Electric field phase sensing for wearable orientation and localisation applications

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ABSTRACT
We show how to sense the phase of the ambient electric field from a body-worn sensor with respect to a reference and discuss how phase information could contribute to relative orientation sensing and indoor localisation. Our system uses 7mW and can be enclosed in a plastic case which makes it suitable for new wearable devices.

Author Keywords
Wearable sensing; electric field; phase sensing;localisation.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous; I.2.9 Robotics: Sensors

INTRODUCTION
Mains wiring act as charged geometries from which field lines emanate. This field can be sensed with an electric potential sensor (EPS): a capacitive sensor able to measure small variations in electric field remotely. An EPS measures a displacement current on the input electrode which is the result of the capacitive coupling between the electrode and the source of the time varying field. Previous work on wearable electric field sensing focused on sensing electric field amplitude, such as for activity and gesture recognition [1, 3] and touch detection on ambient surfaces [2] and of objects [4]. The contribution of this paper is: 1) a method to sense the phase of the electric field; 2) an illustration of wearable and ubicomp scenarios where this information could be valuable.

WEARABLE ELECTRIC FIELD SENSING PRINCIPLES
We measure the electric field with a wearable platform comprising an EPS based on a PS25255 chip [5] with a 20GΩ input impedance and a 16Hz-60Hz first order bandpass filter (fig. 1) sampled at 1KHz. The extension uses 7mW. The backplane acts as the local ground for the device, however both the electrode and the backplane are capacitively coupled to nearby objects. As the instantaneous mains frequency depends on the load we use two nodes to accurately measure phase. A reference node points to a mains line 10cm away: it provides the “ground truth” for phase sensing. The other node is worn on an elastic wristband, reflecting integration in a smartwatch. Both nodes are time synchronised. Data is processed offline to extract the average signal amplitude and phase (fig. 2). We quantify “phase” in ms assuming 50Hz mains. After 40-60Hz filtering, we identify phase in a 500ms sliding window as the smallest positive or negative delay to add to one signal to align its peaks with the other one.

Figure 1: Wearable electric field sensor.

Figure 2: Two nodes point to mains wiring (first 5 seconds); then one node is moved at 30cm distance still pointing to mains (5-20s); it is then turned to point away from the wiring (23-30s). The raw signal (top) is filtered (middle) and then the average distance between peaks indicates the phase (bottom).

USE CASES
Relative orientation sensing A screened room characterisation (fig. 3) shows that phase sensing provides relative orien-
tation information. We placed a sensor at different distances from a mains wire facing towards it with an angle. When rotating the sensor to face away from the wire there is a sharp drop in amplitude as the angle approaches 90° and 270° and then an abrupt phase change by 10ms. When facing towards the wire, the sensing electrode is coupled to the wire and the backplane to the ground. As the node starts to face away from the wire the dominant coupling changes and the backplane is coupled to the mains wire, while the sensing electrode is coupled to ground. This explains the 10 ms phase shift (180° for 50Hz mains). This is akin to swapping a voltmeter black and red leads on a two point voltage measurement. Distance does not affect this phenomena up to maximum distance measured (1.1m). Phase sensing could be used to sense the orientation of objects augmented with the electric field sensor, the orientation of a user within the environment, or of objects with respect to the user. This could use mains sources or dedicated electric field beacons placed at locations of interest.

Indoor fingerprinting for localisation We mapped the ambient electric field amplitude and phase in a 3x6m office on a mesh grid of 4x7 50cm-spaced points to see whether field phase sensing could provide helpful information for indoor localisation using a fingerprinting approach. We repeated the experiment with the user facing north (towards the window), east, south and west (fig. 4). The amplitude maps show localised peaks that reflect the proximity to mains (indicated by P). The phase maps instead tend to consist of regions with constant phase followed by abrupt transitions. For instance, in the North map (overlay in fig. 4) there are phase transitions of up to 8ms within one grid point (50cm displacement). This behaviour is similar to the characterisation of the phase in the screened room when the sensor was rotated and these rapid phase transitions could as well be related to the change of dominant coupling between the electrode and backplane and the surroundings. This difference in behaviour between amplitude and phase map shows that phase sensing provides additional complementary information that could be useful in a fingerprinting-based localisation. This information could also be used as landmarks within a SLAM framework, in the same way that Wifi or GSM radio fingerprinting has been suggested until now.

CONCLUSION
Electric field phase can sensed from a wearable node synchronised with a reference node. Phase sensing can be useful for relative orientation sensing, showing clear drop in amplitude and phase reversal as the orientation of the sensor is perpendicular to a mains line. Phase sensing also provides complementary information to amplitude in electric field fingerprinting which could be useful for indoor localisation and could be employed in a SLAM framework. Electric field sensing has however multiple challenges, as EPS measure juxtaposition of effects and are extremely sensitive to what happens in their surroundings. Future work is required to evaluate to which extent electric phase sensing could increase robustness over amplitude sensing for these applications. It could also provide valuable information for activity or gesture recognition, complementing existing work mentioned in introduction.

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REFERENCES