Tactile Feedback Glove To Detect Current Induced Electromagnetic Fields

ECE 445

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Introduction/Abstract

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 less developed 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 wearable, 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 intensity increases. This tactile response would inform the electrician or first responder of a nearby live wire/electrical source that could harm them, that they may or may not have been aware of previously. The tactile feedback created by 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.

Furthermore, 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 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’ ghosts [2].

Review of Literature

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 is much more sensitive than we would need for our purposes, and my experiment developing a torsion balance magnetometer to detect induced magnetic fields generated by cosmic ray showers, shows that a highly sensitive magnetic field detection instrument is easily available/created [5]. Thankfully, a torsion balance setup is unneeded as digital magnetometer IC’s exist to be used in such experiments. 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 also a plus.

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 a 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.

Electric field sensors are available in three basic variations: the electrometer type, the radioactive sensor type and the A.C. carrier type of fieldmeter. The electrometer type is basically a capacitively coupled D.C. amplifier with a shunt capacitor for calibration. Positives of this design include low cost, simplicity, small size and the ability to make extremely high speed measurements; all very good for our design purposes. Negatives of this design are the need to periodically zero, and the inability to use them in an extremely ionized air environment, both of which shouldn't pose too much issue. The radioactive sensor type ionizes the air in its immediate vicinity. When this ionized air is exposed to an electric field, a current will flow that is proportional to the electric field. That current is then measured to obtain an electric field reading. Positives of this design include simplicity, D.C. stability and small size [6]. However, due to the fact that it uses radioactive materials, this design will be left out of consideration. The A.C carrier type detector module detects electric fields by modulating a capacitance pickup when in an electric field. This type of sensor is simple in design and highly accurate as well, and can be made rather small with the probe size being one to two cubic inches. Size is an important consideration when attempting to mount the device on a glove. Upon reviewing these pros and cons, both the electrometer type and the A.C carrier type are valid choices for our design. Both are readily available for use.

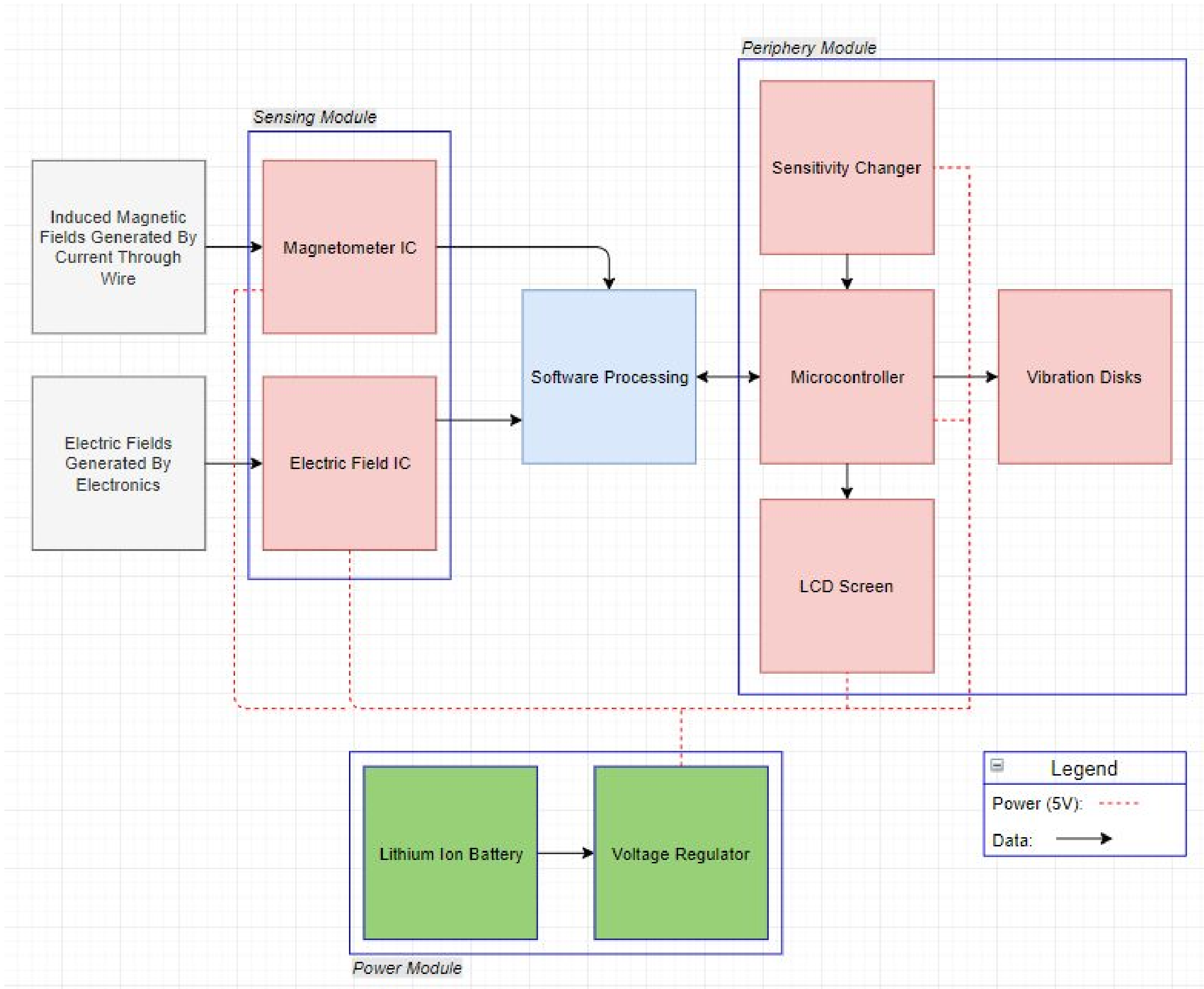
In conclusion, we present the use of a magnetometer to detect induced magnetic fields generated by wires, or electric field sensors to measure electric field strength near wires and other electrical components as two valid ways to solve our problem. Either one of these devices can be used alone as the detecting portion of the glove design or if time permits in tandem.

High Level Requirements

If this project is to succeed as intended, there are three main objectives/requirements that must be completed.

1. The device must be able to detect live wires and other electrical hazards via magnetometer, electric field sensor or a combination of both.
2. The device must be able to provide tactile feedback to the user in the form of vibration once a potential hazard is detected.
3. 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.

Integrated Design



This design integrates both the magnetometer as well as the electric field sensor. This serves multiple purposes. It increases the reliability of the design, as if one instrument fails to detect something, the other might. The addition of an electric field sensor also allows us to detect non-moving accumulations of voltage, which a magnetometer could not detect. For the purposes of ECE 445, it also increases both the hardware and the software complexity. This will be the version of the design we end up using.

Component Specifics

Battery:

Most of the components in our design require 5V of power or less. A lithium-ion battery should be able to provide this amount of voltage for several hours as the energy requirement for most components is rather low.

Requirements: Must be able to provide 5V of electricity for a reasonable length of operation (ideally a few hours).

Voltage Regulator:

Some components such as the microcontroller and nano-tesla sensor require around 5V of electricity. Other components such as the vibration disks require less (1.5-3.0 V). The purpose of our voltage regulator is to be able to provide constant voltages at different levels so our components can run at peak performance without risk of damaging them through unintended higher voltage levels.

Requirements: Must be able to regulate voltage at a constant level and provide components with the right amount of voltage.

Magnetometer:

The magnetometer we choose needs to be small, have a high data output, and be very sensitive. The sensitivity has to be fine enough to detect magnetic fields in the microtesla range. For this reason we have selected the MAG3110 IC or the DH Type Nanotesla sensor. They both are triaxial, which allows us to detect in 3-dimensions around the glove, have a high data output rate which will allow us to detect alternating fields, and are sensitive enough to detect even nano-tesla fields.

Requirements: Must be small enough to fit on a glove, have a high data output to detect alternating fields, and be sensitive enough to detect fields in the microtesla range. It must be able to detect fields at a range of at least 1 foot.

Electric Field Sensor:

The electric field sensor we choose needs to be small, as it will be sharing space on the glove with a magnetometer and other components. The sensitivity won't be much of a problem because electric fields around what we are trying to detect will be high. It just needs to have a wide range of field strengths it can detect, and data output that can feed to our microcontroller.

Requirements: Must be small, as it is sharing space with other components, and be able to detect a wide range of electric fields. Also must be able to communicate with our microcontroller. Must be able to detect at a range of at least 1 foot.

Microcontroller:

Our microcontroller must be able to handle inputs from both the magnetometer and the electric field sensor. It must also be programmable so it can send readings to the display, as well as turn on the vibrating disks once a certain threshold value is crossed. We assume a microcontroller similar to an Arduino will suffice, since it is small and capable of doing all of the above.

Requirement: Must be small, able to handle inputs from both the magnetometer and electric field sensor, and communicate with any peripheral devices such as the display and vibration disks.

LCD Display:

The LCD's job is rather trivial. It simply needs to display the magnetic field data and the electric field data provided by our sensors. It will need to be small enough to fit on a glove, but still be easily readable.

Requirements: Must be small, and able to display magnetic and electric field data provided by our sensors.

Vibration Disks:

The vibration disks will likely be those used in smartphones as they are extremely small and able to produce a significant amount of tactile feedback.

Requirements: Must be able to provide an adequate amount of vibrational feedback upon encountering a hazard. Ideally able to vibrate at varying degrees of intensity.

Sensitivity Changer:

Since the magnitude of electric fields varies heavily, we want to have some way of altering the threshold values to some degree. To simplify the process we are thinking of utilizing preset buttons for Household AC Power and higher voltage things like transformers and solenoids that are used outside.

Requirements: Buttons that can tell the microcontroller which electric field threshold values to use.

Glove Design

The design of the glove, although an afterthought to the completion of the circuit, is an important portion of our project. As stated in the high level requirements for success the glove has to protect the user, protect any sensitive electronics, and accurately detect the desired objects. There are also other considerations such as placement of electronics so they do not obstruct dexterity, which material we want to use, and aesthetics of the device, as one day it could become a marketable product.

Glove Material:

The glove material is a relevant portion of the design to allow us to protect the user and the electronics. We ideally want something that is a good insulator, as well as light so using the glove doesn't become too cumbersome to use. Common insulating glove materials include rubber, cotton, leather and kevlar. We will use kevlar to provide electrical insulation as well as waterproofing and cut resistance.

Glove Size:

The glove size is surprisingly important as it needs to be able to house all the electronics, minimize weight and be able to fit a normal sized hand. A standard sized electrical glove should be suitable, as they are quite large.

Placement of Sensors:

The sensors will be placed on the back of the hand to not obstruct grip and other motor functions.

Placement of Battery Pack:

The battery pack will be placed closer to the wrist/forearm as far as possible from where people will be making contact with wires.

Risk Analysis

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.

Safety and Ethics

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 of 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. We also acknowledge the importance of ethical concerns in our careers as engineers; however, we were not able to identify any ethical concerns associated with our project, and thus will not be addressing ethics in our proposal.

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 cals 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.

Citations

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[6] Monroe-electronics.com. (2019). [online] Available at: https://www.monroe-electronics.com/ESD/pdf/APNE-0011.pdf [Accessed 8 Feb. 2019].

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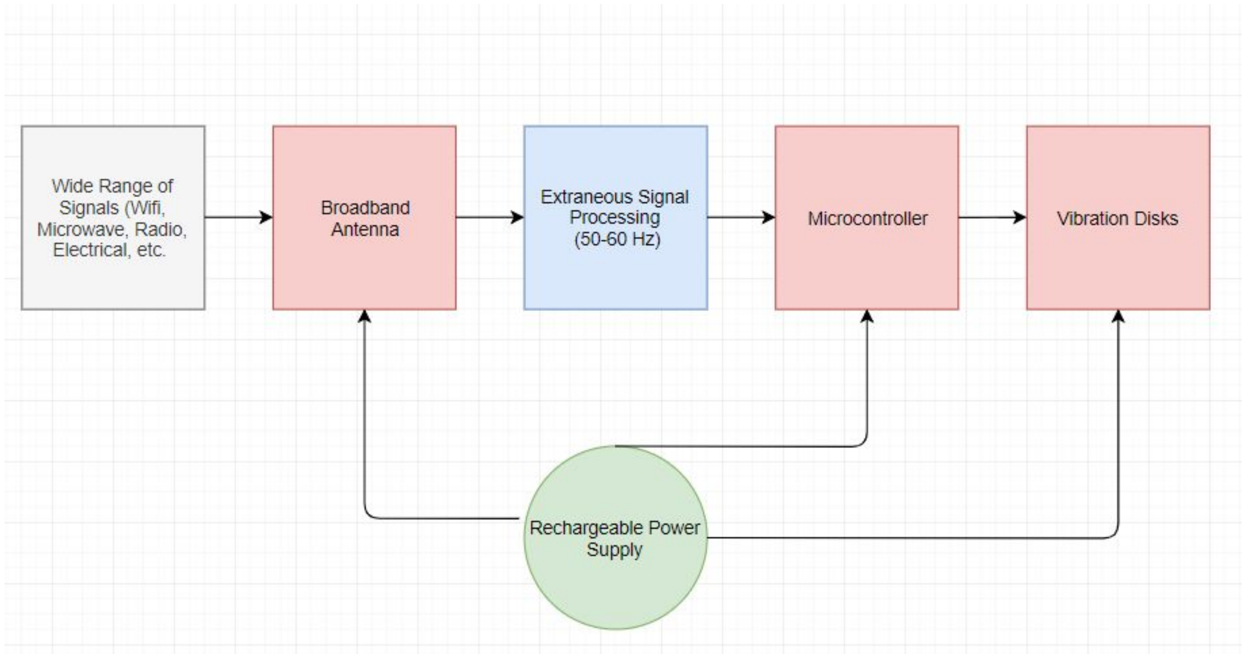
[9] Dupont.com, “Kevlar Technical Guide”, 2019. [Online]. Available: http://www.dupont.com/content/dam/dupont/products-and-services/fabrics-fibers-and-nonwovens/fibers/documents/DPT_Kevlar_Technical_Guide_Revised.pdf. [Accessed: 07-02-2019].

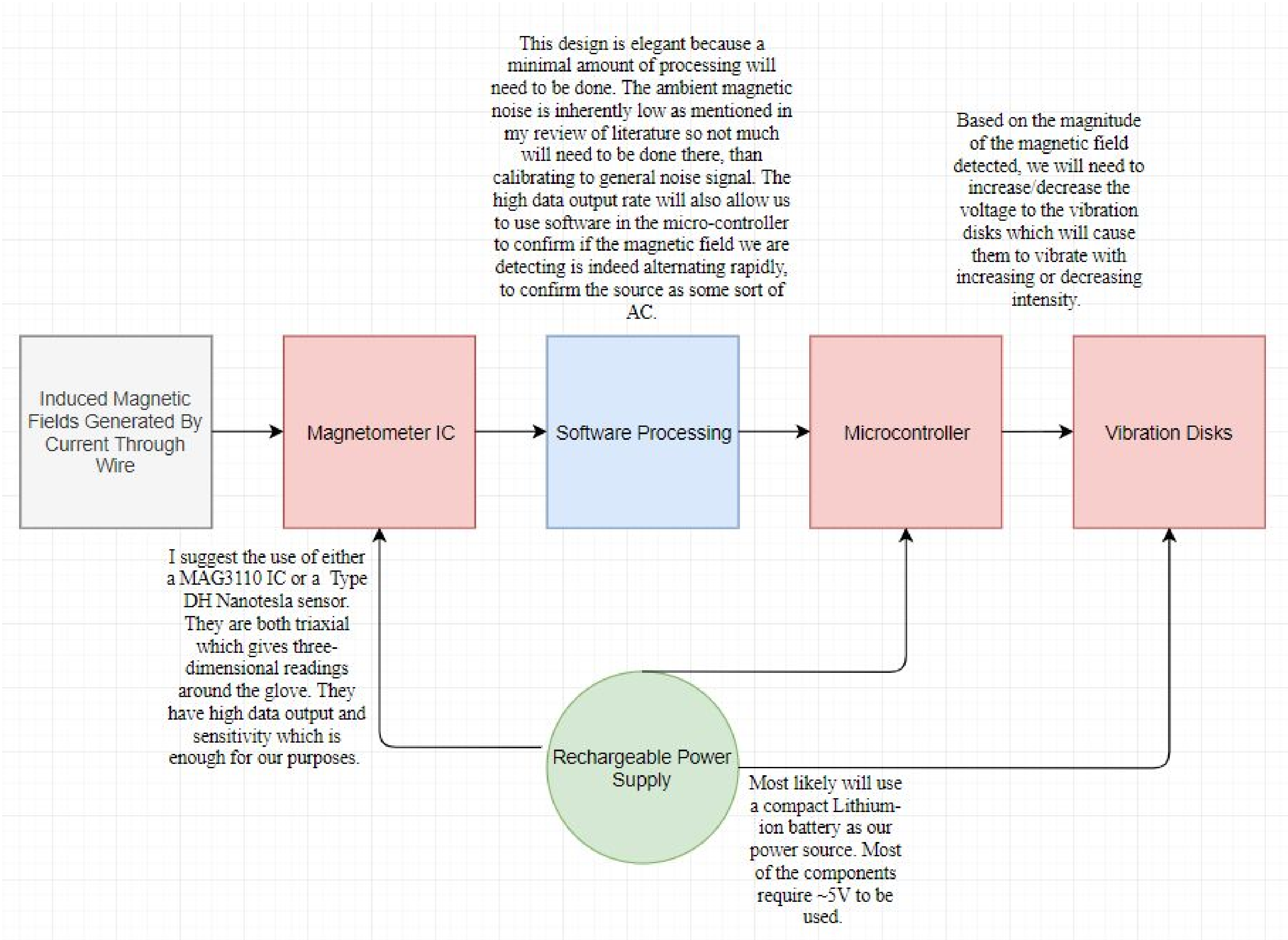
Appendix A: Other Designs

1. Broadband Antenna



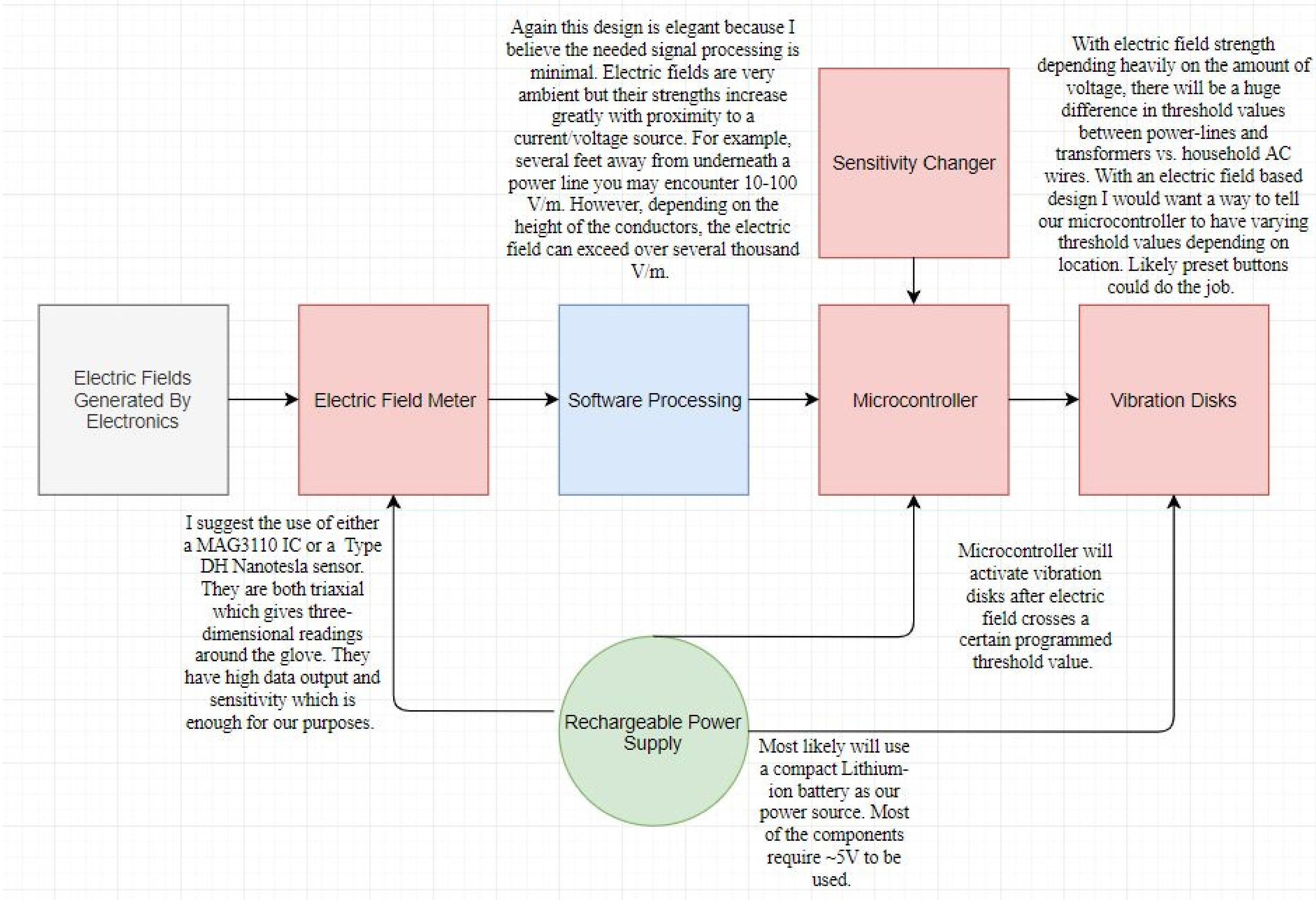
This design was the initial design offered to me by a TA. It involves the use of a Broadband Antenna to ideally pick up some sort of 50-60 Hz signal, separate out the noise and then feed that output into a microcontroller which then increases/decreases the vibration of the disks in the glove. The problems we have with this design are that the broadband antenna will pick up a multitude of different signals, including but not limited to: wifi, radio, microwave, etc. We are also not confident that a noticeable signal would be picked up from a live wire/power source. Furthermore an antenna on a glove would be a bit of a nuisance, as well as severely increasing the risk of an arc to the glove. For these reasons, we provide two alternate designs which we believe will better suit our purposes.

Magnetometer Design



This design exploits the fact that current flowing through a wire generates a magnetic field. We suggest the use of the MAG3110 IC chip to serve as our detector, due to its triaxial capabilities, high data reading outputs, and incredible sensitivity, which is exactly what we need for our purposes. Due to the fact that ambient magnetic noise is low in most environments, any magnetic fields detected when near wires will most likely be a result of those wires. We will calibrate the magnetometer baseline levels as well as check for an alternating field using software, to confirm that we are not detecting something like a permanent magnet. This data will then be used to increase or decrease the disk vibration intensity.

Electric Field Design



This design uses the electric fields generated by all charges to serve as our signal. We do not have a concrete recommendation for the detector we will use, but it will either be a electrometer type or A.C carrier type. This design requires an extra component we have dubbed a sensitivity changer, as electric fields generated near power lines and transformers will be vastly different than those generated in buildings, meaning there would be different required threshold values. Ideally, there would be two buttons on the glove which have preset values for HV (120V AC) and EHV (Powerlines, Transformers, Etc.) The magnetometer design would not require this as the magnetic field is mostly a property of the current, and we have a built in “threshold check” by searching for alternating magnetic fields.