Development of Tiny Wireless Position Tracker Enabling Real-Time Intuitive 3D Modeling

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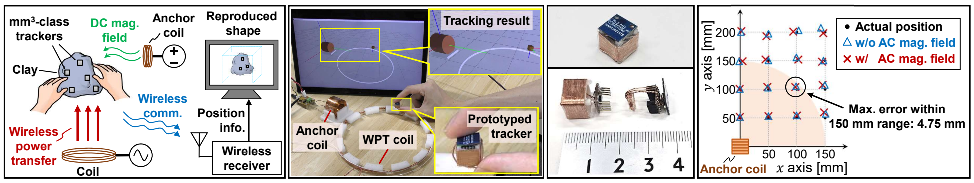

(a) (b) (c) (d)

Figure 1: (a) 3D modeling system using clay embedded with mm^3-class position trackers. Trackers are wirelessly powered and perform wireless communication and DC magnetic field-based localization. Computer reproduces clay shape based on position information of trackers. (b) Prototyped system tracking the position of a wirelessly powered tracker. (c) Appearance of assembled and disassembled tracker. (d) Localization results with and without AC magnetic field for WPT.

Abstract

We propose a wirelessly powered and communicable position tracker implemented in a 10 mm cubic volume. Measurement results with a prototype show that the proposed adaptive power receiver (APR) maintains constant wireless power delivery regardless of the tracker's position. Additionally, the system achieves a maximum localization error of 4.75 mm.

Keywords

3D modeling, wireless position tracker, wireless power transfer

ACM Reference Format:
Yuki Maegawa, Masanori Hashimoto, and Ryo Shirai. 2024. Development of Tiny Wireless Position Tracker Enabling Real-Time Intuitive 3D Modeling. In *SIGGRAPH Asia 2024 Posters (SA Posters '24), December 03–06, 2024, Tokyo, Japan.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3681756.3697874

1 Introduction

Advancements in computer architecture and graphic processing technology have led to a growing number of applications utilizing 3D models. To meet the increasing demand for 3D models, there is a rising need for methods accessible to non-experts, rather than traditional 3D CAD, which requires expertise. While 3D scanners can be used by non-experts, they cannot accurately reproduce internal cavities of objects. To address these challenges, [Hashimoto et al. 2017] proposed the "iClay" system, shown in Fig. 1(a). The iClay system allows users to make their own 3D models only by deforming the clay since it can recognizes the clay shape based on position information of trackers. To realize the iClay system, wireless real-time position trackers are required, such as that proposed by [Huang et al. 2015]. However, the tracker developed by [Huang et al. 2015] requires three coils whose sizes are ϕ4 mm $\times$ 15 mm with ferrite cores, preventing mm^3-scale downsizing.

To address this issue, we categorize the necessary technologies for small-volume trackers in iClay into three elements: wireless power transfer (WPT), wireless communication, and localization with tiny sensor. For WPT, AC magnetic field-based methods can provide sufficient power even to tiny trackers. However, in applications like iClay, where receiver (RX) positions vary significantly, excessively received power could damage the circuit when the device approaches the transmission (TX) coil, necessitating additional power control circuits. For wireless communication, the method proposed by [Shirai et al. 2017], which does not require dedicated antennas and is easily miniaturized, suits iClay. For localization, the DC magnetic field-based method proposed by [Shirai et al. 2021], using mm^3-scale MEMS magnetic and acceleration sensors, is applicable to iClay. However, the size of the tracker proposed by [Shirai et al. 2021] cannot be reduced to the mm^3-scale since it uses a battery as a power source. Utilizing WPT can help reduce the tracker volume. However, the compatibility of wireless communication and localization methods in the presence of the strong magnetic field used for WPT remains unclear since a wirelessly powered DC magnetic field-based position tracker has never been reported.

2 Proposed tracker structure

This section proposes the structure of a tiny position tracker embedded in the clay shown in Fig. 1(a). Fig. 2 illustrates the circuit structure of the proposed tracker, and Fig. 1(c) shows the disassembled prototype tracker. The tracker consists of a newly proposed

SA Posters '24, December 03–06, 2024, Tokyo, Japan

ACM ISBN 979-8-4007-1138-1/24/12
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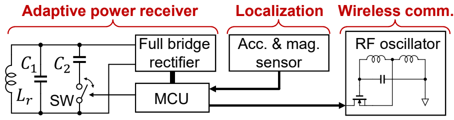

Figure 2: Structure of proposed wireless position tracker.

adaptive power receiver (APR), a 6-axis sensor (accelerometer and magnetometer) for localization, and a radio frequency (RF) oscillator for wireless communication. As for 6-axis sensor, we used LSM9DS1 from STMicroelectronics, which is capable of performing 1,000 measurements per second, thereby enabling real-time position tracking. The coil L_r is responsible for receiving wirelessly transmitted power and is shaped as a 10 mm × 10 mm × 10 mm cube with 24 windings. The external WPT circuit generates a magnetic field at a frequency of $1/2\pi\sqrt{L_r C_1}$, and the tracker receives power through a resonator consisting of L_r and C_1. The microcontroller unit (MCU), which controls the APR, monitors the amount of received power. The MCU closes the switch (SW) when the tracker approaches the TX coil and the supplied power becomes excessive; otherwise, the SW is kept open. By closing the SW, the resonance frequency of the resonator changes to $1/2\pi\sqrt{L_r(C_1 + C_2)}$, consequently reducing the received power to less than 1/1000 and preventing damage to the circuit. The tracker utilizes an accelerometer and a magnetometer to estimate its position based on the method proposed by [Shirai et al. 2021]. The MCU drives the RF circuit proposed in [Shirai et al. 2017], which consists of a Hartley oscillator, to transmit information from sensors wirelessly. This RF communication circuit does not require a dedicated antenna and hence we can reduce the implementation volume. To avoid the interference with the magnetic field for WPT, RF oscillator outputs far high frequency compared to that of the signal for WPT.

3 Evaluation

This section evaluates the performance of the prototype tracker. First, we evaluates the proposed APR circuit. Fig. 3(a) illustrates the evaluation setup. We introduce a TX coil with a diameter of 200 mm and two windings for WPT. An AC power source connected to the coil outputs a signal with a frequency of 230 kHz and an amplitude of 92 Vpp. With this setup, the TX coil can deliver sufficient power to the tracker at a distance of up to 7.5 cm, and input voltage adjustments extend this distance beyond 10 cm, which is suitable for the iClay system. Fig. 3(b) presents the measurement results. In Fig. 3(b), the output voltage of the APR circuit drops below 2.0 V shortly after 10 ms, prompting the MCU to open the switch (SW). When the MCU detects that the output voltage has risen to 3.6 V, MCU closes the SW again to prevent exceeding 3.6 V, successfully maintaining the voltage between 2.0 V and 3.6 V.

Next, we evaluate the RF communication performance in the presence of a strong AC magnetic field for WPT. Fig. 4(a) illustrates the evaluation setup where the setup of WPT is identical to that in Fig. 3(a). We employ a VHF band superheterodyne receiver to capture the targeted signal amidst the strong magnetic field. With this receiver, the evaluated maximum communicable distance is 16.5 cm, which is sufficient for iClay system. The frequency of the RF signal emitted by the tracker is 96 MHz, and the communication distance between the tracker and the receiving antenna is 10 cm,

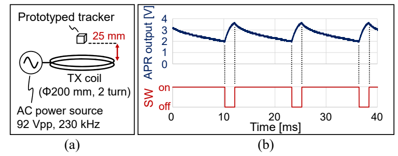

Figure 3: Evaluation of proposed APR. (a) Evaluation setup. (b) Status of SW and measured output of the APR circuit.

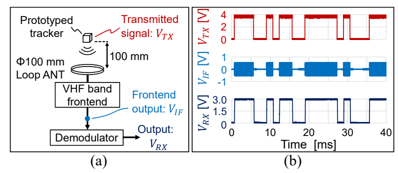

Figure 4: Evaluation of wireless communication function. (a) Evaluation setup. (b) Measured waveform of TX signal, output signal from RF frontend, and reproduced signal.

a typical distance for communications within the iClay system. Fig. 4(b) displays the waveform of the original signal transmitted by the trackers, the RF signal output from the superheterodyne VHF band frontend, and the signal processed by the demodulator. Fig. 4(b) demonstrates that the receiver successfully reproduces the transmitted signal, confirming that wireless communication is feasible even in the presence of WPT signal.

Finally, we perform DC magnetic field-based localization in the presence of a magnetic field for WPT. The measurement setup and results are shown in Fig. 1(d). The anchor coil whose size is ϕ43 mm × 30 mm is placed at $(x, y) = (0, 0)$ on the xy-plane, and a current of 1 A is injected into it. We evaluate the 2D localization performance, given that DC magnetic field generated by the coil is axially symmetrical. The performance is evaluated in two scenarios: with and without the presence of a strong AC magnetic field. Fig. 1(d) presents the average localization results from 1,000 samples at each point, indicating that the localization accuracy is not compromised by the AC magnetic field. With the proposed APR, the wireless communication, and the localization method, we enable the tiny wireless position tracker as shown in Fig. 1(b).

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP22K17867.

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