Coverage-scalable Instant Tabletop Positioning System with Self-localizable Anchor Nodes

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ABSTRACT

This demo paper presents a desktop 3D positioning system, which is implemented with geomagnetic sensors and coils for DC magnetic field generation.Our system is composed of sensor nodes for localization, which sense and transmit the magnitude of the magnetic field to a host computer, and anchor nodes, which intermittently generate DC magnetic field with the functionality as sensor nodes. An advantage of our system is that the cover range and estimation accuracy can be enhanced instantly by adding anchor nodes since the added anchor node is also automatically localized. Also, the sensor node can be implemented in a mm-scale form factor with small power consumption thanks to the geomagnetic sensor, which enables us to attach the sensor nodes to various things. Object tracking could serve as a primary application of this system, such as virtual reality (VR), interactive educational experience and rehabilitation which can benefit the human computer interaction.

CCS CONCEPTS

• **Human-centered computing → Collaborative interaction**; *Virtual reality*; *User interface design.*

KEYWORDS

Positioning System, Desktop Positioning System Application, DC Artificial Magnetic Field

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1 INTRODUCTION

Positioning system has thrived for tens of years and has opened up many areas, such as industrial automation, navigation on emergency conditions and medical devices, and the operation coverage can range from worldwide to workspace. Although there already exists some research on the positioning system, the system which in the indoor environment and tabletop application is still challenging due to the accuracy and coverage with limited power. Magnetic field based methods are thought to be suitable because it provides excellent penetration properties through most non-metallic materials [2] and the simple architecture. The magnetic field-based methods for positioning system mostly use artificial DC or AC signal as the source signal and analyze the variation of the magnetic field to acquire location information. In the case of AC magnetic field-based methods, smaller numbers of signal sources and receiver sensors are adequate [3], but the AC magnetic field easily attenuates due to metallic obstacles. Instead, we use DC magnetic field, which is relatively robust to metallic obstacles and can be measured by a geomagnetic sensor whose form factor and power are very small.

2 METHOD

Figure 1 shows our system consisting of sensor nodes for localization, which sense and transmit the magnitude of the magnetic flux density to a host computer, and anchor nodes, which intermittently generate DC magnetic field with the functionality as sensor nodes. To estimate the position of the sensor nodes, after one anchor node coil is enabled, each sensor node measures the magnetic flux density *Bx, By, Bz* and the root sum square (RSS) of *B*, which is independent of the rotation on the sensor or signal source, is transmitted to a host computer, where the effect of terrestrial magnetism is subtracted. Here, in electromagnetic theory, there is a viable magnetic dipole formula to model the relationship between the magnetic field and current which flow through the coil. The derived magnetic flux density is addressed in [1], and it shows that the distance is inversely propositional to the cube of RSS of *B*. Then, we can get the distance information using this relation. Note that we do a fitting to make the dipole model more appropriate in proximity condition. This measurement is repeated by changing the enabled anchor node.

Then, we localize each sensor with triangulation at the host computer. After that, a possible way is to use gradient descent to compute the position of the sensor nodes. Gradient descent is a general solution, and it is robust even when the distance information includes inaccuracy.

An important feature is that the anchor node also has a functionality of a sensor node, and the anchor node itself can also be localized in the system. When adding a new anchor node, we will first regard it as a sensor node. After estimating its position using other anchor nodes, it becomes an additional reference point to support estimation. In our system, the coverage area and the estimation accuracy can be improved by adding anchor nodes. Figure 3 shows a simple example, where the red points are the positions of anchor nodes and the blue circle represents the coverage of the anchor nodes. Since the node localization needs at least three anchor nodes

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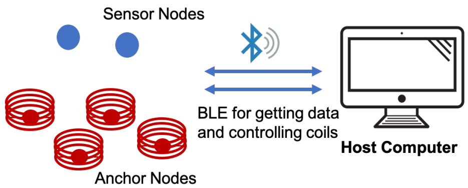

Figure 1: Structure of the proposed positioning system.

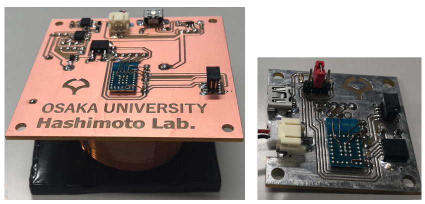

Figure 2: Prototyped anchor and sensor nodes.

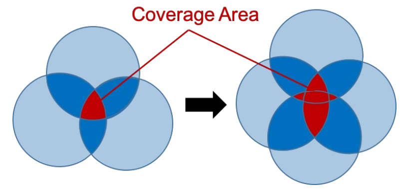

Figure 3: Coverage area illustration: The fourth anchor node extends coverage

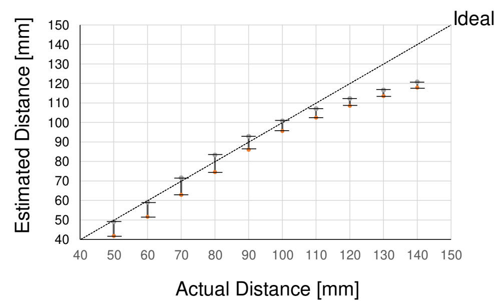

Figure 4: Distance estimation result.

as reference points, with three anchor nodes in the left-hand side figure, we can only estimate the location in the darkest region. On the other hand, when adding another anchor node as shown in the right-hand side, the position estimation coverage is extended. Also, the estimation in the region covered by four nodes can be more precise than the node covering by three anchor nodes by using most likelihood estimation instead of simple triangulation.

When the number of anchor nodes is smaller than three during the setup process, our system defines the coordinate system and locate them in it. The first anchor is located at the origin, the second anchor is located on the x-axis, and the third one is placed on the x-y plane. When giving a rule of the third anchor location, for example, clock-wise order, we can place the third anchor as we expected without flip ambiguity.

3 IMPLEMENTATION

There are two types of nodes in our system: anchor nodes and sensor nodes. Both types of nodes are equipped with geomagnetic sensors to measure the magnetic flux density. We choose geomagnetic sensor BM1422AGMV to sense the magnetic flux density owing to its tiny volume and low power consumption. Each anchor node uses a copper coil for DC magnetic filed generation, whose ϕ size, height, and winding number are 42mm, 30mm, and 243, respectively. We provide 1A current to the coil. Both sensor and anchor nodes use Bluetooth Low Energy (BLE) technology to communicate with the host computer. Fig. 2 shows the prototyped anchor nodes and sensor nodes with the size of 7cm×7cm×3.5cm and 4cm×4cm×0.2cm, respectively. Note that these nodes are rapidly prototyped and they not optimized yet for form factor minimization.

4 EVALUATION EXPERIMENT

We first evaluate the accuracy of the estimated distance between an anchor node and a sensor node. After setting an anchor, we placed a sensor node at eight positions on the circle whose origin was the anchor. Figure 4 shows the experiment result. The error bar for each corresponds to the difference between the maximum and minimum estimates. As the distance becomes large, the accuracy degrades since the signal-to-noise ratio (SNR) deteriorates. If we can accept 1 cm error, for example, the coverage distance of an anchor node is 12 cm. In contrast, we guess a magnetic field mismatch from the dipole model arises near the anchor node due to, for example, battery and PCB. When the node form factor is minimized, this mismatch is expected to be mitigated.

We also conducted experiments showing the nodes can be localized and the coverage area can be extended by adding a new anchor node, which can be found in the demo video.

5 CONCLUSION AND FUTURE WORK

In this paper, we presented a positioning system which used the artificial DC magnetic field for distance estimation. magnetic field. Both anchor and sensor nodes are equipped with a geomagnetic sensor, and hence the anchor nodes themselves can be automatically localized. This feature enables us to extend the coverage area instantly just with a new anchor node, which was demonstrated in our experiment. Our near future work includes accuracy improvement with maximum likelihood estimation and latency minimization with sophisticated anchor activation scheme.

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