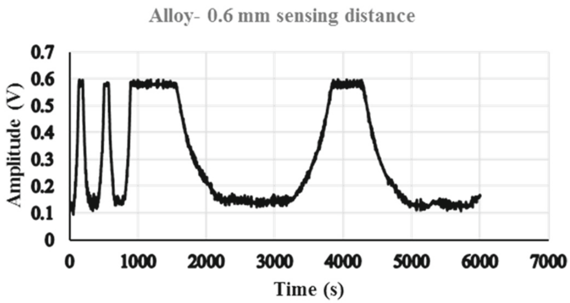
Secondly, the sensing distance (h) is changed correspondingly on the material. From there, the distinction of the output signal shape from the analog sensor is also determined precisely. In this case, the movement speed of the sensor is kept at a constant merit. The experimental result is shown in Fig. 6.




(a)




(b)




(c)

**Fig. 5.** Shape of output signal when testing various metal

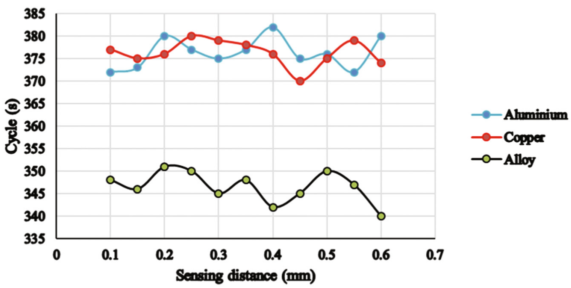



**Fig. 6.** The relationship between output signal and sensing distance

## 3 Results and Discussions

Overall, it is clear that there are differences in terms of the shape of the output signal when identifying non-ferrous and alloys. Since the velocity of the stepper motor is not too fast, the received signal is less noise than the result in [13]. This causes the electromagnetic of the sensor to sweep through the metal is relatively stable. From there, it improves the accuracy of metal identification in practice.

### 3.1 The Shape of the Output Signal on Various Metal

At the same sensing distance, the amplitude of the signal received when testing the alloy is greatest almost 0.6 V, while the amplitude of the signal from aluminum is the smallest approximately 0.3 V. This is explained by the difference in static properties when the identification of proximity switch with various metals has been studied in [14]. Nevertheless, the identification range of the proximity sensor for aluminum is larger than copper and alloys. This is a key element for aluminum applications in the research of mobile robot devices.

Experimental results on Fig. 5a–c prove that it takes about 360 s for the amplitude of output signal to reach a peak for the first time when testing aluminum tape. Meanwhile, the height of signal peaked for the initial time at almost 150 s when identifying copper metal. Conductive properties between various non-ferrous metal have trigged of this phenomenon.

### 3.2 The Relationship Between the Output Signal and Sensing Distance on Various Metal

Line graph illustrates the change oscillation cycle of the signal by sensing distance. It is also noticeable that the shape of the signal when the copper and aluminum identification is the same. This is distinguished from the measurement of the alloy. This is explained by the similarity of static characteristics between the two metals which are also mentioned in [14]. This result also demonstrates that non-ferrous metal is easier than alloys to detect and identify road. This is also similar to the results which found in [15].

In addition, it is obvious that the output of the periodic signal almost does not change the value according to the sensing distance. This is a significant direction for the design of unmanned vehicles running on the rugged road.

## 4 Conclusions

In this study, the properties of analog proximity sensor have been carried out by means of lab measurement. The results indicate that the shape of the output signal from the sensor is relatively different between metals and alloy. The output signals in this study are less interfered because the measurement system is carefully set up.

Specifically, the shape of the signal almost does not depend on the distance of the sensor in the same material. In addition, the comparison of the average oscillation period between each material also demonstrates that the use of mobile devices to detect metals is easier than the alloy.

On the other hand, aluminum has some special properties between various metals. Due to its properties, a mobile robot may detect road or identify easily. This is a critical element to research and control of devices in autonomous vehicles.

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