Design Document

Tactile Feedback Glove to Detect Induced Electromagnetic Fields

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1. Introduction

1.1. Objective

The job titles “Electrical Worker” and “First Responder” consistently rank in the top ten most dangerous jobs in the United States. There are around two deaths by electrocution per day for electrical workers in the US, and even more in underdeveloped countries with less rigorous safety standards. These deaths frequently come as a result of accidentally touching a live wire the individual was not aware of, voltage leaks, arc flashes, etc. We need a measure to reduce the number of these preventable deaths [1].

The proposed device is a pair of insulated gloves that can detect the induced electromagnetic fields (EMF’s) generated by AC power lines and wires from a distance. The gloves would then vibrate with increased intensity as field strength increases. This tactile response would inform the electrician or first responder of a nearby live wire/electricity source that could harm them. The vibrations would allow one to increase their reaction time to avoid the hazard, similar to how one recoils when touching a hot stove.

We believe, if properly executed, these gloves would be of valuable commercial and safety use to electricians and power line operators who need to be diligent at all times, as well as first responders who need to be aware of live wires and other electrical hazards in the event of a building collapse, when visibility is low and they may be feeling around.

Lastly, the product has a market outside of what was mentioned above. Normal consumers would be very interested at this novel technology as a way to “feel” the electromagnetic fields in their house and the world around them. We are sure that many people would buy the product as a novelty/unique experience. There is also a niche group of people who refer to themselves as ‘ghost hunters’. These ‘ghost hunters’ claim that ghosts have the ability to manipulate electromagnetic fields, and as a result a surprisingly large number of people interested in these sorts of things buy standard EMF detectors to hunt for ‘ghosts’. We are positive that many of them would buy this product to be able to ‘feel’ the ghosts [2].
1.2. Background

There are two types of fields important to discuss that are relevant to this project: magnetic fields and electric fields. Magnetic fields are vector fields that describe areas where an object exhibits a magnetic influence. These fields affect neighboring objects along magnetic field lines. These fields can attract or push away other magnetic fields. Magnetic fields are commonly observed in everyday life in the form of permanent magnets, which are objects that retain magnetic properties in the absence of an inducing field. Magnetic fields are also able to be generated by a charge in motion, i.e., a current. This is particularly important to our project as current flows through live wires which is the exact thing we desire to detect [3].

The fact that current passing through a wire generates a magnetic field is a useful property we can potentially exploit for our design. If we can detect the magnetic field generated from the wire, we can safely avoid it. The issue lies in the fact that while power lines, and transmission cables generate sizeable magnetic fields, AC wires in houses are generally current-balanced because wherever there is a current, ideally there should be an equal return current in the same cable and the magnetic fields cancel each other out [4]. This is almost never the case in practice however, and there will always be some small detectable magnetic field. The magnetic field will increase if there is an undesirable connection somewhere in the house between neutral and earth so the currents are no longer balanced, which is another thing this device could prove useful to detect.

This means that we need a device which can consistently detect magnetic fields in the nanotesla/microtesla range. A device that can perform this task is known as a magnetometer. The most advanced magnetometers can detect magnetic fields in the order of $10^{-18}$ Tesla. This sensitivity is much more than we would need for our purposes and instead we will likely use Digital Magnetometer IC’s. These digital magnetometers are cheap, sensitive and provide a high throughput of data. The latter proves extremely useful as we can differentiate between fields caused by 50/60 Hz AC power, and other extraneous sources by selecting for magnetic fields that oscillate at frequencies near 50/60 Hz. Magnetic field noise should also be limited in most environments so this is to our benefit.

The second field that is generated by wires, power lines and other electrical components is the electric field. Like the magnetic field, an electric field is also a vector field surrounding an electric charge that exerts force on other charges. Unlike the magnetic field however, the charge does not have to be in motion to generate an electric field. The electric field generated from a live wire is also much more powerful than a magnetic field, and thus is more easily detectable. Due to this same observation, there is much more electric field noise in our environment then
there is magnetic field noise. As a result, electric field sensors are generally calibrated to the environment and then any large increase from the baseline level is generally due to some electrical source. For example, near the bottom of an AC power line is in the magnitude of a few volts per meter, but within a foot of the wire it can increase to over tens of thousands of V/m.
1.3. High-level Requirements

If this project is to succeed, there are three main objectives/requirement that must be met:

❖ The device must be able to detect live wires and other electrical hazards using a magnetometer and a electric field sensor.
❖ The device must be able to provide tactile feedback to the user in the form of vibration once a potential hazard is detected. The vibration will increase in intensity as magnetic/electric field strength increases.
❖ The glove must be well insulated enough to protect both the user and any internal electronics from current and voltages commonly found when working with commercial and residential AC power.
2. Design

2.1. Block Diagram

Successful operation of our system relies on three modules: a power module, a sensing module and a periphery module. The power module sends 5V regulated voltage to all components that need it. The sensing module is composed of a magnetometer to detect magnetic fields, as well as a non-contact voltage detector so that we may detect static voltage build up as well. These signals then feed into our microcontroller, which displays magnetic field strength on the LCD as well as varies the voltage on the vibration disks.
2.2. Physical Design

Our physical design is very important to the success of this project for many reasons. First, we need to utilize space as efficiently as possible. There are many different components to this design, and all of it will need to fit onto/in a glove. Secondly, there is the risk of other components interfering with each other, so we need to choose the location of the components carefully. For example, we have placed the power module and most of the electronics near the back of the glove, away from both the voltage detector and the magnetometer. We will magnetically shield these components so they do not interfere with our sensors.
2.3. Functional Overview, Requirements and Verification

2.3.1. Magnetometer

We will be using a DH Type Nanotesla Sensor from Aichi Micro Intelligent Corporation. This sensor is capable of detecting fields as small as 1 nanotesla. This is essential as we will be searching for fields that can be as small as 0.1 microtesla. By restricting the cut-off frequency to 0.1 Hz, this sensor is also able to ignore static magnetic fields such as geomagnetism and respond to only alternating magnetic fields with high sensitivity. This feature is ideal as we would like to negate as much magnetic noise as possible. We will need to experiment to find the exact threshold values to search for, but the fields will most likely be in the 0.1-5 microtesla range for wires, and 10-50 microtesla range for electronics carrying motors and appliances.

Specifics of the sensor are as follows:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model No.</td>
<td>MI-CB-1DH</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>5.0V (Typ.)</td>
</tr>
<tr>
<td>Detecting Range</td>
<td>4.0μTpp</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>1V/μT</td>
</tr>
<tr>
<td>Frequency Response</td>
<td>0.1Hz to 1kHz @ -3dB</td>
</tr>
<tr>
<td>Output Linearity</td>
<td>Less than 2%FS</td>
</tr>
<tr>
<td>Noise</td>
<td>200pT/1σ</td>
</tr>
<tr>
<td>Size</td>
<td>35mm x 11mm</td>
</tr>
<tr>
<td>Operating Current</td>
<td>15mA</td>
</tr>
</tbody>
</table>
### Requirements

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Must be able to filter out static magnetic fields such as geomagnetism and permanent magnets, and detect alternating fields instead.</td>
</tr>
<tr>
<td>2.</td>
<td>Must be able to detect fields of as low as 0.1 microtesla generated from AC wires from at least 6 inches away.</td>
</tr>
</tbody>
</table>

### Verification

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
| 1. | Requirement 1  
   a. Test sensor by placing next to static permanent magnet and setting cut-off frequency to 0.1 Hz.  
   b. Expose sensor to an oscillating magnetic field by either shaking the magnet rapidly or running AC current through a coil. |
| 2. | Requirement 2  
   a. Place sensor near an AC wire and record magnitude of field observed.  
   b. Increase distance of sensor until the field is no longer detectable. |

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**2.3.2. Voltage Detector**

There is the possibility of encountering a static build up of high voltage, which would not create a magnetic field that we could detect. For this purpose we are including a voltage detector in our design. The detector would be composed of a series of transistors wired so they have huge gain. This massive gain would allow us to detect the smallest movements of electricity, even those created at a distance by induction or static charge. When the voltage detected crosses a certain threshold value it will send a signal to the microcontroller which will power the vibration discs.
This is the voltage detector design. We may need to change values of resistances and transistors to achieve our desired level of gain.

![Voltage Detector Circuit Diagram]

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Must be able to detect commonly encountered AC voltages (3-30 V/m) from a distance of 6 inches or greater.</td>
<td>1. Requirement 1</td>
</tr>
<tr>
<td>2. Must be able to detect static electricity build up from a distance of 6 inches or greater.</td>
<td>a. Place sensor near AC wire and see if diode lights up from at least 6 inches away. If not, adjust gain.</td>
</tr>
<tr>
<td></td>
<td>b. Place sensor near static electricity source, charged balloon, Van de Graff Generator, etc. See if sensor diode lights up from at least 6 inches away.</td>
</tr>
</tbody>
</table>
2.3.3. Voltage Regulator

Most components in our design require a steady input of ~5V for optimal operation. The only component that requires varying voltage are the vibration disks in order to increase or decrease the vibration, but this varying voltage can be provided by the microcontroller (0-5V). For this reason we have decided to use a 5V voltage regulator to provide constant voltage to our components. We will be using the Sparkfun L7805 voltage regulator, a three-terminal positive regulator with a 5V fixed output voltage. The regulator provides a local regulation, internal current limiting, thermal shutdown control and safe area protection for our project.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The only requirement is that the voltage throughout the circuit is regulated to 5V, regardless of the loads placed on it by the sensors and other components.</td>
<td>1. Requirement 1</td>
</tr>
<tr>
<td></td>
<td>a. Place the maximum load (sensors, discs, LCD, etc.) onto the regulator and measure the voltage.</td>
</tr>
</tbody>
</table>
2.4.2 Supporting Material
3. Cost and Schedule

3.1. Cost Analysis

3 persons x 20 hrs/person/week x $50 x 13 weeks = $39,000

<table>
<thead>
<tr>
<th>Parts and Labor</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raspberry Pi 2 Model B</td>
<td>$41.64</td>
</tr>
<tr>
<td>Type DH Nanotesla Sensor</td>
<td>$185.00</td>
</tr>
<tr>
<td>Adafruit Vibrating Motor Disc (5x)</td>
<td>$9.75</td>
</tr>
<tr>
<td>5V Voltage Regulator</td>
<td>$0.95</td>
</tr>
<tr>
<td>Lithium Ion Battery</td>
<td>$54.95</td>
</tr>
<tr>
<td>OLED Display</td>
<td>$10.99</td>
</tr>
<tr>
<td>Electrical Insulating Gloves</td>
<td>$42.10</td>
</tr>
<tr>
<td>Labor</td>
<td>$39,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$39345.38</strong></td>
</tr>
</tbody>
</table>

3.2. Schedule
4. Discussion of Ethics and Safety

As future electrical and computer engineers, we hold a responsibility to our society and to our profession to make a positive impact on the world. This can be best stated by the IEEE Code of Ethics— in particular, our promise to “hold paramount the safety, health, and welfare of the public,” as well as to “avoid injuring others [or] their property … by false or malicious action” [7]. Just like in all our future endeavors as engineers, we must take these considerations into account when designing and building our project. We must explore all possible risks to personal safety or private property associated with use of our project.

A key risk associated with our project comes from our use of lithium ion batteries. If the lithium ion battery in our device is overcharged or introduced to extreme temperatures, there is the possibility of explosion [8]. Fortunately, Kevlar is a thermal insulator, which should prevent the device from seeing any spikes in temperature [9]. We will also carefully test all charging circuitry on our device to ensure that it remains within safe bounds for our selected battery.

Furthermore, we need to prepare for the possibility of the battery or other electronics in our project being introduced to water. While we can strongly discourage users from using our project in damp or moist environments, we still have the obligation to protect our users from the consequences of accidental exposure of components to water. We will address this by building our glove out of Kevlar, which is very water resistant. When exposed to water, the filament tenacity of Kevlar remains virtually unchanged even after 200 days, and hydrolysis only results in a 5% loss of strength after 20 hours [9]. We can thus rest assured that a Kevlar glove will keep our electronic components safe from brief exposure to water; however, to minimize the risk to the user, we will not recommend extended exposure.

In addition, considering the environment our project may be used in, there is also the concern of arcing from electrical equipment to our glove. Fortunately, Kevlar is also commonly used as protection from arc flashes and will thus offer protection from
electrical hazards [9]. We’ll also make sure to note how many calls the Kevlar gloves are rated for- although our gloves are not a replacement for personal protective equipment in the lab or production environment, we don’t want to risk being liable to user injury by failing to specify the acceptable conditions for use of our project. In addition, if a user were to decide to include our glove as part of their PPE, knowing the specific arc flash rating will allow them to remain NFPA 70E compliant.

The largest risk to the successful completion of this project is being able to detect and establish threshold values for detection. It is our assumption that this will require a bit of experimentation, especially for the electric field aspect of our design. We need to establish threshold values for alternating magnetic fields, and electric fields which vary greatly from place to place. Once this is taken care of however, we believe that the rest of the construction will go very smoothly.
5. Citations


