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Wireless Magnetic Motion Capture System for Multi-Marker Detection

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A wireless multi-motion capture system using five LC resonant magnetic markers has been developed and is demonstrated. Each marker has an individual resonant frequency, 157, 201, 273, 323, and 440 kHz, respectively. A new measuring technique is applied in order to reduce the acquisition time. In this new technique the markers are excited by a superposed wave corresponding to the all resonant frequencies, while the voltage signals induced through pick-up coils are separated in a frequency spectrum by FFT analysis. Regardless of the number of markers, the voltage amplitude for each resonant frequency can be easily obtained simultaneously and thus the proposed system can detect multiple markers. The positional accuracy for five markers is less than 2 mm within 100 mm of the pick-up coil array.

Index Terms—**FFT analysis, LC resonant magnetic marker, multi-marker, wireless motion capture system.**

I. Introduction

Wireless motion capture for multi-point detection at close range is a candidate technique for virtual input devices or medical treatment applications. In such applications, particularly for measurements of the motion of fingers, the markers used must be small and free from electric wiring to allow normal motion. In addition, the location and orientation of the markers must be known exactly during the measurement. Furthermore, if a dead angle is likely to occur, an optical method is unfavorable. There have been several investigations into determining the position of a magnetic object by measuring its magnetic field [1]–[6]. However, conventional systems require a comparatively large magnetic object as a marker or the marker must contain electric wiring, in order to obtain a high SN ratio for the magnetic signal from the marker. To address this, we have proposed and developed a wireless magnetic motion capture system using a magnetically-coupled LC resonant marker [7], [8]. The small sized marker uses a soft ferrite core with a coil, representing a minimal LC circuit with no battery, driven wirelessly by electromagnetic induction. The magnetic signal of the marker is detected by a matrix-designed pick-up coil array. Our proposed system allows the approximate orientation and the position of a single marker to be determined accurate to within 1 mm in a space 150 mm from the pick-up coil array. It also allows multi-point detection because the system allows the use of several markers with individual frequencies. In this paper, we extend our system to detect multiple markers and we examine the accuracy of the system in detecting the positions and orientations of the markers.

II. Components and Measuring Method of the System

Fig. 1 shows a schematic diagram of the motion capture system for multi-marker detection. The system is composed of measurement instruments and a coil assembly, consisting of a

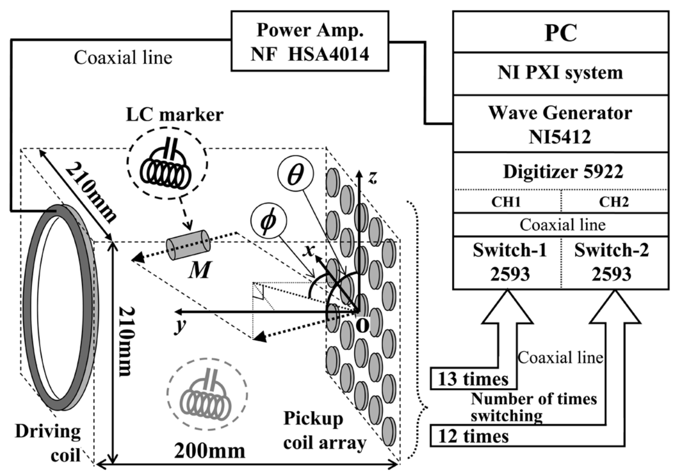

Fig. 1. Schematic diagram of the proposed wireless motion capture system for multiple markers.

driving coil, LC markers, and a pick-up coil array. The marker consists of a Ni-Zn ferrite core (3 mm in diameter and 10-mm long) with a wound coil and a chip capacitor, representing an LC series circuit designed for resonant frequencies of 157, 201, 273, 323, and 440 kHz. The pick-up coil array consists of 25 coils placed at intervals of 45 mm on an acryl board, configuring a matrix layout. Each coil is made of 40 turns of polyester enameled copper wire (PEW) around an acryl bobbin 25 mm in diameter. An excitation of 22 V is applied to the driving coil (10 turns of PEW around the Teflon coil, 200 mm in diameter) and the markers are strongly excited at their resonant frequency by electromagnetic induction. However, the system becomes slow with an increase in the number of markers, owing to time required to switch frequencies and make multiple measurements. In this paper, a new signal measurement method is adopted to increase the system speed. All the markers are excited simultaneously by a superposed wave corresponding to all the resonant frequencies of the markers. As shown in Fig. 2, the induced wave measured by the pick-up coil is analyzed into a frequency spectrum by FFT analysis. First, the spectrum is measured without the markers and then the spectrum is

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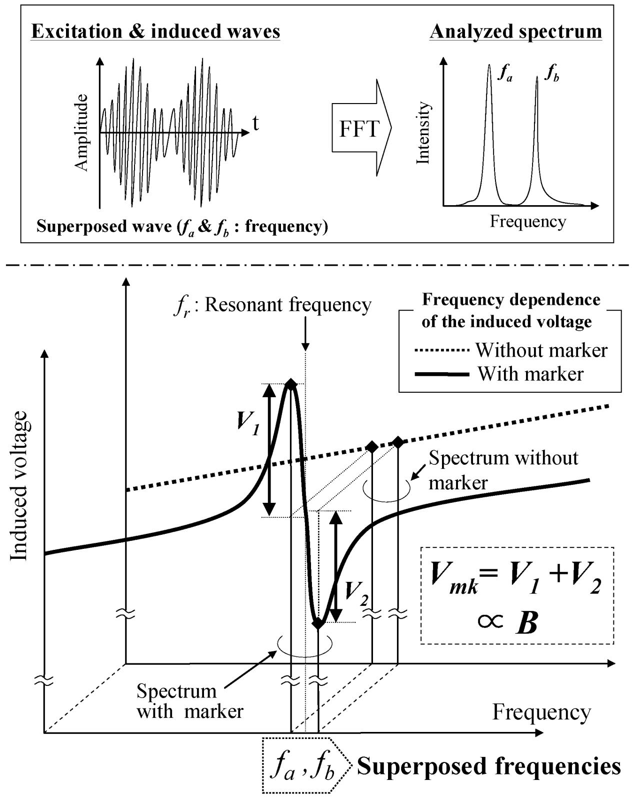

Fig. 2. Signal of LC marker acquisition technique (superposed wave excitation and FFT analysis).

measured with the markers. The induced voltages of the marker contributions, V_{mk}, can be obtained by subtracting as vectors the amplitude of the spectrum without the markers from the amplitude of the spectrum with the markers. The amplitudes V_{mk} measured by each pick-up coil are different from each other and proportional to the flux densities $\boldsymbol{B}$ that the markers produce at the location of the pick-up coils. The position and orientation of each marker is obtained by solving an inverse problem. However, several values (25 values in our study) of the flux density at a known location specify the magnetic flux source. To solve this problem, the generated flux density from a marker is considered to be a magnetic dipole field. Under this assumption, the position and orientation of a marker are calculated using the nonlinear method of least squares by the Gauss–Newton method [9]

$$S(\vec{p}) = \sum_{i=1}^{n} \left| \vec{B}_{\mathrm{meas}}^{(i)} - \vec{B}_{\mathrm{cal}}^{(i)}(\vec{p}) \right|^2 \rightarrow \text{Minimum} \tag{1}$$

$$\vec{B}_{\mathrm{cal}}^{(i)}(\vec{p}) = \frac{1}{4\pi\mu_0} \left\{ -\frac{\vec{M}}{r_i^3} + \frac{3(\vec{M}\cdot\vec{r}_i)\cdot\vec{r}_i}{r_i^5} \right\} \tag{2}$$

$$\vec{p} = (x, y, z, \theta, \phi, M). \tag{3}$$

Here $S(\vec{p})$ is an objective function (the least squares value), i is the coil number, n is the total number of coils, $\vec{B}_{\mathrm{meas}}^{(i)}$ is the measured flux density, $\vec{B}_{\mathrm{cal}}^{(i)}$ is the theoretical flux density that takes into account the magnetic dipole field, $\vec{p}$ represents the parameters of the marker, $\vec{M}$ is the magnetic moment, (x, y, z) is the position of the marker, and $\vec{r}$ is an ideal dipole field expressed as a function of position and orientation. As shown in Fig. 1, ϕ is the angle between the x-axis and the direction vector when the moment is projected on an xy-plane and θ is the angle between the direction of the moment and the z-axis.

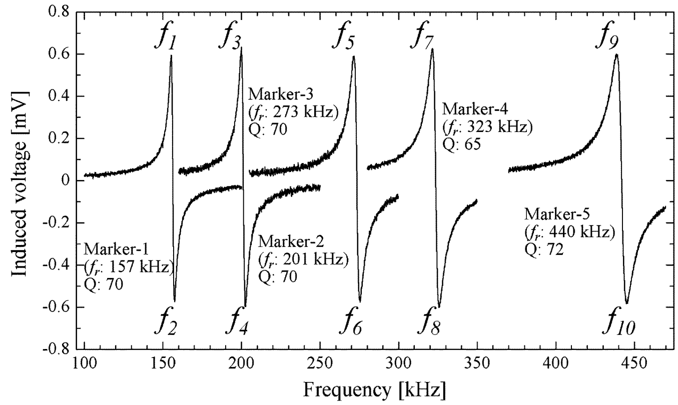

Fig. 3. Induced voltages due to excitation of five markers.

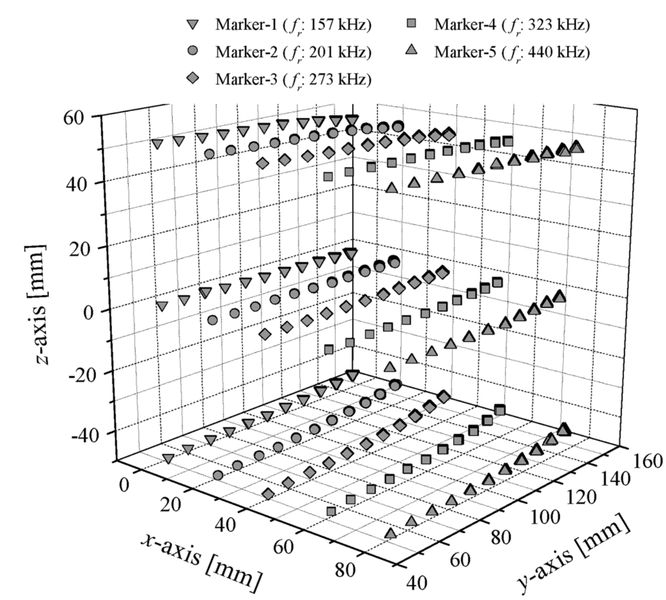

Fig. 4. Evaluation results of detected position (displayed in three dimensions).

Fig. 3 shows the frequency dependence of the induced voltage from the markers. Sharp signals due to LC resonance of the markers were observed and there is no influence on neighboring signals from the skirts of the signals. In practice, the superposed wave, which is composed of ten frequencies corresponding to upper and lower peaks $(f_1 - f_{10})$, shown in Fig. 3 was used for excitation.

III. Results and Discussion

The position accuracy was verified experimentally for the system. Fig. 4 shows the detected positions and Fig. 5 shows the detected orientations when the five markers were lined up in five ranks parallel to the y-axis at 20-mm intervals. The markers were swept from $y = 50$ mm to 150 mm in 10-mm steps along the y-axis in the xy-plane at $z = 50$ mm, 0 mm, -50 mm (refer

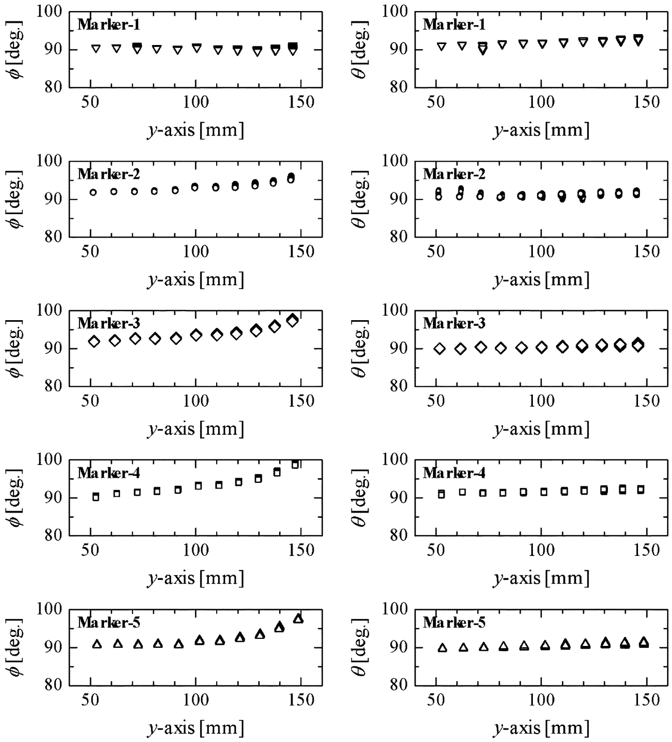

Fig. 5. Evaluation results for ϕ and θ (xy-plane at $z = 0$ mm).

to Fig. 1 for the coordinate system). As shown in Figs. 4 and 5, results can be distinguished to less than 1 mm and the position accuracy for each marker is within 2 mm. Approximately correct orientations were obtained when the markers were located up to 100 mm from the pick-up coil array. These results show that the system is capable of simultaneously capturing the motion of multi-markers wirelessly with a high accuracy. However, the detected positions were deflected toward the y-axis (the center axis of the pick-up coil array) gradually as the marker position increases over 100 mm from the pick-up coil array. Accordingly, the deviation of the attitude angle ϕ increases gradually up to about 10 degrees. A maximum positional deviation of around 6 mm was observed for markers located at (80, 150, 50), (80, 150, 0), and (80, 150, −50), whereas, as shown in Fig. 6, the intervals between adjacent markers were less than 3 mm in terms of relative position accuracy. The relative error of the measured position of all the points at intervals between adjacent markers was evaluated and expressed as an averaged value with a standard deviation. The results are as follows: 19.03 ± 0.88 mm at Mk1-2 (interval between Marker 1 and Marker 2), 18.79 ± 0.25 mm at Mk2-3, 19.88 ± 0.65 mm at Mk3-4, and 20.55 ± 0.41 mm at Mk4-5.

The increase in the detection error for large distances is thought to be due to the relation between the size and arrangement of the driving coil and the pick-up coil array, though the exact cause of these deflects is not yet clear.

IV. Conclusion

The performance of a proposed wireless magnetic motion capture system for multi-makers was evaluated for five LC resonant magnetic markers with individual resonant frequencies. The positional accuracy of the markers was found to be less than 2 mm and the approximate orientation of a marker could be determined when the marker was located within 100 mm^3, up to 100 mm from the pick-up coil array. However, the detected positions were deflected toward the y-axis (the center axis of the pick-up coil array) gradually as the distance of the marker from the pick-up coil array increased.

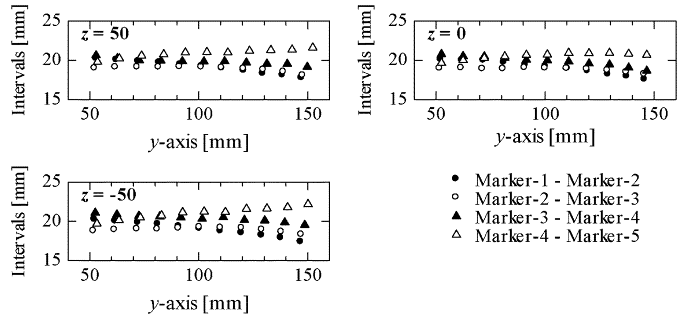

Fig. 6. Intervals between adjacent markers.

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