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A Robot System Maintained with Renewable Energy

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Abstract

Energy autonomy is a system that is sustained by energy from an independent and distributed source such as renewable energy. In this paper, we propose a robotic energy autonomy in which a robot obtains energy from a renewable energy source with a limited storage capacity. As an energy transfer method, wireless power transfer is used to solve the problem of the conventional contact charging method, mechanical complexity, and to obtain high energy transfer efficiency, the image information is used to align the transmitting and receiving coils accurately. A small scale thermoelectric energy source with boost converter, battery charger, and wireless power transfer coil is constructed and an actual charging experiment is conducted to verify the proposed autonomy system.

Keywords: *Robotic Energy autonomy, Renewable energy, Thermoelectric energy source, Wireless power transfer, Image information*

1. Introduction

Mobile robots and drones have found applications in various industries and in recent years, their uses have been extended to other areas of application such as agriculture, delivery, search and exploration. Some mobile robots have a combustion engine and fuel tank on them, but most are operated by electric motors and powered by an on-board battery. If a robot moves and works for a long time, the battery becomes exhausted and then recharging is needed. The problem of battery recharging for mobile robots has long been an issue. The most common method is to manually charge the robot. For a home robot, especially a vacuum-cleaning robot, automatic recharging is generally implemented and various types of recharging systems have been proposed. Because home mobile robots do not have enough position accuracy to make unassisted contact with a recharge station, a guide mechanism around the recharge station is used to correct the position of the robot for stable contact between it and the recharge station [1]. A robot finds the recharge station using vision [2] or an infrared LED and then a guide mechanism assists the robot with making contact with the recharge station. In addition to the usual automatic charging method, there has also been proposed a method for the robot to intake or replace a charged battery [3,4]. This method has the advantage of reducing the time

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required for charging, however the mechanism is complicated. The energy source used to charge the robot is usually a commercial power source, but a variety of energy sources have also been studied. A typical example is to use a photovoltaic cell, which is widely used, but it is difficult to use in the absence of sunlight or when there is a limitation in weight of load, such as a rotary wing drone. A robot that consumes organic substances instead of electrical energy and uses it as an energy source has been proposed [5]. There is also a robot that operates by harvesting its own energy, which is only applicable to micro robots such as insect robots because the amount of energy to be obtained is small [6]. In the case of non-micro robots, more energy should be stably supplied from outside.

In this paper, we present a robot system that obtains energy by itself from an external energy source that is distributed, independent, and has a limited storage capacity, such as renewable energy, in the event that a robot does not receive sufficient energy from the commercial power source. A method of transferring energy from a distributed energy source to a robot is also an issue to be solved. The conventional automatic charging method by mechanical contact is an effective commercial technology, however, in the outdoor environment, when the charging terminal is contaminated by dust, moisture, or abrasion, contact becomes incomplete. In the case of a battery exchangeable type, it is difficult to use it in a distributed small-scale energy source because the mechanism becomes complicated. In order to solve the problems of the conventional energy transfer method, wireless power transmission is used as an energy transfer method in this paper. Wireless charging, which has been regarded as an auxiliary charging method due to efficiency and environmental problems, is now recognized as a solid charging method [7]. Wireless power transmission techniques are classified as non-radiative and radiative. With a non-radiative technique, power is transferred over short distances using various coupling methods such as inductive coupling, resonant inductive coupling, capacitive coupling and magneto-dynamic coupling. With a radiative technique, power is transferred over substantial distances in the form of electromagnetic radiation. There have been several studies using wireless power transfer for mobile robots. An automatic charging system of a mobile robot using image information has been proposed [8, 9], and Junaid et al. implemented the automatic charging system of the rotary wing drones [10]. A robot supplied energy to the sensor network in [11] and other fellow robots in [12].

In this study, we propose a robotic energy autonomy system that can survive by acquiring energy from energy sources with distributed and limited storage capacity [13]. A thermoelectric element is used as an energy source. When energy is transferred from the energy source, the wireless power transfer is used to solve the problem of contact charging and the image information is used to align the transmitting and receiving coils accurately. The organization of this paper is as follows: in section 2 the problem statement and an implementation of an energy autonomy is presented. Section 3 describes an experiment and finally section 4 presents our conclusions.

2. Implementation of a robotic energy autonomy

2.1 Problem statement

The activity space of the robot consists of work space and energy acquisition space, and there are N energy nodes in the energy acquisition space. When the energy of a robot is exhausted, it visits the energy node to charge the energy. Each energy node stores electric energy generated from an energy source in an energy storage system (ESS) composed of a battery or a supercapacitor having a limited capacity, and transmits energy to the robot when the robot visits it. Each energy node consists of an energy source, a power converter, an energy storage system, and a transmitter and a coil for power transmission, as shown in Fig. 1.

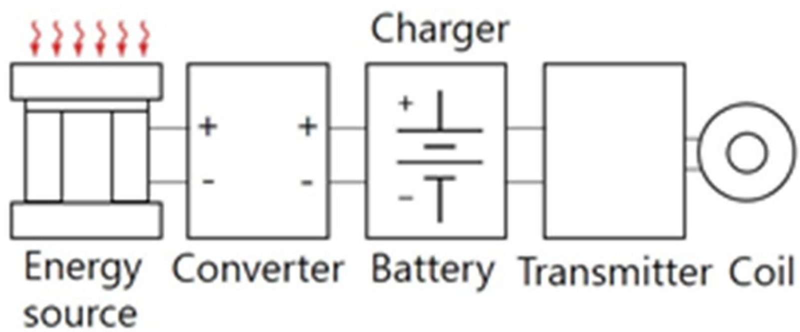

Figure 1. Structure of an energy node

The energy to be charged and to be transferred are approximated using a linear model as Eq. (1) ~(3), because the delivered energy is proportional to the delivery time .

$$\epsilon_i = sat_{E_i}(g_i \cdot t_g + \epsilon_{i0}) \tag{1}$$
$$e_{iT} = \mu \cdot t_T \tag{2}$$
$$e_{iR} = \eta \cdot \mu \cdot t_T \tag{3}$$

Where

ϵ_i: Energy stored in node i (initially, ϵ_{i0})
g_i: Energy generation rate of energy node i
t_g : Energy generation duration
e_{iT} : Energy transmitted from energy node i
e_{iR} : Energy received from energy node i on the secondary side
μ : Energy transfer rate of wireless power transfer coil
η : Energy transfer efficiency
t_T : Transmission duration
$$sat_M(x) = x, if\ x < M$$
$$= M, if\ x \geq M$$

Energy transfer efficiency η is the product of wireless power transfer efficiency and battery energy efficiency. The wireless power transfer efficiency depends on how well the transmission and receiving coils are aligned. Battery energy efficiency is about 0.8 for Li-Ion battery [14]. For other types of batteries, this value is lower. To visit an energy node, the robot consumes energy, and the energy it gets must be higher than the energy consumed to acquire energy. The power consumed by the robot during the movement, p_{trip} consists of the power for driving and the power consumed by the controller as equation (4) [15]. The p_c is the sum of the energy consumed by the controller board, ultrasonic sensors, LIDAR sensor and other sensors.

$$p_{trip} = p_m + p_c \tag{4}$$

p_c : Robot Power consumption for computing
p_m : Robot Power consumption for driving

2.2 Thermoelectric energy source

A thermoelectric module (TEM) has a structure in which a plurality of P and N-type semiconductors are electrically connected in series and thermally connected in parallel. Electricity is generated by the Seebeck effect, in which an electromotive force is generated by a temperature difference between both sides which is generated by heating one side and radiating the other side. The configuration of the thermoelectric power generation node is shown in Fig. 2. The voltage generated by the thermoelectric power generation is expressed by Eq. (5) [16].

$$V = N \cdot \alpha \cdot (T_H - T_C) \quad (5)$$

Where, N is the number of modules, α is the Seebeck coefficient, T_H means the hot side temperature, and T_C is the cool side temperature.

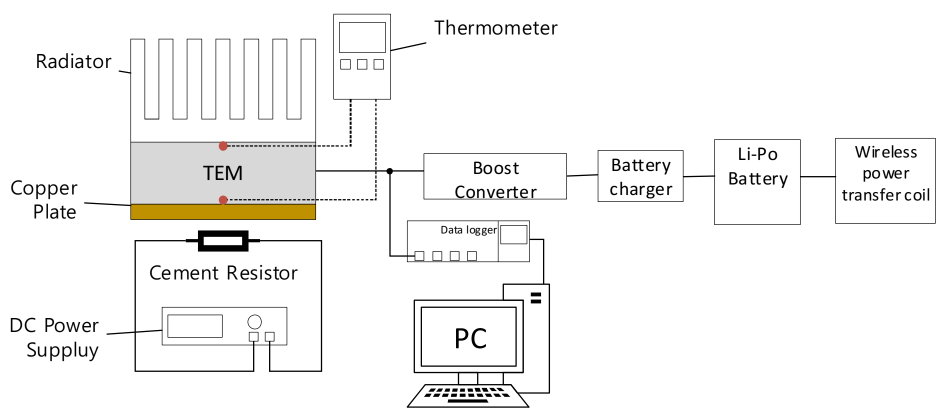

Figure 2. Structure of a thermoelectric energy node

Table 1 shows the voltage, current, and power generated from the thermoelectric energy node used in this experiment.

Table 1. Outputs of a thermoelectric energy node

Condition	Voltage[V]	Current[A]	Power[W]
$\Delta T = 15$℃ ($T_H = 62.7$℃)	2.54	0.08	0.20
$\Delta T = 22$℃ ($T_H = 62.7$℃)	3.13	0.12	0.38

3. Experiment

3.1 Experimental setup

The autonomous charging experiment was performed using a mobile robot. The surrounding environment where the energy node is located is shown in Fig. 3. Initially, the robot is in the standby-position and then moves to the charging station for charging. With the module used in the experiment, the robot must have position accuracy of 1cm and angular accuracy of 20 degrees, for efficiency [12]. If accuracy maps are not given, it is difficult to obtain this precision in mobile robots.

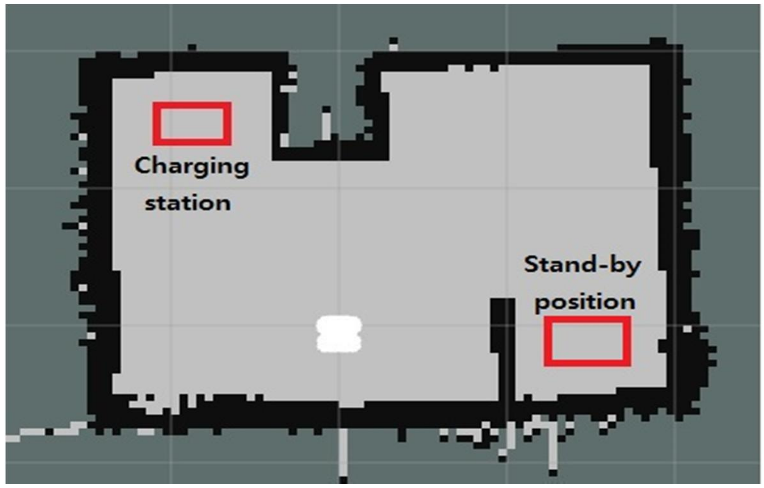

Figure 3. Surrounding environment for experiment

If accuracy maps are not given, it is difficult to obtain this precision in mobile robots. Therefore, in this experiment, after moving to the vicinity of the charging station, the robot recognized the marker through the camera. The robot detected four points on the marker and calculated the position and direction of the correct charging coil. Fig. 4 shows this charging process.

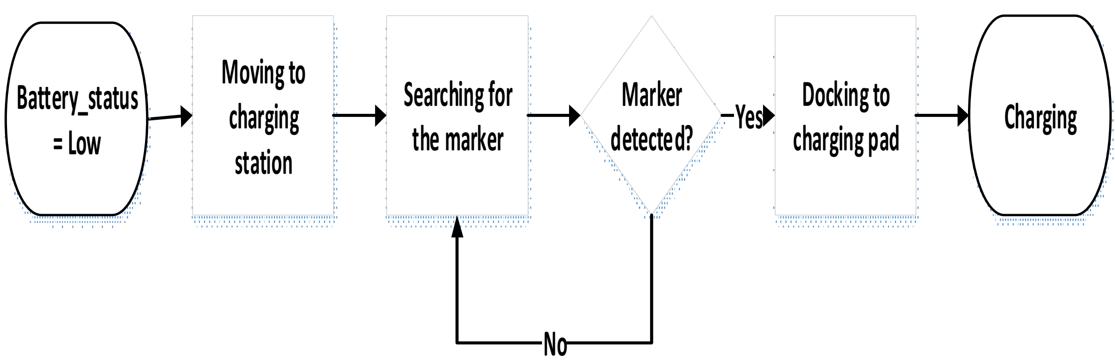

Figure 4. Flowchart showing charging process

The control software is based on ROS(Robot Operating System) [17]. The node configuration for energy management and movement of the robot is shown in Fig. 5. Each node sends and receives data through message communication, and at the battery_charge_manager node, the battery_status of the robot is subscribed, and the position and orientation of the charging station are transmitted to the action server of the navigation stack, and feedback of the driving result is received.

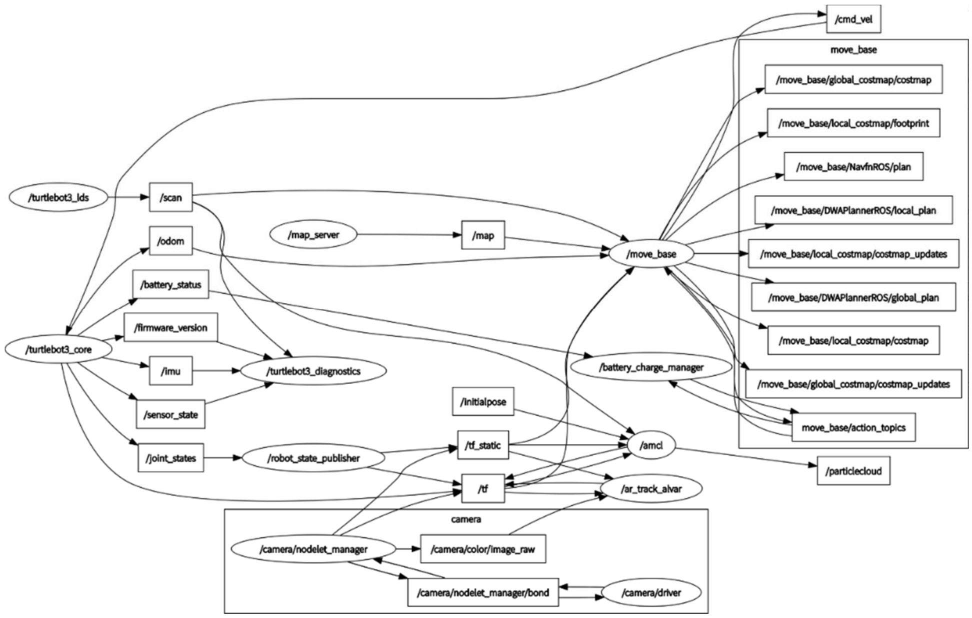

Figure 5. ROS nodes configuration

3.2 Experimental results

In order to precisely align the transmitting and receiving coils, the position and direction of the robot were corrected by recognizing the marker about 50 cm ahead of the station. The image of the marker recognized by the robot is shown in Fig. 6.

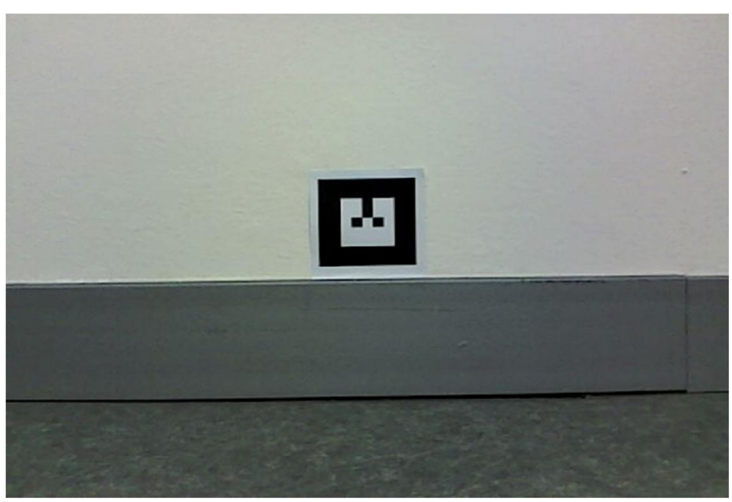

Figure 6. Detected marker for coil alignment

The results of the docking with the charging coil after moving from the initial position to the charging station are shown in Fig. 7 and Fig. 8. It shows that the position accuracy required for wireless charging can be obtained by image information. The mobile robot consumed 6.2W at the stop, which was the sum of the power consumed by the controller and the sensors. When the mobile robot traveled a flat terrain at 0.2 m/s, it consumed an additional 3.9W.

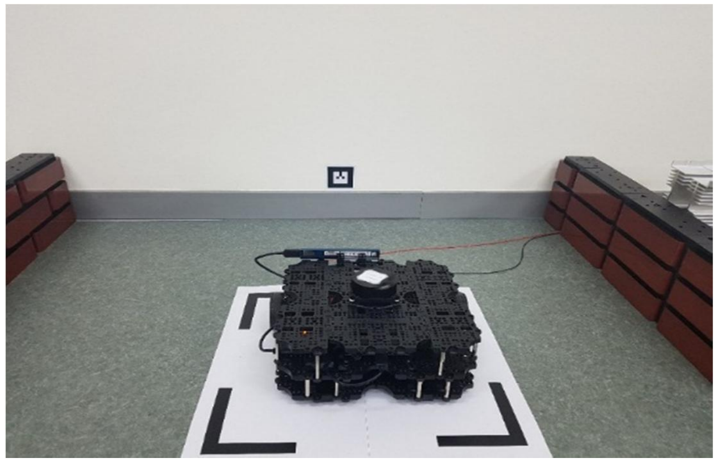

Figure 7. Robot in charging position

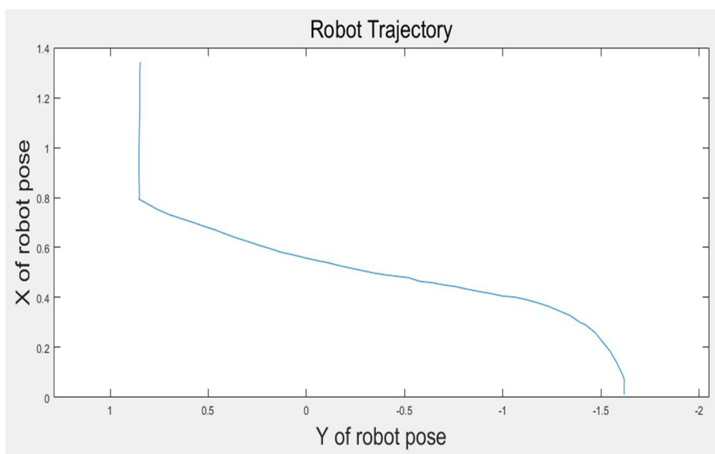

Figure 8. Robot trajectory

4. Conclusion

In this study, we proposed a robot energy autonomy in which a mobile robot used thermoelectric energy, which was renewable energy, as an energy source. The previous studies, where robots use renewable energy, have dealt with the case of having a generator in the robots, however there was a limit to the type of energy available and the conditions. In this study, a renewable energy source exists outside, and the robot is retained by acquiring this energy. A wireless power transfer method was used to solve the mechanical complexity problem of the energy transfer device. The efficiency of wireless energy transmission depends on the alignment condition of the transmitting and receiving coils. Image information was used to accurately align the robot and the transmitting coil. In order to show the validity of the proposed method, actual charging experiments were performed. The robots had sufficient precision for wireless charging, showing that they can be used for robot energy autonomy.

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