A Wearable Magnetic Field Based Proximity Sensing System for Monitoring COVID-19 Social Distancing

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ABSTRACT

We present a wearable, oscillating magnetic field-based proximity sensing system to monitor social distancing as suggested to prevent COVID 19 spread (being between 1.5 and 2.0m) apart. We evaluate the system both in controlled lab experiments and in a real life large hardware store setting. We demonstrate that, due physical properties of the magnetic field, the system is much more robust than current BT based sensing, in particular being nearly 100% correct when it comes to distinguishing between distances above and below the 2.0m threshold.

CCS CONCEPTS

• **Human-centered computing** → *Ubiquitous computing*.

KEYWORDS

Magnetic Field; Proximity Sensing; COVID-19; Social Distancing

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1 INTRODUCTION

Social distancing defined as keeping between 1.5 to 2.5 meter distance, together with contact tracing, is widely recognised as one of the most important contributions to the containment of epidemic spread such as COVID-19. Thus, given a contagious patient, it is imperative to find other people whom he/she might have infected. Here the "magic" 1.5 -2.5 meter distance is again of importance: anyone who has been within this distance of the contagious person for a significant amount of time could potentially have been

infected. Since recalling (or in many cases even knowing) all the people who have been within such a proximity for the last 14 days (the consensus maximum incubation period) is impossible, there has been significant interest in automatic sensor-based solutions. Today contact tracing apps that use Bluetooth proximity sensing have been deployed world wide. While they have the advantage of being easily deployable as they require nothing more than a standard smartphone, they tend to suffer under the well known accuracy and reliability problems [5, 8, 12]. For everyday consumer applications the ease of deployment of smartphone-based solutions may out-weight the accuracy problems. Yet for other more sensitive settings, such as healthcare, critical industries, or education (opening schools in the midst of a pandemic), there has been significant interest in more reliable dedicated proximity sensing solutions. Ultra-sound [7] can give higher distance accuracy but suffer from the robustness of the signal. Capacitive body sensing [1] enjoys low cost, low power consumption but relies on dynamic environment change to generate meaningful results. Other viable methods including thermal image [13], cellular and GPS[14], AI-based computer vision [3, 4, 11] are often under privacy policy debate, as the users' visual appearance or exact location path reveals more information than that needed for mere contact detection.

Figure 1: The distancing detection prototype hardware

In this paper, we demonstrate how oscillating magnetic field localisation technology [9, 10] can be adapted into compact, wearable, highly accurate proximity tracing system. We leverage the fact that the magnetic field strength is attenuated at cubic relationship with the distance: generating magnetic fields covering indoor scenarios, such as room, hallway, or factories, typically requires strong stationary sources with large coils with high inductance. Smaller oscillating magnetic field systems suitable for wearable

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applications generate just enough radius for the range of social distancing. Different from the concept of localisation, our approach essentially creates a small magnetic field 'bubble' surrounding the moving user for their social distancing zone.

Overall, we have the following contributions:

- (1) The general concept for using oscillating magnetic field for contact tracing,
- (2) A wearable prototype systems optimised for highly reliable detection of proximity around 2.0 m.
- (3) Evaluation of the systems both in the lab and in a real life construction material market setting showing near perfect detection of the required social distance of around 2m.

2 APPROACH

2.1 General Principle

The strength of a magnetic field measured at a distance d from its coil (assume the size of the coil is negligible compared to d) is proportional to $\frac{1}{d^3}$. An alternating current through a coil generates an oscillating magnetic field. According to Faraday's law of induction, if another coil is placed in such an oscillating field, voltage proportional to the magnetic field will be induced in that coil. This is the basic physical principle behind our work. The basic principle has two advantages over radio frequency (and to a degree also ultrasound based) approaches:

- (1) With coils of a size that is reasonable in a wearable system (2-3cm diameter) and typical currents (not more half ampere) the field is virtually undetectable outside a range of 2-3m.
- (2) The signal is NOT a propagating wave (such as RF or ultrasound signals) but a closed-loop field. Thus, we do not have to deal with refraction, reflection and the resulting multi-path effects.
- (3) Magnetic fields are not significantly affected by objects in the environment. However, large ferromagnetic objects do distort the field and is a problem when we want to address in the future.

The systems worn by different users generate their magnetic field impulses by time domain multiplexing (TDM). While in the experiment we used a central server sending Zigbee signals for synchronisation, the protocol can also work in an asynchronous way similar to the ALOHA WiFi protocol. To this end each system (1) sends impulses at random time intervals, (2) when receiving a pulse (other than its own pulse) broadcasts its ID over RF (Zigbee or BT).

2.2 Implementation

Figure 1 and 2 illustrate two prototypes and the architecture of the system. It consists of transmitter and receiver sub-systems.

The transmitter sub-system generates the magnetic field with a frequency of 20kHz by driving a H-bridge of two serially connected commercial 3.3 mH inductors. The low resistance of the coil benefits a high resonant voltage after tuning to the resonant circuit. The coil at the receiver side with a value of 10 mH is specially crafted with MnZn-ferrite material, contributing to low losses and high saturation induction. Three sets of coil construct a cube structure to measure the three-dimensional magnetic field.

The receiver sub-system uses tri-axis coils to measure the induced voltage, which is then filtered, amplified (Figure 3) by a 4-order Butter-worth filter and a logarithmic amplifier, which aims to compress the signal with a wide dynamic range to its decibel equivalent via a precise nonlinear transformation. A 24-bits resolution analog-to-digital converter finally samples the voltage with rate of 166,7 Hz.

For evaluation, the data is stored locally into the SD card. The receiver sub-system consumes 120 mA current at 3.7 V. The transmitter sub-system consumes 170 mA current at 10 V. A rechargeable 1500 mAH battery supplies the power with an 11.1 V output and supports a working time of more than five hours. For ease of evaluation, we use Zigbee to synchronise the transmitters, which can be discarded for practical social distancing systems. The size of one system is 16 cm x 6.5 cm x 6 cm. However, the size of our prototype is restricted by the modular boards and the big rechargeable batteries. The system architecture from Figure 2 can be optimized and integrated into smaller footprints in the future.

Figure 2: System Architecture

Figure 3: Schematic of the Butterworth filter and logarithmic amplification chain.

3 LAB EVALUATION

3.1 Sensing Range Test

Figure 4: Detection range test with one transmitter activated

To establish a baseline for our implementation, we moved a receiver away from a transmitter in a controlled tabletop experiment.

Figure 4 shows the received rectified magnetic field strength with different distances between the activated transmitter and the receiver (0.5 to 2.0 m).¹ Since the transmitter only activates the field on one axis and the receiver was not rotated during the experiment, the receiver coil in Y axis shows the most relevant signal, which will level off beyond 2 m. This means that we either have to mount all devices in the same orientation on the body (which we did for our prototypes) or have a transmitter transmit on all three axis (which is essentially just increases circuit complexity which we wanted to avoid, but have done for our magnetic indoor positioning [10]).

Figure 5: Detection range test with two body-worn systems. One in stationary state and another in mobile state

A second detection range test was performed by deploying the devices on the users. Two volunteers took part in the test. Firstly two testers stood still with different distances from 3 m to 0.5 m. Then the systems were switched off for another walking-by test, where one tester stood still and another did walking-by events with different minimum distances. Figure 5 shows the sampled strength signal, again we see a detection range beyond 2.0 m. We also noticed that the receivers have different sensitivity which needs to be individually calibrated. Thus to deduce the actual distance information, we used a curve fitting method as exemplified in Figure 6 for each of the prototypes (for tracking social distancing, accuracy with cm level is not a demand).

Figure 6: Fitted strength-distance relation of one system

¹The Rectified Strength depicted in all figures is not the physical magnetic field strength with the unit of Tesla. It is the raw value from the analog to digital converter, representing the strength in a way.

3.2 Sensing Robustness Test

Next we investigated the robustness of our system with respect to disturbance through different objects in the environment. We placed two systems on two tables with a fixed 1.5 m distance. Different obstacle objects from Figure 7 were placed once at a time between the two devices. The transmitters were deactivated while switching the objects. We tested six everyday objects in our daily life: human body, metal grille, magnetic white board, sofa with wood and metal, thick textile, thick wood. As shown in Figure 8, with period A having nothing between the systems and the other periods with the six everyday objects in between, the registered signal strength was not altered by those obstacles, demonstrating the robustness of our proximity sensing modality.

Figure 7: Robustness test with various obstacles between two prototypes

Figure 8: Received strength signals from two prototypes after removing demo's own magnetic field signal

Figure 9: Practical Test outside and inside the construction material supermarket

4 REAL LIFE EXPERIMENT

To demonstrate the feasibility of our approach in a practical scenario, four volunteers wore the prototype systems on the body and walked outside and inside a large hardware store, where a more complex and dynamic environment exists. All volunteers wore the face masks during the test. In addition we ran a simple Bluetooth scanner application where each of our phones broadcast a legible ID (to circumvent the BT MAC anonymization strategy [2].) while at the same time scanning for signals from the other phones (based on their known IDs). This was to provide an illustration of how our system compares to established contact tracking [5, 6, 8] approaches.

As Figure 9 shows, At the beginning of the evaluation the four volunteers stood close to each other outside the supermarket. After that they paired up with one pair keeping a distance of less than 1 m while the other tried for 1.5 m (around 2 arms lengths). The distance between groups was beyond 3 m. In that formation the groups walked through the market for around 14 min.

Figure 10: TDM transmission/reception when the four volunteers are below (left) and above (right) the 2-2.5m range.

Figure 10 gives a closer look of the sampled raw strength signal with two 3 s window showing how the volunteer "sees" the others. Figure 11 gives an overview of the observed magnetic signal strength for each volunteer after the strength data is smoothed by a moving average method with a 10 seconds window, which clearly shows the sensed field strength variation during the whole test.² At the starting and ending period, all the other volunteers could be "seen", and during the middle period, only one volunteer was within the detection range for each volunteer. After interpreting the strength information into the practical distance with a quadratic equation (Figure 6), the social distance of each volunteer is showed in Figure 12. Although we have no ground-truth distancing data during the test, the similarity of "P1_sees_P2" and "P2_sees_P1" (or "P3_sees_P4" and "P4_sees_P3") could demonstrate the truth of distance between them in a way.

In contrast, as Figure 13 shows the Bluetooth RSSI signal supplied by the smartphones. It can be seen that the difference of the signal strength are not nearly as pronounced as in the case of the proposed magnetic field sensor. While for P1 (top diagram) the signal from his immediate partner walking next to him (P2) is consistently stronger than any other signal (as would be expected and desirable), this is neither the case for P3 or P4.

²The scale of each signal strength in Figure 11 is not identical, which is reasonable since the hardware cannot supply the exact same level of reference voltage in level of mv (Figure 3).

Figure 11: Magnetic field signal strength of each system in the whole test

Figure 12: Distance Tracking of Four Volunteers in a construction material supermarket

Figure 13: BT-RSSI signal strength of each phone in the whole test

5 CONCLUSION

Regarding the COVID-19 caused global level social distancing rule, we designed magnetic field-based proximity sensing prototype systems as a sensing media being able to track a safety social distancing. The wearable system owns a detection range of beyond 2 m and is robust to everyday environments. A practical evaluation showed that this system could efficiently track the individual's social distancing in real-time and enjoys higher reliability than Bluetooth RSSI signal based social distance tracking system. Future work will be focused on the privacy scheme, firstly using asynchronous protocol for a mass deployment scenario, secondly combining this sensing modality with the Bluetooth MAC anonymization strategy to achieve a privacy well-considered system.

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