Experimental study on the effects of groups of people on magnetoquasistatic positioning accuracy

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***Abstract*—Position and orientation measurements have been demonstrated, recently, using low-frequency magnetoquasistatic fields and complex image theory for distances up to 50 m [1]. The key motivation for using magnetoquasistatic fields is to enable accurate estimation of an object's position and orientation when near weakly conducting dielectric obstacles, e.g., groups of people. An example application is tracking an American football during game-play [1]. In this paper, we present measurements using the magnetoquasistatic technique to show that the presence of a large group of 25 people introduces a peak distance error of less than 4.5 cm for an emitter-receiver distance of 10 m.**

I. Introduction

Recently, a position and orientation measurement technique using magnetoquasistatic fields and complex image theory was shown to enable long range, one-dimensional [1] and two-dimensional position [2] and orientation [3] measurements. In this technique, an electrically-small current loop was used to generate low-frequency magnetoquasistatic fields by using a frequency of approximately 360 kHz. This frequency is somewhat higher than conventional magnetic tracking techniques, which operate below 4 kHz [4], thus providing a much larger signal-to-noise ratio (SNR) and hence increased range. The use of higher frequencies necessitates the use of complex image theory to account for induced eddy-currents within the nearby earth. By using complex image theory in our previous work, we showed a one-dimensional peak and RMS error of 23.01 and 11.74 cm, respectively, for distances between 1.3 and 34.2 m [1].

Because low-frequency magnetoquasistatic fields are not strongly perturbed by nearby weakly conducting dielectric bodies, this technique performs well in non line-of-sight (LoS) environments, such as around groups of people. To verify the insensitivity, we conducted preliminary measurements in [1] with a small group of people blocking the LoS between a vertical emitting and receiving loop with a circumferential field coupling. The result of this measurement showed a peak error of 1.1 cm for a frequency of 400 kHz, with an increase in measured error for higher frequencies and a peak error of 53 cm for a frequency of 13 MHz [1]. These previous measurements where limited as they were primarily conducted to determine the effect due to various frequencies, were conducted only for circumferential field coupling, and performed with a small group of 4 people. Our previous work is further limited due to a very short distance between the emitter and receiver, and that the group is only positioned to block the LoS and not located to surround the emitter or receiver [1].

In this paper, we present measurements for a large group of 25 people over a much longer distance (10 m) with two different antenna configurations. The results show that the presence of a large group of people introduces a peak position estimation error of less than 4.5 cm for an emitter-receiver distance of 10 m, regardless of whether the group is blocking the LoS between the emitter and receiver, or surrounding the emitter or receiver. We use a frequency of about 360 kHz in this work, which has been shown to enable positioning over distances of up to approximately 50 m [1]. We describe the experiment and present results in Section II, and conclude in Section III.

II. Description of Experiment

In a practical outdoor environment (for example, tracking an American football during game play by embedding an emitter into the football), successful long distance positioning systems must offer immunity to LoS blockage or effects due to the induced currents from nearby conducting objects [1]. In most outdoor use cases, this involves working around large weakly conducting bodies. To verify the insensitivity to blocking the LoS by large weakly conducting bodies, measurements using a large group of people were conducted. Figure 1 shows the setup for the measurement. The group of people was positioned with people in very close proximity to each other, and to block the LoS between the emitting loop and the receiving loop. In order to obtain a complete measurement of all field components, we conducted circumferential and radial field coupling measurements, as indicated in Fig. 1 by the gray and black lines, respectively. For the LoS blockage measurement, the group's center position was at a_y=5 m and the distance between the emitter and receiver was L=10 m. We also conducted measurements when the group was surrounding the emitter for a_y=0 m, and when the group was surrounding the receiver for a_y=10 m. Measurements were conducted by sequentially

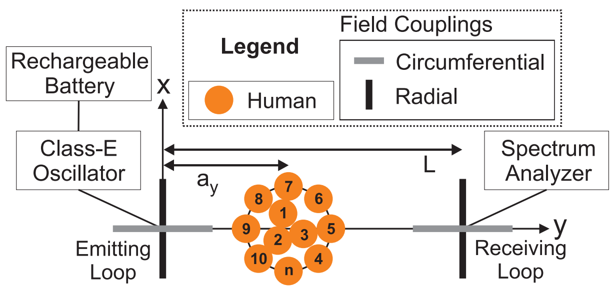
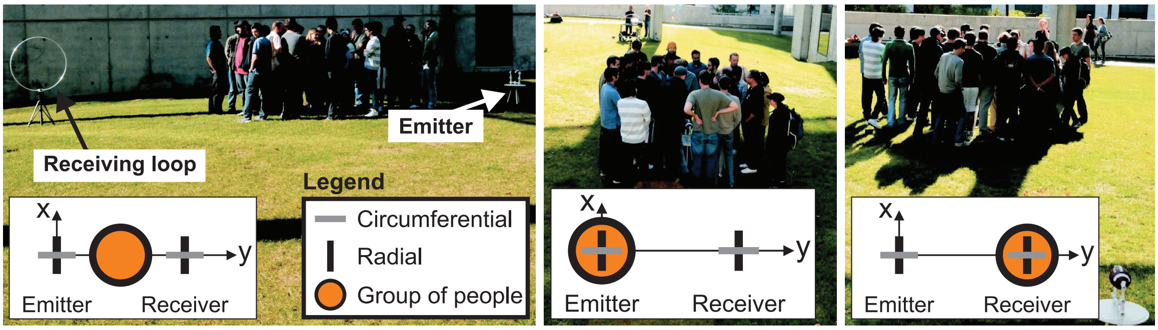


Fig. 1. Measurement setup with a group of n-people, where $n = [1, ..., 25]$, with an emitter-receiver separation distance of $L = 10$ m. Measurements were conducted when the group blocked the LoS for $a_y = 5$ m, and when the group surrounded the emitter ($a_y = 0$ m) and receiver ($a_y = 10$ m). Note that the people were not added in any order or with any regular spacing.



(a) (b) (c)

Fig. 2. Pictures of measurements conducted, showing: (a) a large group of 25 people blocking the LoS during a circumferential coupling measurement; (b) a large group of 25 people surrounding the emitter during a radial coupling measurement; (c) a large group of 25 people surrounding the receiver during a radial coupling measurement. The figure in each inset pictorially depicts the location of the group of people for each measurement.

incrementing the number of people in the group, up to a total of 25 people. Figure 1 also shows the measurement block diagram. The receiver system consisted of an active receiving loop (model LFL-1010 by Wellbrook Communications) and a spectrum analyzer (model 8593E from Agilent Technologies), and was similar to that used in [1]. The emitter consisted of 45-turns of 32 AWG wire and a high-efficiency class-E oscillator with an output signal of 360 kHz and an output power of 0.56 W. The 45-turns of wire was coiled around the smaller-circumference of the American football, and the coil, class-E circuit, and rechargeable battery was integrated into the shown American football (on white RF-translucent tripod in Fig. 2). The emitter was similar to that used in [2], with the exception that the present system was integrated into the football.

Figure 2 contains three pictures taken during the measurements, showing a large group of 25 people blocking the LoS during a circumferential coupling measurement, a large group of 25 people surrounding the emitter during a radial coupling measurement, and a large group of 25 people surrounding the receiver during a radial coupling measurement. By measuring the induced voltage in the receiving loop with and without the group of people, the change in measured power was obtained and is shown in Fig. 3. The results show that the large group of people does not significantly impact the low-frequency magnetoquasistatic field strengths. The black triangles in the figure indicate measurements for when the group of 25 people (entire group) surrounded the emitter/football or the receiver. From the measurements with and without the group of people, the change in estimated distance was computed using the technique

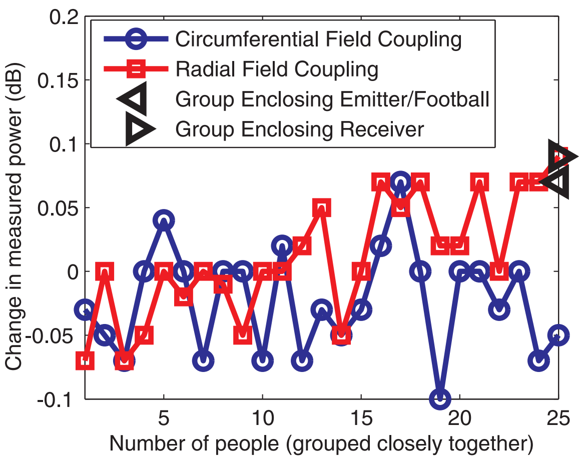


Fig. 3. Change in measured power at the receiver due to the presence of a group of 1 to 25 people. The triangles indicate measurements for when the group of 25 people (entire group) surrounded the emitter/football or the receiver.

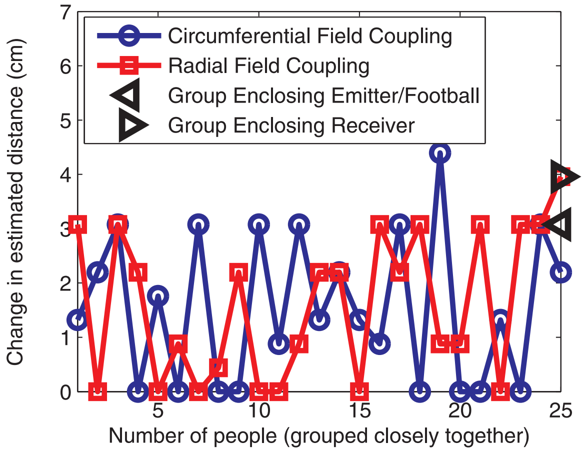


Fig. 4. Change in estimated distance due to the presence of a group of 1 to 25 people. The triangles indicate measurements for when the group of 25 people (entire group) surrounded the emitter/football or the receiver.

outlined in [1] and is shown in Fig. 4. The results in Fig. 4 show that the presence of the large group of 25 people introduce a peak position estimation error of less than 4.5 cm, regardless of whether the group was blocking the LoS between the emitter and receiver, or surrounding the emitter or receiver. The results presented here provide evidence that position measurements using low-frequency magnetoquasistatic fields are insensitive to large groups of people.

III. Conclusion

In our previous work [1], we showed that the use of magnetoquasistatic fields and complex image theory enables long-range (tens of meters) position tracking and operates when in proximity to small groups of people - even when the line of sight is blocked. In this paper, we present measurements using the magnetoquasistatic technique to show that the presence of a large group of 25 people introduces a peak distance error of less than 4.5 cm for an emitter-receiver distance of 10 m, regardless of whether the group is blocking the LoS between the emitter and receiver, or surrounding the emitter or receiver.

References

[1] D. Arumugam, J. Griffin, and D. Stancil, "Experimental Demonstration of Complex Image Theory and Application to Position Measurement," *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 282–285, April 2011.

[2] D. Arumugam, J. Griffin, D. Stancil, and D. Ricketts, "Two-dimensional position measurement using magnetoquasistatic fields," *Antennas and Propagation in Wireless Communications (APWC), 2011 IEEE-APS Topical Conference on*, pp. 1193–1196, Sept. 2011.

[3] ——, "Wireless orientation sensing using magnetoquasistatic fields and complex image theory," *IEEE Radio and Wireless Symposium (RWS)*, 2012.

[4] F. Raab, "Quasi-static magnetic-field technique for determining position and orientation," *IEEE Trans. on Geoscience and Remote Sensing*, vol. GE-19, no. 4, pp. 235–243, October 1981.