Application of LoRa with MEH in Maintenance-Free IoT

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Abstract – *With the recent demand for IoT, there has been a growing focus on power supply using energy harvesting technology. Magnetic Energy Harvesting (MEH) has several advantages over other energy harvesting methods, such as solar, thermal, and vibrational energy. However, conventional methods often depend on unstable environmental conditions such as sunlight or temperature differences, which limit continuous operation in indoor or shaded environments. Long Range (LoRa) is a low-power wide-area network (LPWAN) technology designed specifically for IoT devices. By combining LoRa and MEH has the potential to create truly maintenance-free IoT systems that can operate autonomously for long periods of time. The objective of this study is to evaluate whether a LoRa module can be operated using only power harvested from environmental magnetic fields. Experiments were conducted by generating an environmental magnetic field and connecting the MEH coil output to the LoRa communication module through a rectifier and DC-DC converter to verify communication feasibility. As a result, communication was not possible, even using an improved version of LoRa with lower power consumption. The results of this study clarify future considerations for intercommunication. In conclusion, insufficient power supply from the MEH module was identified as the main limitation, and improvements to the power conducting module, LoRa circuit board, DIP switch, and film capacitor will be required to realize maintenance-free IoT systems.*

Keywords*: IoT, LoRa, Magnetic energy harvesting*

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I. Introduction

The Internet of Things (IoT) has revolutionized various sectors by enabling seamless communication between devices, leading to improved automation and data-driven decision making. However, a major challenge in IoT implementation is to ensure long-term, maintenance-free operation with battery less devices, especially in remote and inaccessible locations. Low Power Wide Area Network (LPWAN) technologies such as LoRa (Long Range) have emerged as a promising solution as they enable communication over long distances with minimal power consumption [1].

LoRa technology operates in the sub-GHz frequency bands and offers better propagation characteristics compared to higher frequency bands. By using a unique modulation scheme known as Chirp Spread Spectrum (CSS), LoRa enables robust communication over long distances, making it particularly suitable for IoT applications where devices are distributed over wide areas and need to transmit data over long periods of time [1]-[2]. LoRa operating in unlicensed frequency bands, thus reduces the cost and complexity of spectrum licensing [3]-[4]. The low power consumption of LoRa allows it to use power efficiently for data transmission. This enables a battery life of over 10 years. LoRa can operate for extended periods on a single battery charge, making it ideal for maintenance-free applications [4].

Recently, the integration of energy harvesting technologies, in particular Magnetic Energy Harvesting (henceforth: MEH), with LoRa has attracted a lot of attention. MEH uses magnetic fields in the environment to generate electrical energy. This reduces or eliminates the need for battery replacements, which lowers maintenance costs and increases sustainability [5]. The combination of LoRa and MEH has the potential to create maintenance - free IoT systems that do not require batteries and can operate autonomously for long periods of time. This approach is particularly beneficial for IoT applications in

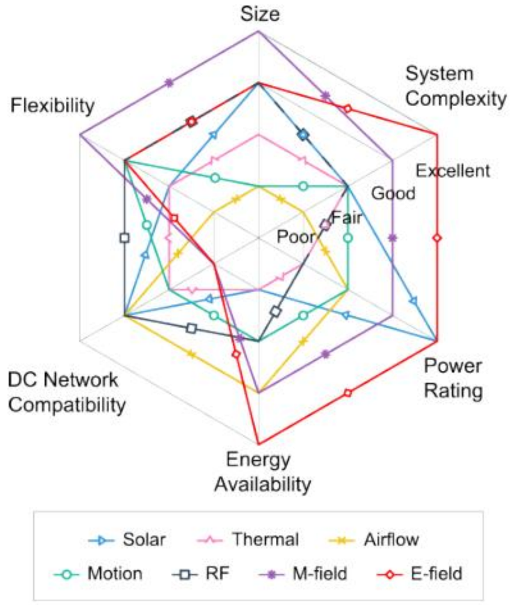

Fig.1. Comparison of Existing Energy Harvesting Techniques [7].

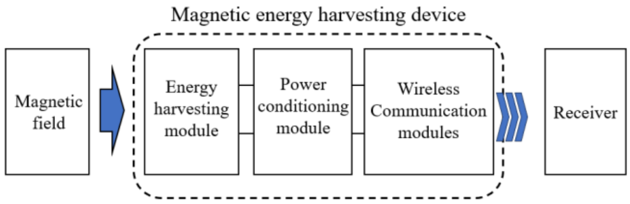

Fig.2. The configuration of Magnetic Energy Harvesting.

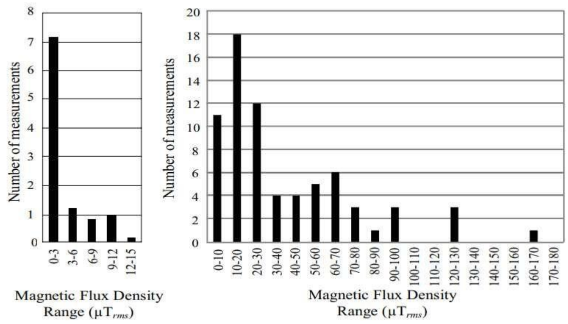

Fig.3. Leakage flux density of substations [12].

remote or hard-to-reach locations, as it ensures continuous operation without human intervention [6] - [7]. Figure 1 illustrates the characteristics of various existing energy harvesting techniques, highlighting the superiority of magnetic field harvesting [7].

MEH offers several advantages over other energy harvesting methods, such as solar energy, thermal energy and vibration energy. MEH can be used in environments where other energy sources are unreliable or unavailable. The use of solar energy, for example, is highly dependent on the availability of sunlight, which makes it less effective in indoor or shaded environments [8] - [9]. Similarly, the utilization of thermal energy requires a significant temperature gradient, which is not always available [10]. In contrast, MEH can continuously harvest energy from ambient magnetic fields, providing a more consistent and reliable power source for IoT devices [8] - [11].

This research investigates the application of LoRa technology in combination with Magnetic Energy Harvesting (MEH) to develop maintenance-free IoT solutions. The prototype integrating MEH systems with LoRa modules has been proposed and developed. In the following subsection, the basic principles and methodology for the proposed MEH-powered LoRa module are described. This is followed by an analysis of the data transmission capabilities of the module.

TABLE 1
ICNIRP2010 (REFERENCE LEVELS FOR GENERAL PUBLIC EXPOSURE) [14]

Frequency range	Magnetic flux density, B [T] (f in Hz.)
1 Hz — 8 Hz	$4 \times 10^{-2}/f^2$
8Hz — 25 Hz	$5 \times 10^{-3}/f$
25 Hz — 50 Hz	2×10^{-4}
50 Hz — 400 Hz	2×10^{-4}
400 Hz — 3 kHz	$8 \times 10^{-2}/f$
3 kHz — 10 kHz	2.7×10^{-5}

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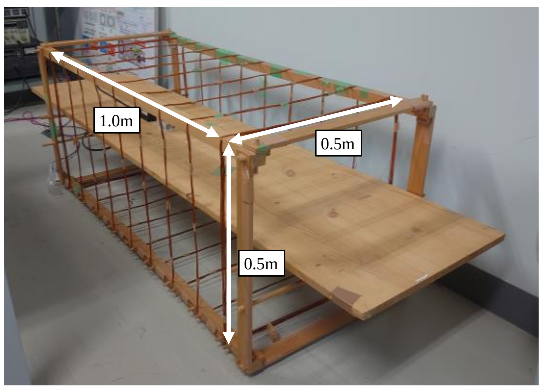

Fig.4. Simple-Box-9 coil system.

II. Materials

A. Magnetic Energy Harvesting

MEH converts ambient magnetic fields into electrical energy. Utilizing this energy as a power source for IoT devices enables self-sustaining operation and reduces the need for battery replacement. Figure 2 shows the configuration of magnetic energy harvesting. There are three key components of ambient magnetic field power generation.

The first is the magnetic field excitation coil. The magnetic field excitation coil generates a uniform magnetic field. The second is the generator coil. The generator coil collects magnetic energy and converts it into AC power. The third is the rectifier and regulator. These convert AC power into DC power and are suitable for powering electronic devices.

Magnetic energy harvesting uses Faraday's law of electromagnetic induction to define the magnetic field below the exposure limit in a living environment as the environmental magnetic field, which is then used for power generation. Figure 3 shows an example of the maximum intensity of the magnetic field from a power generation facility. Magnetic fields of up to 160-170 µT exist near substations. By using this leakage magnetic field to operate LoRa, a monitoring system for power transmission and distribution equipment can be built. Magnetic fields have exposure limit standards set to prevent health damage. Guidelines were established in 2010 by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Table 1 shows the public exposure standard values in the ICNIRP 2010 guidelines [13]. As an example, it is set at 200 µT at 50 Hz. As an example, it is set at 200 µT at 50 Hz. Previous studies have obtained 1-5 mW of power at 50 Hz at 7 µT [14]-[16]. On the other hand, IoT devices require 100 mW of power to operate [17]. Considering the harvesting power, this report examines communication at a magnetic field of 200 µT as specified in the ICNERP guidelines.

Figure 4 shows a coil for generating an ambient magnetic field. The ambient magnetic field is simulated by an excitation coil with a uniform magnetic field, and the coil recovers the magnetic field to generate a current from the ambient magnetic field. The recovered AC current is rectified and regulated to generate DC current that can be supplied to the power grid, electronic devices, and IoT devices. This device is called SimpleCubic9 (henceforth: SB9) [18]. Table 2 shows the specifications of the SB9 used in the experiment.

B. LoRa Module

The 920 MHz private LoRa communication module employed in this study is one of the promising technologies

TABLE 2
SPECIFICATION OF SB9

Cross area	0.5m × 0.5 m
Length	1.0 m
Number of turns per coil	16:8:8:8:8:8:8:8:16
Magnetic field generated per unit current	76.2 $\mu T/A$
Possible frequencies	50Hz — 1 kHz

TABLE 3
LORA MODULE SPECIFICATIONS. (POWER-SAVING VER.)

Frequency	920.6 ~ 928.0 MHz
Modulation Method	LoRa spread spectrum method
Bandwidth	124 ~ 500 kHz
Spreading Factor	5 ~11
Data Rate	1.7 ~ 62.5 kbps
Transmission Power	7 dBm
Receiver Sensitivity	-129 dBm
Current Consumption (at 3.3V)	Transmission:43mA, Reception:8.2 mA
Power Supply Voltage	Operating Range: 3.3 ~ 5.5 V
Operating Temperature Range	-45 ~ +85 °C
Power / Tx LED	OFF

Fig.5. LoRa Transmitter Terminal (Left) / Aggregation Station (right).

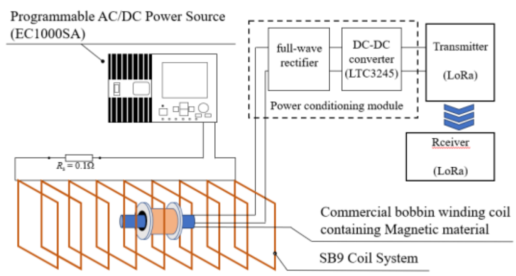

Fig.6. Experimental block diagram.

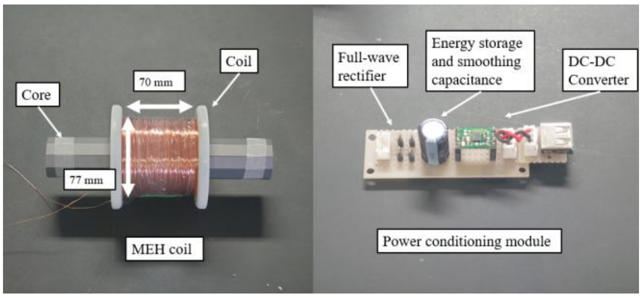

Fig.7. MEH coil and Power conducting module.

in the field of the Internet of Things (IoT). In Japan, it has been increasingly adopted in smart electricity meters equipped with communication functions by domestic power companies. Combined with a wireless multi-hop communication method, this technology facilitates the formation of large-scale, wide-area networks, enabling operational efficiency through automated meter reading [19].

In IoT systems, LoRa is well-known for its long communication range, high energy efficiency, and low cost. The LoRa module used in this experiment operates in the 920 MHz band, which is an unlicensed band requiring no radio license. Due to its propagation characteristics, such as low propagation loss and relatively good diffraction around structures and obstacles, it enables communication with sensors deployed over a wide area even with low power consumption. The expected communication range is up to 3 km in urban areas, up to 10 km in suburban areas, and over 10 km in line-of-sight conditions.

Table 3 shows the details of the specifications of the adopted device. The appearance of the transmitting terminal and the base station used in this experiment is shown in Fig.5.

III. Methods and Results

A. Communication Experiments

Figure 6 shows the experimental block diagram: an environmental magnetic field is generated using SB9 and applied to the MEH coil. The magnetic field generated was 50 Hz, 200 μT. The AC power obtained by electromagnetic induction is converted to 5 V DC power by a rectifier circuit and a DC-DC converter. The converted power is supplied to LoRa for communication. The coil and Power conducting module is shown in Figure 7. A schematic diagram of the coil core is shown in Figure 8. The specifications in Table 4 and Table 5. The coil used in this study is a commercially available bobbin-wound magnet wire. The core is made of electromagnetic steel plate and is hollow in shape. From previous research, a maximum power of 142 mW can be transmitted [20].

TABLE 4.
SPECIFICATIONS OF MEH COIL.

Coil size [mm]	77×70
Bobbin size and Wire Type	P-1, UEW
Weight, [kg]	1
Wire diameter [mm]	0.5
Core length, [mm]	213
Core sheet width, [mm]	0.5
Number of steel plates in the core	10
Resistance, [Ω] (Measured)	49
Open circuit voltage, [V] (Measured)	5.29 (AC)
Maximum Harvesting Power, [mW] (Calculated)	142

TABLE 5.
SPECIFICATIONS OF POWER CONDITIONING MODULE.

Full-wave rectifier	Diode part number	1N5818
	Energy storage and smoothing capacitance, C_s [μF]	1000
	Max Efficiency [%]	70
DC-DC Converter	Converter name	LTC3245
	Input voltage range [V]	2.7 – 38
	Output Voltage [V]	5.0
	Max Efficiency [%]	80
	No load quiescent current [μA]	18

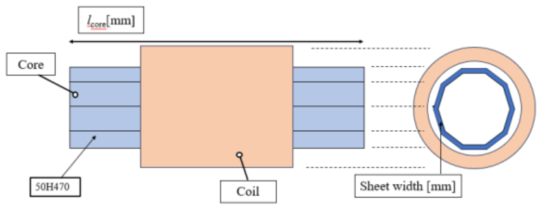

Fig.8. MEH coil core schematic diagram as well as the dimension.

Figure 5 shows the LoRa module. This is a similar device to the one used in the previous study. Only the transmitter has been rewritten in software to save power. The transmitter power is halved and the LED circuit is switched off.

B. Results.

The AC power of the MEH coil and the 5 V DC power after rectification and constant voltage were checked. The power feed was also checked when LoRa was connected. Communication experiments were carried out for one day. However, communication was not successful. The reason could be that the MEH module and the LoRa module were not matched and did not supply enough power.

IV. Discussion

A. MEH issue.

The availability of power supply to LoRa has enabled the construction of IoT sensor systems. However, communication cannot be demonstrated and needs to be improved.

The coil used in this case can supply a maximum of 142 mW. This is the case when resonance is performed in the rectifier circuit and impedance matching is performed with the load; the impedance of the LoRa is not known, but it is highly likely that the coil is not matched. For future consideration, it may be possible to solve this problem by measuring the impedance of the LoRa and preparing a matching coil.

Another issue is that the power-conducting module used in this study has a maximum supply efficiency of around 50%. Therefore, it is possible that the power-conducting module consumed the power of the MEH and did not supply enough power to the LoRa. For future study, the nodal voltages of MEH and LoRa will be measured to design the power supply to LoRa and the power generated by MEH.

In addition, changes in the shape of the MEH coil can be considered. The power supply capacity of the MEH increases with increasing the length of the core [21]. It is necessary to prepare cores of several lengths and conduct experiments.

B. LoRa issue

This study investigated the feasibility of operating LoRa devices using MEH as a power source. Compared to conventional battery-powered systems, several challenges were identified. First, it was shown that if MEH can provide a power supply equivalent to that of battery operation, it could be widely integrated into IoT devices. However, during the experiments, operational failures were observed due to the instability of the power supply. To address this issue, software-based power-saving approaches such as reducing transmission power and turning off LED lamps were implemented. Nevertheless, challenges in operational stability remain. Future considerations include the following:

1. **Redesigning the Circuit Board**: Optimizing the design to adapt to the low-power environment inherent to MEH.
2. **Improving Dip Switches**: Designing high-efficiency switches to minimize power loss.
3. **Replacing Capacitors with Film Capacitors**: Optimizing capacitors to reduce standby current.

V. Conclusion

In this report, we examined a maintenance-free IoT system using MEH and LoRa, and conducted experiments of LoRa data communication with power supplied by MEH. The results are shown below.

(1) Communication experiments using LoRa and MEH showed that communication was not possible.

(2) The reason for the communication failure was that the MEH module could not supply enough power to the LoRa module.

(3) Future considerations include checking the power supply status of the nodes of the MEH and LoRa modules, and increasing the power efficiency of each module.

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Conflict of Interest

The authors declare no conflict of interest in the publication process of the research article.

Author Contributions

Author 1: Experiment, writing papers; Author 2: Experiment; Author 3: Data analysis, experimental preparation; Author 4: Data analysis, experimental preparation; Author 5: Literature review;

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