Best Channel Selection by the Receiver for the Laser Beam Based WPT

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Abstract — **In this paper, we present the design and experimental implementation of the laser beam based wireless power transmission (WPT), which has best WPT channel selection technique at the receiver side. The transmitter sends the transmission channel information via optically modulated laser pulses. The receiver uses the intensity and digitized data to choose an optimum power transmission path. We demonstrates three experiments with a different energy receiving channels.**

Keywords—Wireless power transmission; power transmission efficiency; Laser

I. INTRODUCTION

Wireless power transmission (WPT) means the method of transmitting power through the air without using a wire, which is used for conventional power transmission. Currently WPT is applied mostly to notebook, tablet PC and smartphone, as well as to many other areas including wearable device, IoT (Internet of Things) system and unmanned aerial vehicle. It is anticipated that complementing some weak points of WPT would promote the popularization of WPT, leading to its application to wider areas [1].

There are three representative WPT methods. The first method involves magnetic induction and magnetic resonance to transmit electrical energy via magnetic field between 2 coils. Magnetic field-based WPT method has the weak point that power transmission efficiency (PTE) decreases rapidly as transmission distance increases, and therefore is applicable only to short-distance (a few centimeters ~ a few meters) energy transmission. The second is microwave-based WPT method. This method has the strong point of long transmission distance (a few kilometers ~ a few hundred kilometers), but high interference with other communication systems can cause problems with power transmission. The third is laser-based WPT method. This method transmits laser light energy to a target, which then converts received light to power using an externally attached or built-in solar cell [2]-[6].

Laser-based WPT method has various strong points. The relatively excellent light-gathering power of laser light enables long distance (a few kilometers ~ a few hundred kilometers) energy transmission. In addition, the extremely low possibility of interference with other communication systems eliminates interaction even between crowded transmitters. Further, if a solar cell receives laser lights simultaneously from many transmitters, the total received power increases to be equal to the sum of all the received power. Because of such strong points, laser-based WPT is being adopted by the WPT application are that demand medium and long distance power transmission (such as military unmanned aerial vehicles and offshore-exploring robots). Laser-based WPT method is currently under active research, especially concerning the technologies for enhancing PTE and the accuracy of energy transmission to target [7][8].

II. RELATED WORKS

While over the years, several laser-based wireless power transmission experiments and applications have been suggested and described, only relatively few actual experiments have been carried out compared to the number and diversity of microwave-based experiments described in the previous section.

Classified experiments involving laser power transmission technology demonstration have been reported to have taken place in the 1980s during the US Strategic Defence Initiative. These seem to have been conducted building on a heritage from the Apollo programme that used ground-based lasers with reflectors on the Moon to measure the Earth-Moon distance. Once of the observatories involved has been the Air Force Maui Optical Station (AMOS) located on top of mount Haleaki in Hawaii, US. The Serial digital interface (SDI) concepts would use ground based eximer lasers with adaptive optics and a roughly 5 m mirror in Geosynchronous Earth Orbit (GEO) and another mirror in a polar orbit at roughly 1000 km altitude [9][10].

One of the advantages of microwave power transmission over the use of laser has been the possibility to avoid moving parts in space by using an electronic beam steering system based on the control of the phase of a matrix of emitters. Recently, Schafer and Kaya have however demonstrated that a similar system is in principle also possible for laser based systems by presenting a new concept for a retrodirective tracking system [11].

Conventional laser-based wireless power transmission requires transmitter (Tx) to provide a series of methods for accurately positioning receiver (Rx). The energy efficiency of

power transmission via laser can be maximized only after the accurate positioning of Rx. Active researches are going on in this regard, because a range of errors is always involved in positioning of Rx, while long distance between Tx and Rx makes the accurate positioning of Rx even more difficult. In order to resolve such problems, the Tx of the present research uses various transmission angles so as to generate various laser beams in the form of coded channels, and then the established channel information is transmitted to the Rx via a wireless Local Area Network (LAN).

III. THE PROPOSED SYSTEM

This paper proposes a laser-based WPT technology that enables Rx to detect optimal WPT channel energy transmission and reception. The proposed laser-based WPT system of this paper, which consists of a Tx supplying power via laser and a Rx capable of detecting optimal WPT channel, selects optimal WPT channel by means of light identification codes for appropriately discriminating between multiple transmitters or power transmission channels.

(a) The conventional method (b) The proposed method

Figure. 1 Laser-based power transmission method

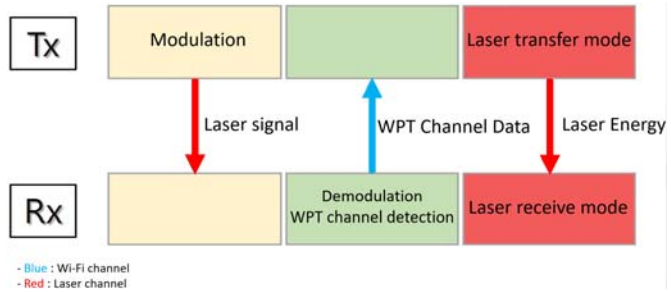


Figure. 2 System flow

Fig. 1 (a) is the conventional method. And Fig. 1 (b) is the proposed method. Firstly, as for Tx, channel coding is carried out with multiple channels of varying angles and times, as shown in Fig. 1. A channel in this paper means an optical pathway through which power transmission can occur between Tx and Rx, and discrimination between individual beam channels is achieved by means of signal coding. Signal coding is carried out by modulating the signal of each channel using a unique code so as to enable discrimination between different channels. The proceedings used by the Tx of laser-based WPT system in order to set a channel for power transmission is as follows. Fig. 1 shows a schematic diagram of Tx's laser signal transmission in N directions. Each channel of Tx is assigned with a unique identifier code for discriminating it from the other channels. Fig. 2 is a schematic system flowchart. When there is a Rx in need of power, Tx transmits N different types of predefined modulated signals via laser, as shown in Fig. 1. Then, upon receiving information about the optimal WPT channel selected by Rx, Tx changes its status to transmit power through that channel.

When Tx transmits various coded signals at maximum power, Rx measures the power quantities received through the individual coded channels that have been detected, and then sends back to Tx the information about the channel through which the largest power quantity has been received. The reason for transmitting maximum power quantity through the multiple channels of Tx is that Rx position is unknown because physical distance between Tx and Rx is not fixed.

Conventional method has problems caused by initially being blind to Rx position — such as the high system complexity of Tx. The proposed system can improve such a problem by eliminating the complicated process of positioning Rx. Thus the proposed algorithm enables Tx to operate at optimal efficiency by determining Rx's position based on the coded channel information from Tx. For this reason it is a highly proper algorithm for laser-based WPT.

Tx and Rx operate in a mutually synchronized manner. Synchronization is to make events occur at the same time in order to achieve the simultaneous operation of different systems. Data transmissions by Tx and Rx are synchronized by means of the Global Positioning System (GPS) satellites launched by the US and orbiting the earth. The laser-based WPT system of this paper achieves time synchronization between Tx and Rx by using time data from GPS. The transmission and reception of laser signal in such a synchronized manner reduces the possibility of unnecessary data input.

IV. EXPERIMENT

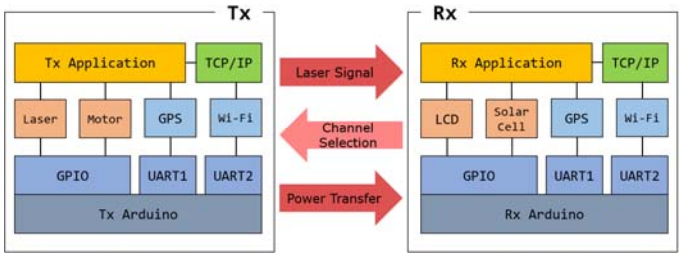


Figure. 3 System configuration diagram

The proposed method was verified using an experimental laser-based WPT system, whose structure is shown in Fig. 3. Tx and Rx were controlled by an Arduino board. The board's built-in General Purpose Input Output (GPIO) and Universal asynchronous Rx/Tx (UART) were used for the operation of laser, motor, Liquid Crystal Display (LCD) , solar cell, GPS and Wi-Fi. Laser is a medium for transmitting light energy to Rx, and the direction of transmission was set by controlling motor. LCD is a text visual device for displaying the reception status of Rx, and presents such information as laser transmission channels and power transmission status. Solar cell is a device for converting received laser light to electric power. GPS is used for synchronization between Tx and Rx. Wi-Fi is used for Transmission Control Protocol/Internet Protocol (TCP/IP) communication. All the devices were connected and could be controlled through an application. Tx sends laser signal to Rx, which then selects an optimal channel and sends information about that channel back to Tx. Based on that information, Tx continuously transmits laser light energy to Rx.

In consideration of the limitations of the experimental environment, it was assumed that Tx used three channels to transmit power to Rx, as shown in Fig. 1 (b). The angle between adjacent channels was designed to be 11.25°. For simulation, a fixed distance of 20m between Tx and Rx was involved, while lens was used to maximize PTE by making the size of beam become same as that of solar cell. The laser-based WPT consisted of a Tx that could transfer power via laser and a Rx that could receive laser light energy.

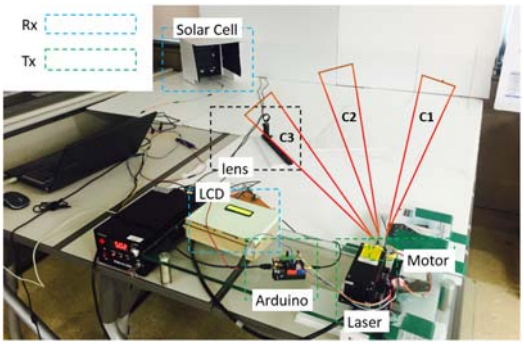


Figure. 4 A photograph of the experimental

Fig. 4 shows the configuration of the experimental devices organized in a small space, with a distance of 2m between Tx and Rx, before carrying out an actual experiment. In Fig. 4, the green box and the blue box are Tx and Rx, respectively, and the red triangles represent laser channels. As part of Tx, laser and motor are connected to the transmission control board Arduino and GPIO. And as part of Rx, although not seen in the figure because of other devices, reception control board and solar cell and LCD are connected to GPIO, The control boards of Tx and Rx have Wi-Fi module, while externally installed GPS has UART. For a short-distance experiment, as shown in the figure above, an arbitrary lens was used that could increase PTE.

A. Tx

Tx consists of transmission board, wireless LAN, GPS, and step motor with attached mirror, and laser. The laser used for Tx is PSU-H-LED from Cangchun New Industries Optoelectronics Tech. Co.,Ltd.(CNI). Laser light can be controlled using laser's external trigger and control board's GPIO. The direction of laser light can be controlled based on the full reflection principle, by rotating a motor to which a mirror is attached. In order for Rx to select optimal WPT channel, the laser of Tx transmits 3 different modulated signals, each consisting of 4 bits, in three different directions. Assuming that 1 and 0 respectively represent laser-on and laser-off, three different codes are respectively defined as 1100, 1010 and 1001. The On-Off Keying (OOK) method is used for signal modulation.

B. Rx

Rx consists of reception board, wireless LAN, GPS, LCD and solar cell. The solar cell used for Rx is A-300 Solar Cell from SUNPOWER. Rx can detect not only laser light signals but other lights as well. However, a relatively high intensity value is detected when a laser light signal accurately reaches solar cell, because laser light energy has higher light-gathering power than other types of light energy. Therefore a pre-defined threshold value is used in order to detect only laser light signals exclusively. Rx defines a modulated code from Tx using 40 bits, by increasing each bit from Tx to 10 bits. Such modulation by Rx is achieved through the sampling of laser light signal at 40Hz. If multiple laser light signals are detected, Rx calculates correlation between received modulated code and pre-defined modulated code. Then the channel through which the signal of the highest correlation value is transmitted is the channel of the highest PTE, and therefore is selected as optimal WPT channel. All the correlation values and Rx's reception statuses obtained throughout such processes are displayed by LCD.

C. Tx and Rx

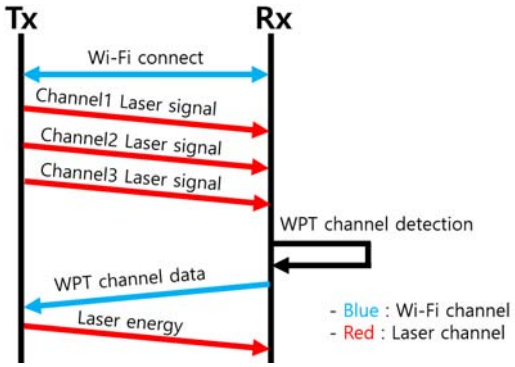


Figure. 5 System processes

Fig. 5 shows the order of processes involved in the proposed laser-based WPT system. Time synchronization was implemented using GPS in order to eliminate unnecessary data input caused by the unnecessary operation of Tx and Rx. Synchronization between transmission and reception was achieved based on the data obtained by parsing only the Universal Time Coordinated (UTC) time information of '$GPRMC' among various data received through GPS. That is, Rx's solar cell is operated to receive laser light signal from Tx only at the moment Tx transmits it. Events were designed to occur with 10-seconds interval. First of all, Wi-Fi setting is for the transmission of data about the optimal WPT selected by Rx to Tx. Before the transmission of laser light signal, Tx does not know which is optimal WPT channel. Tx sends laser light signals in 3 directions, and Rx receives only some of them. At this time, if Rx does not receive the laser signal of a certain channel, then a signal as in Fig. 6 (a) is detected for that channel. Whereas if Rx receives the laser signal of a certain channel, then a signal as in Fig. 6 (b), (c) or (d) is detected for that channel. Rx demodulates the laser light signals it receives and then, based on correlation value, finds out the signal of the highest PTE. The values obtained from repeated experiments on transmission between Tx and Rx are presented in Table 1. This table shows correlation values for correlation between Tx and Rx, according to the position of channel. The channel of the highest correlation value gives the highest PTE, and therefore is selected by Rx as optimal WPT channel. Data about the optimal WPT channel detected by Rx is sent to Tx through wireless LAN. The possibility of continuous laser light

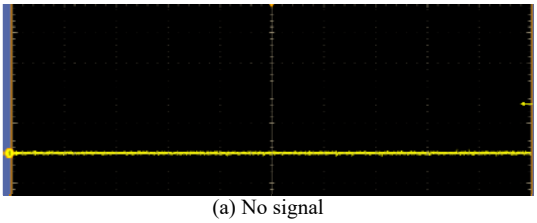
energy transmission and reception by Tx and Rx through the selected channel, as shown in Fig. 6 (e), was verified.

V. CONCLUSION

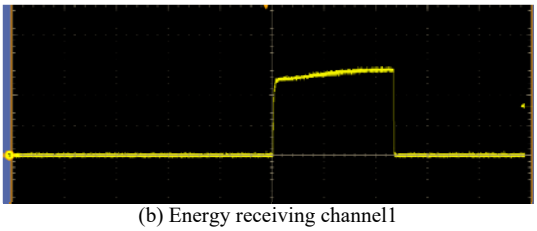
Laser-based WPT has the strong points of involving less interference with other communications systems than the other types of long-distance WPT, and of achieving a high PTE using a small area due to the relatively high light-gathering power of laser energy. The advantage of the laser-based WPT system proposed in this paper is the ability to reduce the complexity of the algorithm of conventional method by employing a proposed method that Tx can use to detect Rx. Unlike conventional method, the proposed method enables Rx to select an optimal channel for laser energy transmission. The system fabricated in this research was designed to be used for an experiment involving three ranges of transmission. However, in consideration of involving wider ranges of WPT in the future, follow-up research is demanded concerning a system that can allow a larger number of domains or that can enhance PTE further. In addition, in consideration of a situation involving multiple power transmitters and receivers, it would be necessary to develop a method that enables Rx to select from among many power transmitters a proper one that can provide sufficient power.

TABLE Ⅰ. CORRELATION BETWEEN TX AND RX

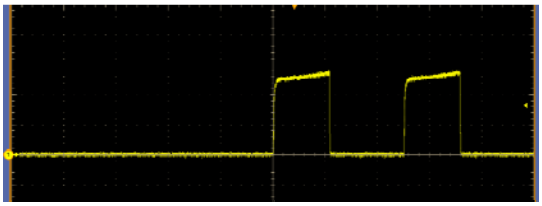
Tx position \ Rx position			Receives modulation codes		
			Channel1	Channel2	Channel3
			1~1~0~0~	1~0~1~0~	1~0~0~1~
Transmitted modulation codes	Channel1	1100	62588	11415	11476
	Channel2	1010	12548	42568	13456
	Channel3	1001	13117	14442	31654



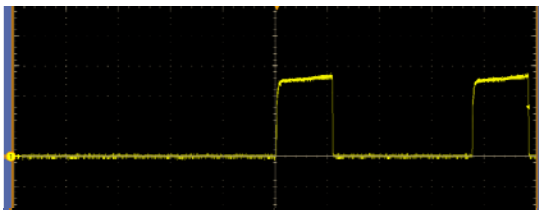
(a) No signal



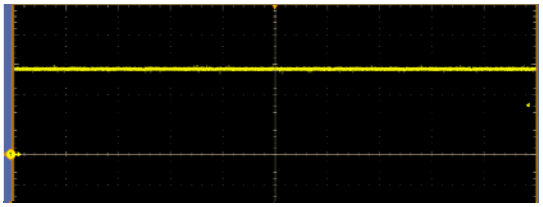
(b) Energy receiving channel1



(c) Energy receiving channel2



(d) Energy receiving channel3



(e) Energy charging

Figure. 6 Experimental results at the different channels

VI. ACKNOWLEDGMENT

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