Demo Abstract: 3D Simultaneous Localization and Mapping with Power Network Electromagnetic Radiation

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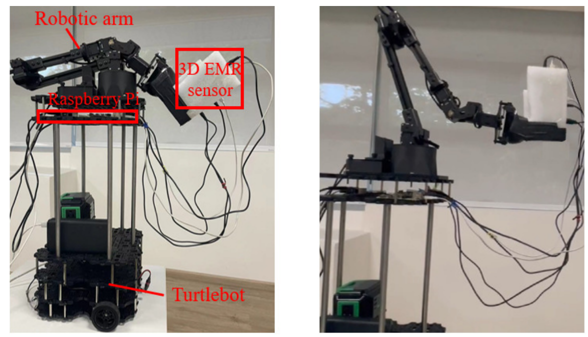
ABSTRACT

Indoor localization by leveraging the existing residential instruments has been widely explored. Given the properties of temporal stability and spatial distinctness, the electromagnetic radiation (EMR) from the powerline network is a promising signal for location sensing. In this demo, we present a three-sensor setup to capture the powerline EMR signal from the three-dimensional (3D) space and formulate a new powerline EMR feature to implement the simultaneous localization and mapping (SLAM). Compared with the single sensor setup, our proposed approach can improve the localization accuracy to decimeter level.

1 INTRODUCTION

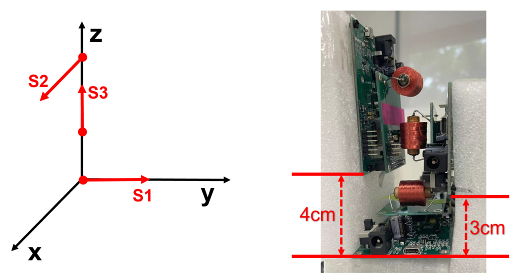
Indoor localization has been an attracting research topic for the past decade. Various location information sensing modalities including geomagnetism, imaging and radio frequency signals have been explored to achieve this goal. However, the above sensing modalities can be inapplicable when the indoor environment has blockage, height fluctuation, or specific privacy requirements. Another drawback is that some localization systems require the deployment of supporting equipment. For example, the system based on WiFi needs the help of wireless access points. This results in extra expense and installation problems to end users. Considering above issues, adopting the ubiquitous power network as the signal source infrastructure is desirable. Because it is not only found to be resistant to the interference suffered by above sensing modalities[2, 3], but also leverages the existing infrastructure.

The key principle behind is that electromagnetic radiation (EMR) emitted by the indoor power network is time-independent while varies spatially. As the generated powerline EMR attenuates along the physical distance, the detected signals at different places provide distinctive amplitudes depending on the density of the electrical wiring presenting at the given place. Based on this property, previous positioning approaches [2], [3] applied two plug-in modules, where one of them injects multiple frequencies actively into the powerline and the other picks up the required signal from the powerline. A recent study [1] adopted a simpler setting with a powerline EMR sensor and proposed a simultaneous localization and mapping (SLAM) and localization scheme. Inspired from these, we design a three-dimensional (3D) powerline EMR-based SLAM framework using a new sensor setup. We put three powerline EMR sensors in mutually orthogonal directions and deploy them on an automatic



(a) mobile sensing system (b) example sensing pose

Figure 1: Setup of 3D powerline EMR sensor on the mobile robotic system.



(a) sensing coordinate system (b) sensor arrangement

Figure 2: The sensing coordinate system (a), and the arrangement of three powerline EMR sensors (b). Three sensors are denoted as 'S1', 'S2' and 'S3' respectively. The red dot and arrow in (a) each represents the center and the direction of the sensor's coil.

robotic system to enable the powerline EMR sensing in 3D space. A new powerline EMR feature is formulated for SLAM. In this demo, we show the mapping and localization results in an office room.

2 SYSTEM ARCHITECTURE

2.1 System Setup

We design a mobile 3D powerline EMR sensing system as shown in Figure 1. The sensing component is a collection of three customized powerline EMR sensors, each of which can sample at 1 ksps. These sensors are arranged using a Cartesian coordinate system originating from one sensor's coil center. As illustrated in Figure 2 (a), each sensor in this coordinate system is represented by a red arrow with a dot, which indicates the direction and center of the sensor's coil respectively. These sensors are set along the axis to be mutually

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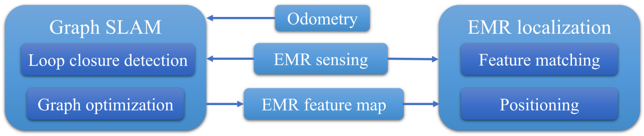

Figure 3: System workflow.

orthogonal. Besides, to avoid mutual interference, they are separated with specific distances which are determined by a series of experiments.

The 3D powerline EMR sensing system is carried by a six-degree-of-freedom robotic arm which is elevated by a platform of a robotic car. When this robotic system moves, the odometry and powerline EMR data along the trajectory is recorded and then used by the SLAM algorithm to construct a powerline EMR feature map. Once a new powerline EMR sequence collected somewhere within the map, its location can be estimated.

2.2 3D Powerline EMR based SLAM and Localization

Based on the properties of temporal stability and spatial distinctness of the powerline EMR, we develop 3D powerline EMR-based SLAM and localization approaches. Figure 3 illustrates the system workflow. The collected powerline EMR signals first pass through a band-pass filter with a pass band of 49Hz to 51Hz. The energy of filtered sequence is calculated at every 0.1 seconds which is the same as the sampling interval of the odometry. The 3D powerline EMR feature is computed as $4 = \sqrt{4_{G}^2 ¸ 4_{\sim}^2 ¸ 4_{I}^2}$, where 4_{G}•$4_{\sim}$ and 4_{I} are the energy along the axis of G•~ and I in the sensing coordinate system. Using the powerline EMR feature sequence and odometry data from the robotic system, the SLAM algorithm detects loop closures to identify the revisited places for graph optimization. Based on that, the trajectory can be recovered. As the powerline EMR and odometry data is synchronized, we generate the feature map by associating the powerline EMR feature with the recovered positions based on their timestamps.

For localization, we use a slide window to match the newly collected powerline EMR feature sequence with the feature map. Specifically, we formulate a distance vector and fill it with the Euclidean distance of the newly collected and windowed sequences. The window is slid from the first point of the feature map and move one point forward each time to traverse all points. After that, we take the minimum value in the distance vector as the matching result. The localization prediction is given as the corresponding position of this matched sequence.

3 DEMONSTRATION

The demonstration is performed in an office room covering 32 m^2 and is shown in Figure 4(a). The used devices are one laptop, a Turtlebot 3 waffle Pi with a wireless router, an Interbotix robotic arm, three calibrated powerline EMR sensors, where each sensor is connected to a Raspberry Pi 4. The laptop and Raspberry Pis are all linked to the network of the robotic system through its router. The laptop remotely controls the robotic system and powerline EMR sensors. When the robots follow the set path, sensing and data

Figure 4: Floorplan of the demo room (a), and the pre-set and recovered pathes of 1D powerline EMR SLAM and 3D powerline EMR SLAM (b).

Figure 5: 3D powerline EMR feature map (a), and the localization results of four electrical appliances at the demo room (b).

transmission processes are activated for SLAM and localization tasks.

In this demo, we show the implementation process of our proposed approach. First, a groundtruth path, represented by red lines in Figure 4 (a), is set for the robots to follow at a constant velocity. Next, we simultaneously start the robotic system and powerline EMR sensors to collect data along the set path. After the path is finished, the SLAM algorithm recovers the trajectory using the transferred powerline EMR and odometry data as shown in Figure 4 (b), and also generates the powerline EMR feature map. Figure 5 (a) shows the feature map, where the the intensity variations of the powerline EMR feature along the path are represented by different colors. Based on this feature map, we localize four electrical appliances along the path. Specifically, we collect a short sequence of powerline EMR data when the robotic system passes by an electrical appliance. Figure 5 (b) shows the localization results of these four electrical appliances from their powerline EMR feature sequences.

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