Open-Source Versatile Amplifier-Control Electronics and GUI for HelmHoltz Cages

We are the MIT Space Telecommunications Astronomy and Radiation Laboratory (STAR Lab). We achieve new scientific results from sensors on distributed space-based platforms. We innovate and use new commercial components to address technological challenges for future science missions, reducing cost and risk.

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1. Introduction

Helmholtz cages are used to test magnetometers and magnetic attitude control systems in a laboratory environment. While some commercial products are available, CubeSat development programs at many academic institutions have kept costs low by designing the coils, electronics, and control circuitry from scratch.

We have created a standard low-cost electronic HelmHoltz cage control system that can be implemented, modified, and improved as an open-source academic community project.

Figure 1: Picture of MIT SSL Helmholtz cage from Prinkey [1]. This cage was used to test our control electronics implementation

2. Background

The MIT Space Systems Lab (SSL) has a hand-built 3-axis 4-coil Merritt Helmholtz cage with coils that are about 1.5 meters per side [1]. We have targeted this design as an example implementation, though our system can be extended to other cage specifications.

Coil Resistance	3.5 Ω
Maximum Current	± 5 A
Maximum Voltage	± 18V

Table 1: MIT SSL Helmholtz Coil Electrical Parameters

Several University-built Helmholtz cages have been reported on in the past, but each tends to use a significantly different coil driver architecture. Once the cost of the physical coils is excluded, the majority of the expense is associated with the large coil driving electronics.

Architecture	Description	Example Hardware	Per-Axis Cost	Example Use
Programmable Power Supply with Polarity Control Switch	Each axis has programmable power supply to set current and a programmable switch to set direction	Sigilent SPD1168X	~$300	Foley 2012 [2]
Four quadrant power supply	Each axis has a bidirectional waveform amplifier driven by a waveform generator.	Accel Instruments TS250-2	~$1500	Bui 2020 [3]
DC-Coupled Audio Amplifier	Audio amplifier with custom implemented current feedback	Crown DC-300 Series II	~$200	Prinkey 2013 [1]

Table 2: Characteristic Architectures with Typical Cost and Example Use

The use of DC-coupled audio amplifiers with a custom programmable source can provide a low-cost implementation of the necessary high-power bidirectional current source. We have used the Crown DC-300 Series II amplifier both for its low-cost and the existence of some prototyping heritage from the work by Prinkey [1].

3. Modular Architecture

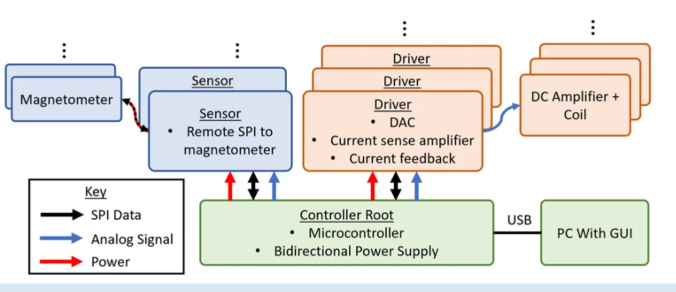

Figure 2: Modular System Architecture: Three driver nodes and 2 sensor nodes are used for the SSL Helmholtz Cage, but these numbers can be varied without hardware modifications depending on the end-users needs

Different test platforms have different hardware needs. The system designed for the MIT SSL Helmholtz cage has targeted two magnetic sensors and three drivers, but the hardware can be stacked to increase the number of sensors and drivers supported. The current design supports up to five sensors and seven drivers.

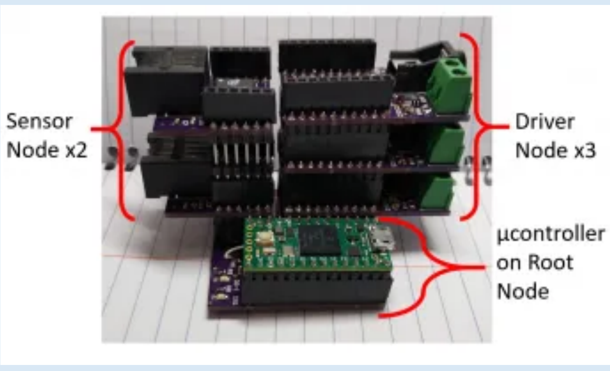

Figure 3: Picture of electronic control hardware with major components labeled

4. Implementation

Driver Implementation

The driver node creates an analog signal used as the input to the DC-coupled audio amplifier. The driver node implements current feedback on the coil current to create the requested current regardless of the gain setting of the external audio amplifier.

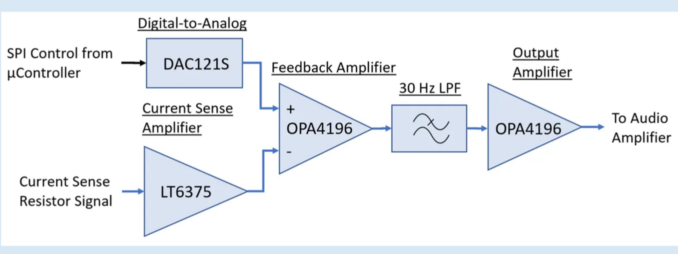

Figure 4: Analog feedback circuit for consistent control of the external amplifier

To maintain stability, we use a single dominant pole to reduce high frequency gain before circuit elements contribute 180 degrees of phase shift. We have dominated all other poles in this circuit with the 30 Hz low pass filter, and have found the circuit to be stable under all audio amplifier gains.

Sensor Implementation

We use a PNI RM3100 sensor on a custom carrier board. The carrier board connects to the sensor node on the main electronics stack with a standard RJ-45 terminated Ethernet cable. The twisted pairs of the ethernet cable are used to power the remote sensor and provide communication over a remote-SPI chip (LT6820).

Interface Type	SPI
Sensitivity	26 nT
Measurement Range	±1100 µT

Table 3: RM3100 Magnetometer Specifications [4]

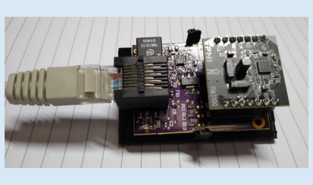

Figure 5: Magnetometer on its carrier board with Ethernet cable plugged in

5. GUI Control

The hardware is all controlled with a Teensy 4.0 Arduino-compatible microcontroller. Code on the microcontroller looks for commands for new current values, and returns field information when a command is received.

A MATLAB GUI provides an easy-to-use interface to the experimenter. The MATLAB GUI connects to the microcontroller over the PC Serial Port.

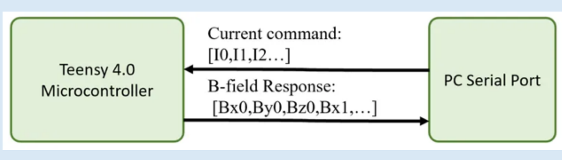

Figure 6: Protocol for serial interface with microcontroller

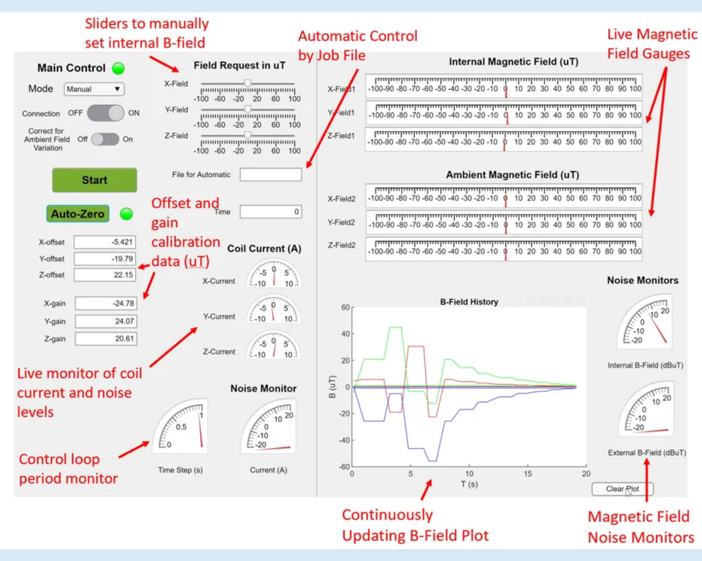

Figure 7: Screenshot of GUI with major components labeled

6. Conclusions

Our electronic control system that will work with many DC-coupled audio amplifiers to provide current control to implement a HelmHoltz cage. As a proof of concept, we have retrofitted this control system to the MIT SSL 3-axis 4-coil HelmHoltz cage, but this design can accommodate a wide range of coil designs as long as the needed voltage and current is within the audio amplifiers specifications.

All software and design files including Gerbers and Altium design files for the PCBs used in this project are provided at: https://github.com/nickb537/HelmHoltz-Cage-Public. Any user interested in using or contributing to the project is encouraged to contact the author at nbelsten at mit dot edu.

Future Work

- Provide detailed instructions for placing PCB orders
- Create 3D printable enclosures for the PCBs
- Improve the refresh rate of the GUI with software optimizations
- Provide more documentation for extending the microcontroller software with other hardware options
- Help users at other universities use our design to get their testing done faster

References

1. Prinkey, "CubeSat Attitude Control Testbed Design: Merritt 4-Coil per axis Helmholtz Cage and Spherical Air Bearing," *AIAA Guidance, Navigation, and Control (GNC) Conference*, 2013.
2. Foley and J. Puig-Suari, "Calibration and characterization of cubesat magnetic sensors using a Helmholtz cage.: a thesis," thesis, California Polytechnic State University, San Luis Obispo, CA, 2012.
3. Q. Bui, W. L. Tew, and S. I. Woods, "AC magnetometry with active stabilization and harmonic suppression for magnetic nanoparticle spectroscopy and thermometry," *Journal of Applied Physics*, vol. 128, no. 22, p. 224901, 2020.
4. "Geomagnetic Sensor: Magnetometer: PNI Sensor Corporation," *PNI Sensor*, 23-Mar-2021. [Online]. Available: https://www.pnicorp.com/rm3100/.

Video

Acknowledgements

Thank you to Rebecca Masterson and Paul Bauer in the Space Systems Laboratory for providing access to the SSL Helmholtz cage.

Thanks to you for reading my poster presentation! Check out the explanatory video above if you haven't yet.