A low cost electromagnetic sensor for detecting holes in metallic sheet

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Abstract
Unwanted hole in metal sheet that use for vehicle body or structure is proved dangerous situation. To prevent disaster this hole needs to be found before its installation, or other wise it will be time and money consuming once it found when already finished installation. Therefore, an inspection using sensor for metal sheet is recommended to prevent this problem. In this paper, we proposed a new sensor using radio wave propagation to detect holes in metal sheet. We propose to use RSSI methods to detect hole based on electromagnetic wave propagation signal strength. Using this method we success to detect 8 mm hole diameter in metal sheet with 1 mm thickness. Using this method, we transmit electromagnetic wave energy at about 20 dBm, and we receive with average -27.53 dBm for iron sheet and -23.13 dBm for aluminum sheet.

Keywords: electromagnetic wave, holey metallic sheet, sensor, shielding effectiveness

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1. Introduction
In modern time like this, metal material is one of the most important components that support human civilization. Almost every device has metal material inside. That metal material works either as electronic conductor because of their characteristic to deliver electron, or to become casing because of their strength and durability. Metal sheet as one of many form of metal material, played a vital role for most today application. Almost every vehicle and structure [1] has metal material to become support or become their body to cover and thus provide safety for passenger inside.

The strength and durability in metal sheet also had their flaw. Processing metal raw material to become metal sheet, sometimes make fatigue for metal sheet, and thus develop become holes [2]. This hole problem can develop become disaster that threaten life, and proved fatal in special vehicle that use metal sheet for its body cover (such as submarine and ships). Such disaster happen in 2008 when Russian spacecraft “Soyuz” experiencing the same problem [3]. The “Soyuz” has hole on its body with only two millimeters wide, but this hole causes oxygen to leak into space and thus pressure were dropping inside and threatening the life of astronauts. Therefore a manual inspection using human eye for metal sheet is a must to prevent this disaster from happen again [4]. But another problem arises when we are using human eye to inspect hole in metal sheet. It was unreliable inspection, because human eye sometimes misses to inspect a very small hole [5].

In this paper, a non-intrusive sensor based on electromagnetic wave is proposed to solve this problem. Several researches have been conducted for this problem, such as using RFID [6-8], using resonator and transformer [9-11], using microstrip and waveguide antenna [12,13]. Other unique methods would be the use of computer vision such as Otsu-Canny Edge Detection Algorithm [14]. Table 1 shows matrix related research. Unfortunately, using RFID system, we need additional readers to calculate RFID tag energy therefore it was costly with range $500 to $3000. Because it was expensive using RFID, therefore our works was not based on RFID, but rather using an electromagnetic wave propagation through material and signal measurement [15-17]. An electromagnetic wave is excited trough metal sheet and if there are hole, it can propagate trough hole. In this work a real time measurement of received signal strength is carried out, and by comparing with a calibration value, the shielding effectiveness of the structure is predicted.
2. Measurement Method

The metallic sheet under test is located between the transmitter and receiver, as illustrated in Figure 1. The transmitter generates the electromagnetic signal with the frequency 2.4 GHz, which is transmitted by the antenna and propagates towards the metallic sheet. A receiver captures the electromagnetic signals penetrating through the hole. The received power can reveal the dimension of the holes under certain calibration.

![Figure 1. Measurement Method](image)

The designed electromagnetic sensor consists of the transmitter and receiver block. The transmitter generates an electromagnetic wave which we tag with “SSID Metal Check”. The receiver catches the electromagnetic wave signal, and using Arduino IDE Serial Monitor calculates the received signal strength. To keep the interference to the minimal level, we placed the transmitter block inside a 0.5 mm thick metallic case and the receiver block on a plastic case. The microcontroller Wemos (esp8266 based) is used as an electromagnetic wave signal transmitter and also as receiver. The microcontroller Wemos is a popular IoT node, which is low cost and has compact size. It is a programmable microcontroller with L106 32-bit RISC microprocessor core based on the Tensilica Xtensa Diamond Standard 106 Micro running at 80 MHz. This microprocessor has also a WiFi capability with an integrated TR switch, balun, LNA, power amplifier and matching network.

The microcontroller wemos is powered by Li-Po battery; the battery charger and boost converter for recharging the battery and powering the entire system; see Figure 2. The transmitter circuit consists of four blocks, microcontroller wemos (A), the battery (B), battery charger and boost converter (C) and the on/off switch (D), as given in the left side of Figure 2. For the transmitter it is essential to set the equivalent isotrop radiated power (EIRP) in order to be able to provide detectable received level behind the hole. The EIRP of the transmitter consists of the transmit power \( P_{\text{TX}} \) and the gain of the transmitting antenna \( G_{\text{TX}} \):

\[
EIRP = P_{\text{TX}} + G_{\text{TX}} \quad (1)
\]

\( P_{\text{TX}} \) = transmit power (17dBm)
\( G_{\text{TX}} \) = gain of the antenna (3 dBi)
The EIRP becomes 17 dBi + 3 dBi = 20 dBi or 100 mW.

Whereas as illustrated in the right side of Figure 2, the receiver is also composed of microcontroller wemos (A), the battery (B), battery charger and boost converter (C) and the on/off switch (D). The received power can be calculated by (2):

\[ P_{RX} = EIRP - PL \geq P_{RX,\text{min}} \]  \hspace{1cm} (2)

\begin{align*}
P_{RX} &= \text{Received Power (dBm)} \\
PL &= \text{Path loss (dB)} \\
P_{RX,\text{min}} &= \text{minimal received power/sensitivity of the receiver (-98 dBm)}
\end{align*}

![Figure 2. (a) Transmitter and (b) receiver circuitry](image)

In path loss we include the geometrical power decrease, all possible disturbances along the propagation path and the gain of the receiving antenna. By this occasion, the effect of the hole in metallic sheets can be described in the penetration of the fields through the hole. The additional loss due to the hole is calculated in a simple way by comparing the received power in the presence of the hole to the case without the hole. As long as, the value of the received power is higher than the minimal detectable received power, we can measure meaningful received power.

Moreover, there is a shielding characteristics due to the presence of the holey sheet [18], which can be quantified by its shielding effectiveness. For a circular hole in a metallic sheet, a simple equation is available as given in [19]:

\[ SE = 20 \log \left( \frac{\lambda_o}{d} \right) \]  \hspace{1cm} (3)

\( \lambda_o \) is the wavelength in the free space and \( d \) is the diameter of the hole.

In this work, we can calculate the shielding effectiveness simply by taking the difference between the received power without and with the holey sheets:

\[ SE = P_{RX,\text{without}} - P_{RX,\text{with}} \]  \hspace{1cm} (4)

3. Metallic Sheets under Test

In this work, we use two different metal specimens; the aluminum sheet and iron sheet. Aluminum is a strong and light weight metal that can be found in everyday life such as food wrapping, furniture, panel [20] etc. More importantly, aluminum is used in most aircraft [21], use for shielding against lightning strike [22], also because its metal feature provides durability against weather (corrosion resistant) [23] and has good thermal conductivity [24]. Meanwhile, the iron can easily be found in a heavy duty application such as bridges [25], roads, and others. In this experiment, we use iron and aluminum metal sheets with 1 mm thickness and the dimension 10 cm x 15 cm. Each aluminum and iron metal sheet we built consist of a hole with diameters of 2 mm, 4 mm, 6 mm and 8 mm, as given in Figure 3.
4. Measurement

A real time measurement is carried out to validate whether this sensor can detect a hole in the metal sheet. In order to do that, at first we are going to measure the received power without metal sheet. This measurement becomes a basis for calibration purposes for other measurements. Any variation of the received power means disturbances in the propagation path, which in this work is a metallic sheet with a hole with different diameter. Table 2 shows the measured received signal strength for free space condition (without metal) and for the case metallic sheets with different hole diameters. Based on the measured received power in Table 2, the shielding effectiveness of holey iron and aluminum sheet is calculated with (4), and for comparison purposes we use also the analytic equation in (3). The results are given in Figure 4.

Figure 4 reveals that iron shows bigger shielding effectiveness than aluminum sheet has. As the hole diameter increases, the value of shielding effectiveness decreases, as also given by the simple analytical expression. We see the order of the measured values is the same like given in the analytical approach.

Table 2. RSSI Measurement obtained for several metallic sheets (values in dBm)

| Specimens | Without Metal | Metal with hole, diameter |
|-----------|---------------|---------------------------|
| Iron      | -4.6          | -33.1 -32.0 -34.1 -27.5   |
| Aluminum  | -4.6          | -27.3 -23.6 -26.1 -23.1   |

5. Conclusion

In this research we proposed a low cost electromagnetic wave based sensor for hole detection in metal sheet. This sensor only cost about $37.8 dollar more cheaper compare with RFID system based sensor. Using RSSI method to simplify the real time measurement, we success to detect 8 mm hole in diameter in 1 mm thickness metal sheet. The transmitted signal strength was 20 dBm and the received signal strength at average -27.53 dBm for iron sheet and -23.13 dBm for aluminum sheet. We were also able to predict the shielding effectiveness of the holes with different diameters and compared the result with those found by analytical expression.

Acknowledgements

The authors would like to thank Kemenristek Dikti for the financial support of this research for the period 2019.
A low cost electromagnetic sensor for detecting holes in metallic sheet (Galang P. N. Hakim)