Measurement of Colored Noise from Spot-Welding Machine in a Factory

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Abstract— A smart factory environment is becoming increasingly important as the 4th industrial revolution has garnered increasing attention. Formulating a complete wireless condition is the most important aspect of a smart factory. Therefore, making a factory suitable for wireless communication is essential. However, excessive spot-welding machines in a factory result in colored noises, which may cause severe performance degradation in wireless communication. In this study, we measured and analyzed channel noise from a spot-welding machine in a Hyundai Motors Group factory using a spectrum analyzer.

Keywords— welding noise analysis; colored noise; indoor factory channel

I. Introduction

The 4th industrial revolution has led traditional factories to be transformed into smart factories [1]. Consequently, several companies are converting their factories into smart factories. Smart factories are factories that are facilitated by Internet-of-things-based wireless machines combined with artificial intelligence technologies, which make the manufacturing process more effective than in man-controlled factories [2]. Thus, wireless machines are mandatory for smart factories, which implies that all machine orders must be transmitted from the controller and received wirelessly by individual machines.

Therefore, there should be no failure in wireless communications in a smart factory. Most of the factory machines are already equipped with wireless chips on 2.4 GHz Bluetooth® or Wireless Fidelity (Wi-Fi). However, indoor factory conditions are unsuitable for quality wireless communication. First, most of the factory buildings are made of steel walls, making the entire factory building a type of iron-shielded room. This steel-covered room is one of the most difficult conditions for a decent communication system because the signal cannot be transmitted through the wall. In addition, steel walls and glass windows work as reflectors, which degrade the signal-to-noise ratio (SNR) and cause numerous multipaths. Reflected signals often result in low SNRs. In addition to the aforementioned structural issues, excessive noise sources are also among the reasons for communication jams in indoor factory conditions. Most of the factories are filled with several machines emitting electromagnetic fields, significant amount of heat, and sound, which affect channel conditions. In addition, other items, including fork lifts, plastic partition walls, and mobile phones of the workers in the factory, also act as channel obstacles. Particularly, in car manufacturing factories, up to thousands of welding machines are attached to the robot arm, and they are all connected to the control board. The welding machine emits a high voltage and current within a very short time period, with sparks included. This can also block the communication signals.

There have been some attempts to identify communication noise and channel conditions in indoor factories. To the best of our knowledge, there is barely any study analyzing below-2.4-GHz channels and noise. In addition, there is almost no study analyzing the welding machine noise in a wireless channel, except one study [3] in which the noise spectrum of a spot-welding machine in a factory was analyzed. However, the measurement was taken only when numerous spot-welding machines worked together; therefore, the analysis of noise from a single spot-welding gun is lacking. In [4], the acoustic noise of a welding machine transformer using different types of voltage generation methods was analyzed. Therefore, [4] is irrelevant to the channel noise analysis. In [5], there was an attempt to study the health issues related to welding machines, which is unrelated to channel noise.

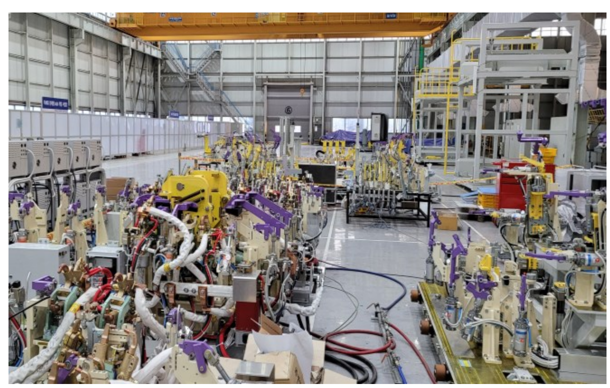

Fig. 1. Hyundai Motors Group indoor car factory with spot-welding machine inside, Ulsan, South Korea

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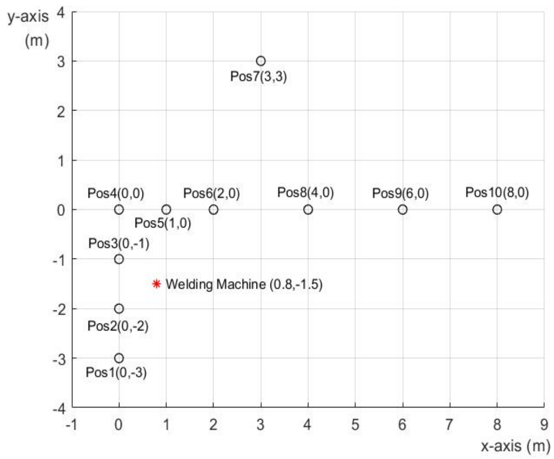

Fig. 2. Measurement position and spot-welding machine position in the factory

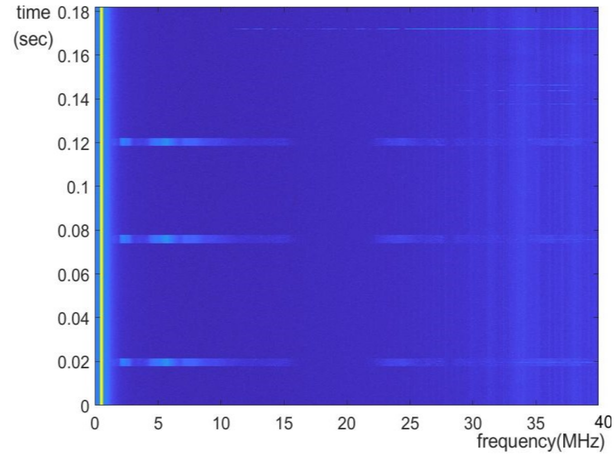

Fig. 3. Spectrogram in position 1 for 0~40MHz

In this study, we analyze the channel noise from a spot-welding machine in a car manufacturing factory. The time–frequency domain spectrogram of spot-welding noise data was captured using a FieldFox® spectrum analyzer in the Hyundai Motors Group factory in Ulsan, South Korea. Based on the captured data, the indoor factory channel noise from the spot-welding machine was analyzed by plotting a spectrum graph. The remainder of this paper is organized as follows. In Section 2, the theoretical background related to channel noise is introduced. Section 3 describes the experimental conditions. In Section 4, the experimental results are discussed. Finally, Section 5 concludes the paper.

II. THEORETICAL BACKGROUND

A. *Channel and Channel Noise*

A channel is usually represented by H, with input x and output y. H is the channel representing a function or a matrix. Input x is usually referred to as the signal from the transmitter, and y is the signal received by the receiver. The ultimate goal of wireless communication is to determine the channel H; therefore, from the received signal y, we can clearly identify the transmitted signal x. The channel is expressed as follows:

$$\mathbf{y} = \mathbf{Hx} + \mathbf{n} \tag{1}$$

The noise term n is expressed as in (1). The greatest threat in the communication channel is the noise. The noise interrupts channel H, resulting in the loss of signal information. One example is additive white Gaussian noise (AWGN). Apart from AWGN, there are several other types of channel noise. Noise sources include welding machines.

B. *Spectrum and Spectrogram Analysis*

The time domain signal is converted into a frequency domain signal using a Fourier transform. The discrete-time Fourier transform equation is as follows:

$$\mathrm{X(k)} = \sum_{n=0}^{N-1} x(n)e^{-j\omega_k n} \quad (\mathrm{k} = 0,1, \dots \mathrm{N}-1) \tag{2}$$

This frequency domain signal is often represented as a frequency (Hz)–magnitude (dB) graph known as the spectrum.

In contrast, the spectrogram has three-dimensional information: time (s), frequency (Hz), and magnitude (dB). Spectrograms are useful for analyzing frequency domain changes over time.

C. *Spot Welding Machine*

In this study, a spot-welding machine in the Hyundai Motors Group car factory was analyzed. The electric current time was 266 msec. Argon gas was injected during welding. The spot-welding jig was attached to a metallic robot arm. A photograph of the spot-welding machine inside the factory is shown in Fig. 1. Several spot-welding machines were connected to the controller, which controlled the welding current output at 8000 A based on the temperature and voltage feedback system.

III. EXPERIMENTAL SCENARIO

A. *Measured Factory Condition*

Factory channel noise was measured at the car manufacturing factory of the Hyundai Motors Group in Ulsan, South Korea. The dimensions of the measured factory were $170\times96\times15\ \mathrm{m}^3$. The factory building consisted of steel wall panels with some windows and doors. In the factory, in addition to spot-welding machines, there were many structures such as plastic wall partitions, machine materials, and a few fork lifts.

The positions of the welding machine jig and the measured spot are shown in Fig. 2. For line-of-sight (LOS) and non-line-of-sight (NLOS) effect analysis, points where LOS and NLOS conditions were satisfied were selected. Positions 8, 9, and 10 were under the NLOS condition because other machineries blocked the LOS path between the spot-welding machine jig and the receiver antenna. Moreover, to analyze the distance effect on noise, points with different distances from the spot-welding jig were selected. Based on these rules, all of the measured points

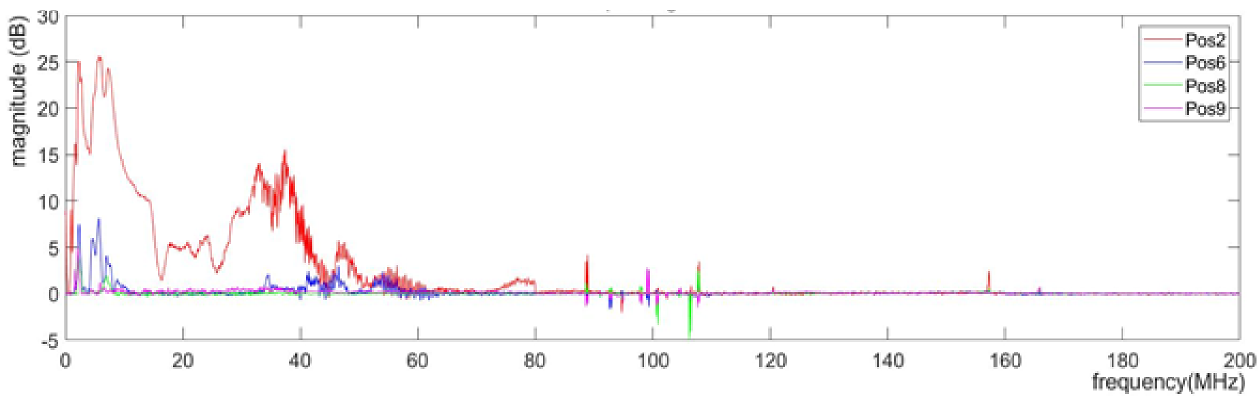

Fig. 4. Spectrum of spot-welding machin in Pos 2, 6, 8, and 9

were selected. In Fig. 2, the spot-welding machine jig is marked with a red cross, whereas the measurement spots are indicated by black circles.

B. Measurement System Setup

For the measurement, a FieldFox® handheld analyzer was used. The sampling frequency was 5000 Hz, with a 0.02 s scan. The bandwidth was 40 MHz; therefore, we had to take five measurements consecutively to obtain a complete spectrogram up to 200 MHz.

IV. Results and Discussion

The spot-welding machine noise was captured using a FieldFox® spectrum analyzer. The spectrogram captured at position 1 up to 40 MHz is shown in Fig. 3. In Fig. 3, three horizontal bands appear in the time axis at 0.02, 0.08, and 0.12 sec, when the spot-welding machine is turned on. To acquire the frequency-magnitude spectrum in Fig. 4, the aforementioned horizontal band signals were averaged, and the existing noise was eliminated. The noise eliminated was acquired by averaging the noise when the spot-welding machine was turned off.

Fig. 4 shows the frequency-magnitude spectrum below 200 MHz. The spectra at positions 2, 6, 8, and 9 are shown in Fig. 4. Red, blue, green, and magenta lines represent the spectra of positions 2, 6, 8, and 9, respectively. Position 2 is the closest LOS point among all measured points. The distance from position 2 to the spot-welding machine is 0.94 m, whereas the distance between position 6 and the welding machine is 1.92 m. Positions 2 and 6 are under the LOS condition, whereas positions 8 and 9 are under the NLOS condition. As shown in the position 2 data, the noise from the spot-welding machine occurred below 60 MHz.

By comparing the spectra of positions 2 and 6, the spot-welding machine noise significantly decreased as the distance from the spot-welding machine increased. By comparing the spectra of the LOS and NLOS conditions, it is clear that under the NLOS condition, noise from the spot-welding machine does not occur. Thus, we can conclude that the spot-welding machine noise does not spread widely, particularly when it is physically blocked by an obstacle.

V. Conclusion

In this study, we analyzed the communication environment of a real car manufacturing factory. The channel noise data were measured using a FieldFox® spectrum analyzer in the Hyundai Motors Group manufacturing factory in Ulsan, South Korea. The spot-welding machine, once expected to be a possible noise source for the 2.4 GHz Bluetooth® and Wi-Fi channel, was found to create channel noise at a frequency below 60 MHz. The spot-welding machine generated channel noise, but did not severely affect the 2.4 GHz channel. As expected, spot-welding machine noise occurred only under LOS conditions, and the noise magnitude was inversely proportional to distance. Under the NLOS condition, no noise was observed. This implies that the spot-welding machine noise cannot spread through an obstacle.

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