An Environmental Sensing System for the High Contrast Spectroscopy Testbed for Segmented Telescopes (HCST)

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Abstract

The Caltech Exoplanet Technology lab utilizes the HCST to enhance their starlight suppression techniques in an effort to characterize planets that are earthlike. The testbed is used to test different technologies to determine the best way to filter out unwanted starlight to obtain the best signal from planets. Though, the HCST is kept in a rectangular enclosure in the lab where environmental factors such as temperature, humidity, and pressure could alter the data being recorded with it. To better understand the limitations of the testbed, and the limitations of current high contrast technologies, I have spent the summer creating an environmental sensing system that measures and records the environmental data inside the testbed and allows the user to interface with this data. This work has involved reading coding documentation and discussion forums, upgrading the current hardware parts, writing documentation for the project and writing and testing code to create the best possible setup that can be used long after I leave Caltech. The environmental sensing system includes a program that shows the live readings of the environmental data inside the HCST, a program that allows the user to look at the environmental data from any desired span of time, and another program that saves all of the data to an SD card.

Introduction

Characterizing exoplanets can be done by analyzing the light that emanates from a planet. Once light is obtained from a planet, spectroscopy can be used to analyze the chemical composition, temperature, and rotation of the planet to determine whether or not it can support life. This is a difficult task because it is hard to distinguish the overpowering light from the host star from the light from the planet.

The HCST is used to test different technologies to determine the best way to filter out unwanted starlight to obtain the best signal from planets. Technology tested at HCST will be used with future space-based telescopes such as the Large Ultraviolet Optical Infrared Surveyor (LUVOIR) and the Habitable Exoplanet Observatory (HabEx) and also with in ground telescopes such as the Thirty Meter Telescope (TMT). Our hope is that technologies developed at HCST will also be used with the Keck Planet Imager and Characterizer (KPIC), which was developed by Caltech and is located at the W.M. Keck Observatory in Hawaii.

To better understand the limitations of the HCST, and the limitations of current high contrast technologies, I have spent the summer working with The Exoplanet Technology lab (ET Lab) to develop an environmental sensing system for the HCST and the Keck Planet Imager and Characterizer (KPIC). In the beginning of the project, there was already pre-existing code written to get the environmental data but it wasn't being used because it had problems with getting the correct time stamp for the data and the hardware was flimsy and would short out and stop working easily. The ET lab also wanted me to develop the code and hardware to have it generate live plots of the environmental data that could be viewed at any time and to have the software not short out easily anymore.

Fig. 1 Photos of the HCST. During my time at Caltech, I put 8 environmental sensors inside this testbed that get the environmental data from inside it 24/7. Inside the enclosure is an optical setup that is used to test starlight suppression techniques.

Fig. 2 Photos of the W.M. Keck Observatory where KPIC is located.

Accomplishments

During my summer at Caltech, I upgraded the environmental sensing system to include a program that shows the live readings of the environmental data inside the HCST, shown in Fig. 3, a real time clock (RTC) to get the correct time with the Arduino, and a program that allows the user to look at the environmental data from any desired span of time, shown in Fig. 4. In the beginning of the project, the lab group and I thought that the Arduino being sensitive to being shorted out was a hardware problem, but during my time here I uncovered that this was instead a software issue. I have updated the preexisting Arduino code to make it not short out anymore, so theoretically, the environmental sensing system should run forever, now. Additionally, since there is an identical environmental sensing system at KPIC, I also made all of these updates to KPIC's system. I also had to modify some of the code and work together with lab members working with KPIC to ensure that my updates would be compatible with KPIC.

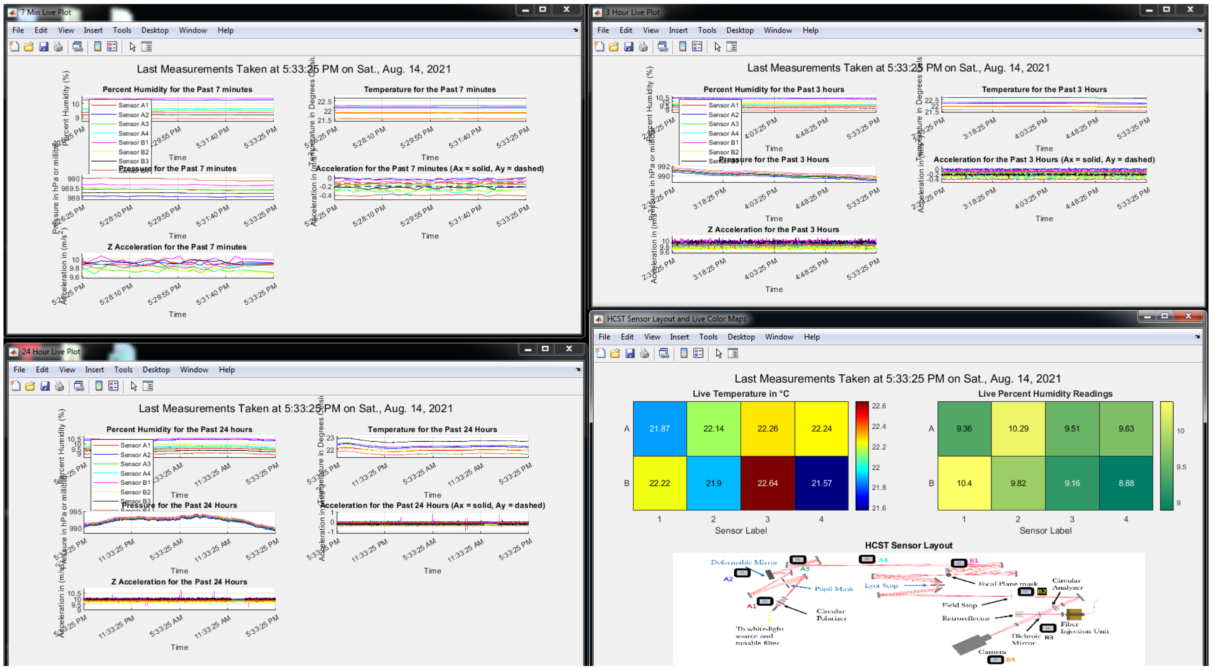

Fig. 3 Output of the live environmental sensing program. The program displays figures with the past 7 minutes, 3 hours, and 24 hours of environmental data along with another figure containing heat maps of the current temperature, humidity, and sensor location in the HCST. This data updates every 15 seconds.

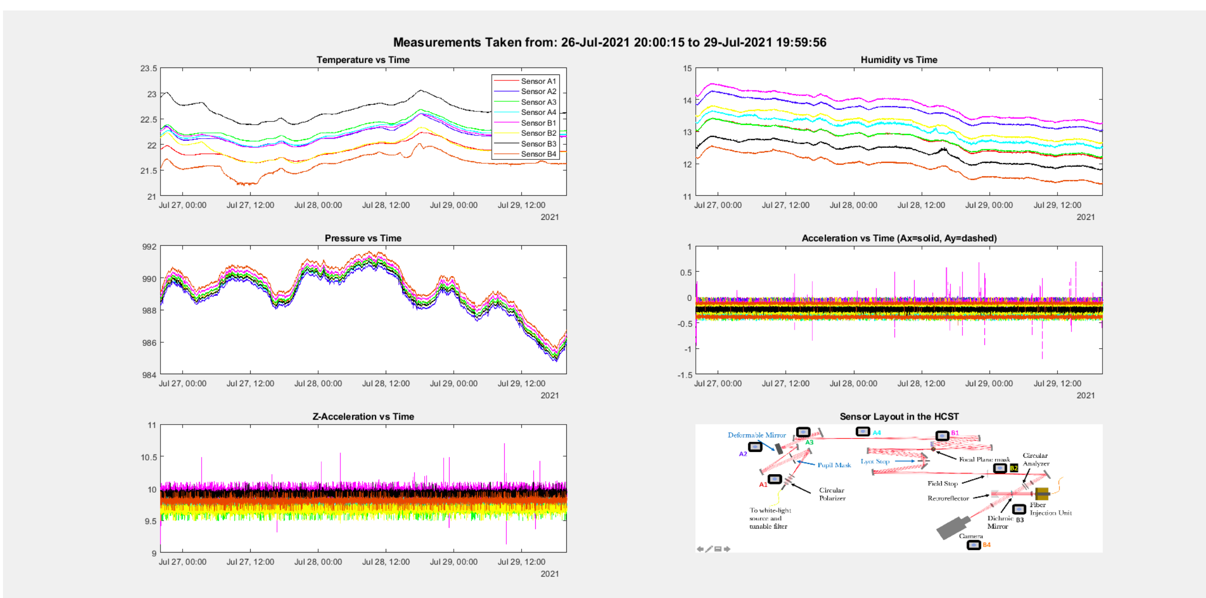

Fig. 4 The output of the program to get any user specified time frame of data. The plots include temperature, humidity, pressure and acceleration versus time. Here, the user decided to look at the environmental data from July 26th at 8pm to July 29th at 8pm.

Eight sensors have been placed inside the HCST, shown in Fig. 5, which measure humidity with 0.008% r.H. resolution, pressure with 0.18Pa resolution and temperature with 0.01◦C resolution (Llop-Sayson et al. 2021).

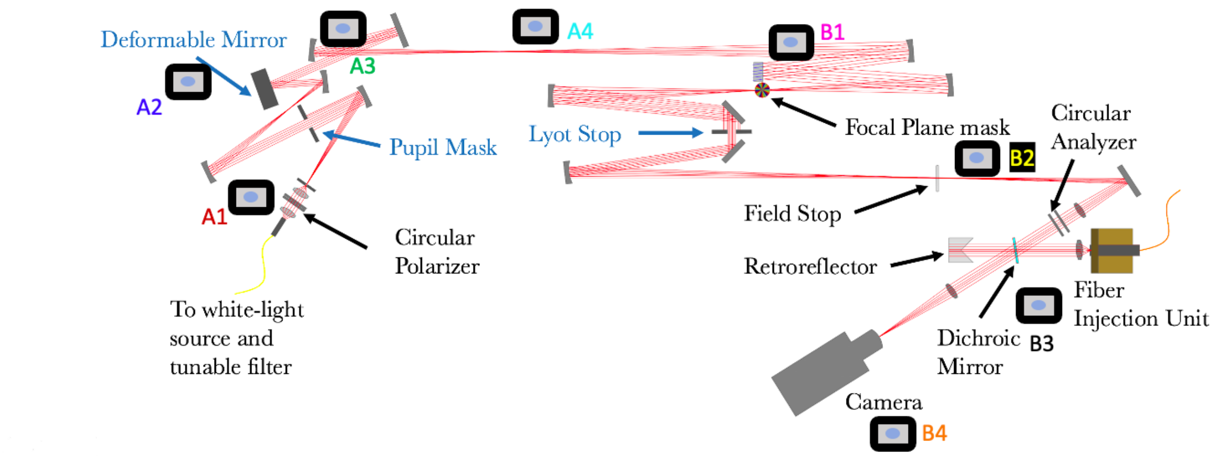

Fig. 5 The current location of the sensors inside the HCST.

During my internship, I also plotted environmental data gathered over the past few years at KPIC and did statistical analysis on this data using MATLAB, shown in Fig. 6. Since this data wasn't collected with the correct time stamp, it is plotted versus file number instead of time. Each new file represents an increase in time. Data for one file typically contains several days of data. The incoherence of this data highlights the importance of my research this summer. In the future, thanks to my work this summer, coherent plots versus time can be made.

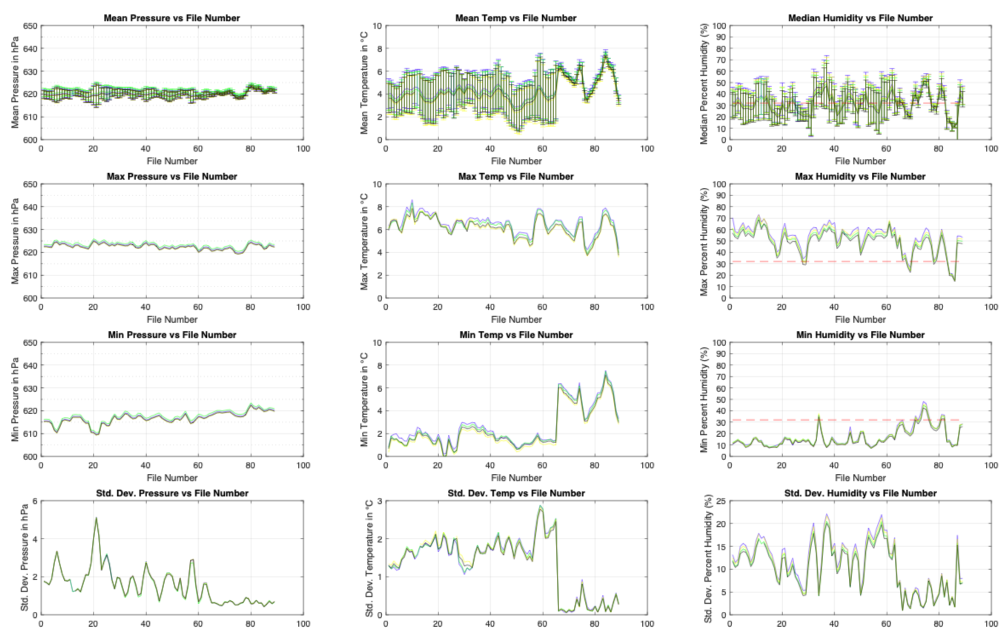

Fig. 6 Statistics gathered from the past few years of data collected with KPIC.

Methods

The work that I have done this summer has involved working with Arduino, an engineering platform that comes with its own programming language that controls the hardware. To explain the block diagram from Fig. 7, to start the environmental sensing program at HCST, the user must first run the Arduino program which is located on Bernard – a computer in the ET Lab. Then the Arduino hardware collects the data from the eight sensors inside the HCST. Since the hardware has a module that allows it to connect to the ethernet, the Arduino program is able to upload the environmental data to the internet at the website "192.168.1.3." From here, the user can decide whether they want to look at the live environmental data inside the HCST or any desired time span of environmental data by running the corresponding MATLAB program. From here, the MATLAB program obtains the data from the website (192.168.1.3) and displays an output similar to Fig. 3 or Fig. 4 to the Bernard computer monitor.

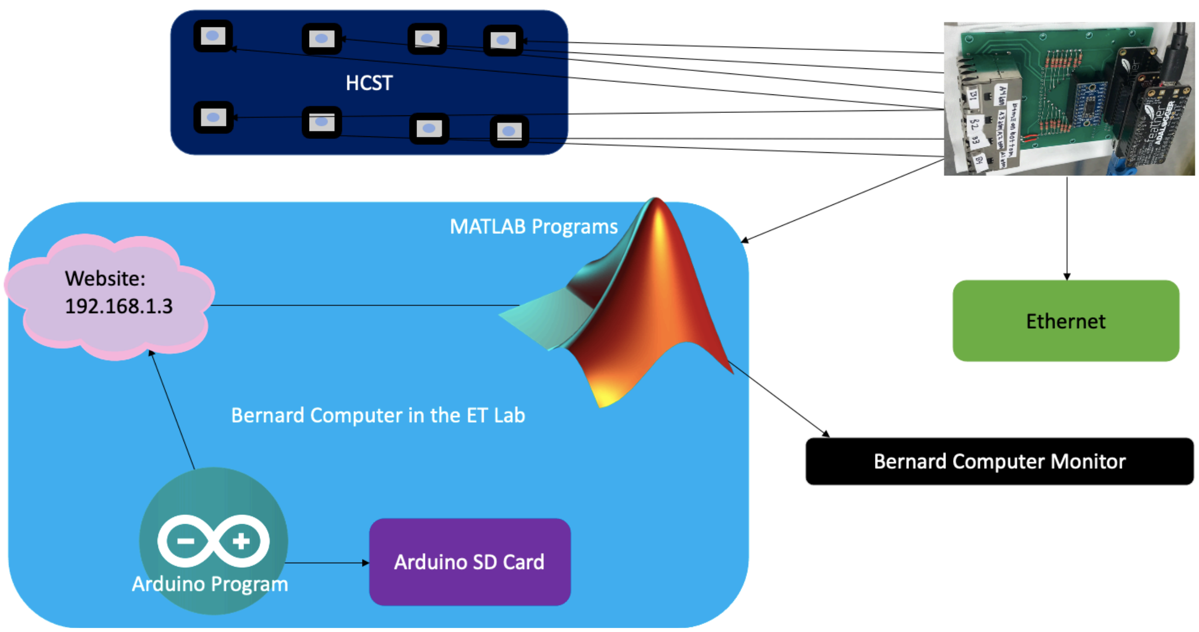

Fig. 7 A block diagram of the environmental sensing system used with the HCST. Bernard is a computer in the ET Lab.

My work has also involved reading coding documentation and discussion forums, upgrading the current hardware parts (adding the RTC module to the hardware), writing documentation for the project and writing and testing code to create the best possible setup that can be used long after I leave Caltech. The two software programs that I have used to write code are MATLAB and Arduino. The Arduino software requires the hardware shown in Fig. 8 to work, with which I had no prior experience before coming to Caltech. I had to do a lot of trial and error to figure out how to use the Arduino properly. I also had to work with members of the lab to figure out how to put the hardware in the protective nonconducting box shown in Fig. 8.

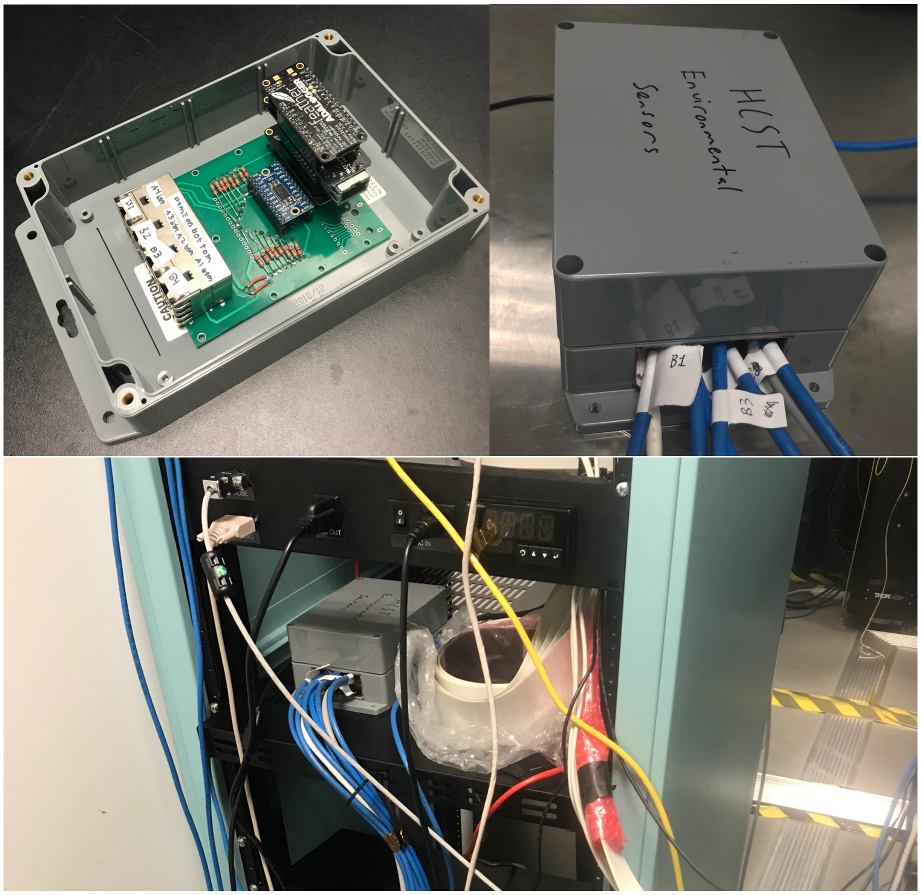

Fig. 8 The Arduino hardware is now inside a protective non conducting box that is screwed in to the location seen in the bottom image in the ET Lab.

Future Work

The current sensors measure humidity with 0.008% r.H. resolution, pressure with 0.18Pa resolution, temperature with 0.01°C resolution, and acceleration with 90mg resolution (Llop-Sayson et al. 2021). The temperature, pressure and humidity are measured with high precision, though the resolution of the accelerometer is not acceptable for our application.

While at Caltech, I researched many accelerometers online and found one with <26 μg noise which is about 1000 times more precise than the current accelerometer, though we are still unsure about whether the accelerometer that I found will be precise enough for use with HCST since the testbed is sensitive to miniscule vibrations. It is possible that no accelerometer will work for our application and a different vibration sensor will need to be implemented. Future work will be needed to research and implement a better vibration sensing system that can be used at HCST.

Discussion

The environmental sensing system will be used to correlate the data collected with HCST and KPIC and the corresponding environmental data. This will help us better understand the limitations of the HCST and KPIC, and the limitations of current high contrast technologies (Llop-Sayson et al. 2021).

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References

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