Modification and Development of a Control Mechanism for the Scanning Microwave Limb Sounder

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The scanning microwave limb sounder (SMLS) is the latest instrument to probe the Earth's atmosphere to come out of the Microwave Limb Sounder (MLS) team. Once deployed to the upper stratosphere, it will use microwave detection to measure geo-atmospheric variables such as temperature, pressure, and chemical composition. In addition to previous missions that used vertical limb scans to observe altitudinal variations, the SMLS will rotate laterally allowing it to establish two-dimensional variable dependencies with a single run. A program was originated by a previous intern that will automatically control the movement of the two rotational axes along with a switching mirror and chopper once the instrument is in flight. However, it lacked the code essential to control system's ability to function fully and reliably. By modifying and rewriting parts of the code I sought to have a finished ready-for-flight control system that would be easy to navigate. Three of the major alterations I made including instituting a gyroscope, implementing a restart button, and instigating the automatic creation of a file log with each run to record the position and orientation of the SMLS.

Nomenclature

V	= Volt
XC	= subset of C programming language
Hz	= inverse seconds
K	= Kelvin

I. Introduction

NASA's Microwave Limb Sounder (MLS) mission is designed to study the Earth's atmosphere to better understand climate change and its dependence on human activity. By vertically scanning the planet's limb for microwaves emitted from atmospheric gases one can construct a profile with various characteristics including temperature, pressure, cloud ice, and chemical composition. These geo-atmospheric variables quantitatively convey what chemicals (natural and unnatural) are polluting our environment and how our global climate has shifted in recent history. The scanning microwave limb sounder (SMLS) is the latest instrument to become part of the MLS team's arsenal and is schedule for deployment later this year. SMLS differs from previous instruments in that it possesses the ability to scan azimuthally for a range of approximately 120 degrees. This unprecedented second rotational degree of freedom will provide the MLS team with data that describes how geo-atmospheric variables change not just with altitude, but with lateral displacement as well. The work discussed in this report relates to my work at the Jet Propulsion Laboratory (JPL) developing and testing several components of the SMLS.

To allow motion in various parts of SMLS a control system was designed. The control system consists of four components: one for each axis of rotation, one for the switching mirror integrated into the front of the instrument, and one for the chopper. Each component connected to an Integrated Motion Systems (IMS) box via two chords, though the chords varied depending on the motor to which they were attached. All four IMS boxes were connected to a power supply of 28 V and a universal XMOS card with its on power supply of 5 V. The XMOS card connected via USB and Ethernet to a computer that contained code written in XC and Python. The code would feed instructions to the XMOS card, which in turn would relay them to the motors and IMS boxes

The Python coding was meant to set up a graphical user interface (GUI) that would allow the user to start and stop data acquisition. It contained Initialize and Stop buttons along with mutually exclusive Start and Stop Data options. Upon beginning the program the user should click Initialize to set the each of the four motors to its appropriate position. To run the control mechanism the user then selects the Start option. The mechanism will continue automatically for as long as the Start option is selected. The Stop Data button halts the mechanism's movement temporarily until the Start button is reselected, at which point it will continue on with its cycle from where it left off. The Stop button stops all processes and

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renders all other buttons inactive. In short, Stop stops the control mechanism entirely and leaves the user no choice but to restart the entire program if they wish to acquire more data. In addition the GUI had three graphs and a line to write the name of the data should the user wish to save it. It was discovered however, whenever text was entered in the line the system encountered a fatal error and was rendered unusable. The three graphs showed positions of the x-axis, y-axis, and switching mirror.

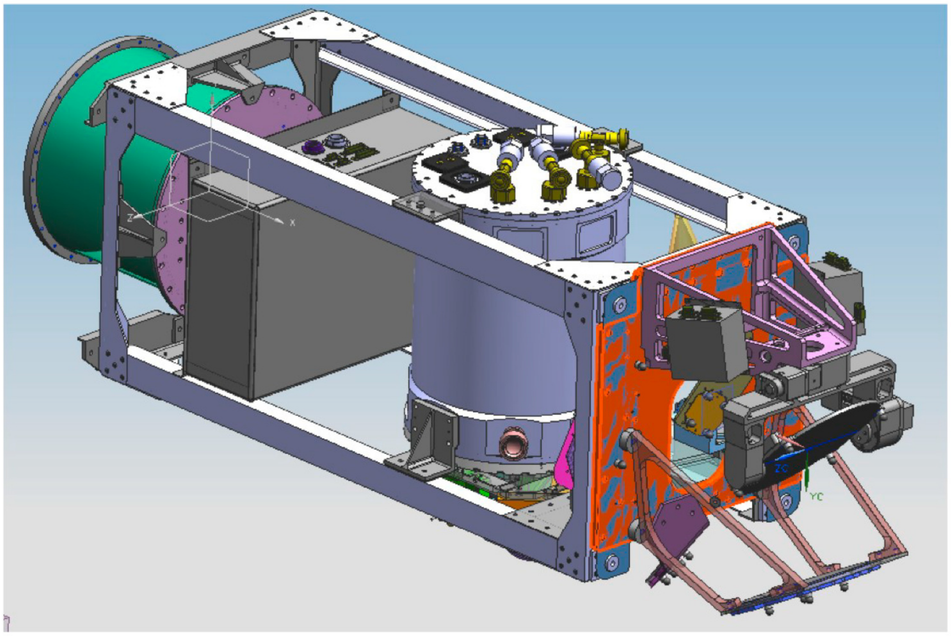

Figure 1: Setup of SMLS with control system in the front (bottom right) followed by the Dewar

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The movement of the control mechanism was synchronized to allow optimized data collection. The chopper was used as a timing standard for the rest of the motors with a frequency of approximately 10 Hz. The mirror would rotate up and down along the y-axis as the x-axis moved slowly across the horizon. The x-axis would move about one degree and stop so the y-axis could rotate downwards and then back upwards. The switching mirror would move to calibration momentarily at the end of each y-axis cycle, and then the x-axis would move another degree. This continued for 60 cycles or about half of the total lateral range of the x-axis gimbal.

Since the SMLS is to be reading microwaves it must be kept at very cool temperatures to reduce noise and contamination. A Dewar will sit behind the spectrometer to keep it at liquid helium temperatures (about 4 K) for the duration of the flight.

II. Objectives

My principal goal was to finish the development of the SMLS control system. Although code existed to run the motors it was not without faults. First, there was no way to restart the scan cycle without restarting the entire program. In lab this was inconvenient enough but once deployed in the field there needed to be a quick and easy method to start the scan over without having to quit, reopen, and re-initialize the entire control mechanism. One of my goals then was to institute a Restart button that would tell the SMLS to start the entire scan cycle over without restarting the program and regardless of its current position. Next I sought to restore each motor's parameters in the occurrence they be forgotten. I noticed that the motors were prone to losing their identities and therefore their necessary parameters for operation. This dilemma will be explained in detail in the subsequent section as it caused a large amount of problems and led to the eventual stalling of my work. However, these parameters were critical to the SMLS functioning properly. Thus my next goal was to modify the existing code to change each motor's parameters from default to those necessitated by the SMLS.

Another endeavor I had to undertake was to incorporate a gyroscope with the mechanical control system. It would be crucial to have data on the orientation of the instrument when obtaining data. My next task then became to flawlessly establish a connection from the gyroscope to the XMOS card (and thus to the computer) and write code that would flawlessly read in the 30-byte binary code and convert it to decimal. Lastly, I needed to develop a new method to record the data from the four motors and the gyroscope. It was essential that this be recorded for data reduction purposes after the flight, and since the current method resulted in a program failure I decided to produce my own way. These were the major modifications that needed to be made to the control mechanism system to make it field-ready from a programming standpoint.

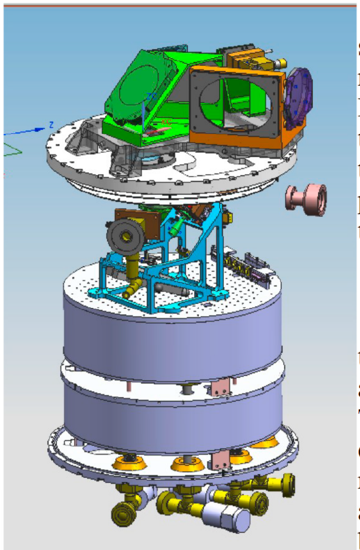

Figure 2: Diagram of Dewar interior

Because microwaves have relatively low frequencies (and thus low energies), spectrometers attempting to detect them are subject to contamination and noise. The results are usable, but it is preferable to avoid this if possible. To combat this problem a Dewar is used to cool the spectrometer. The Dewar has a compartment for liquid helium in the center separated by vacuum from a compartment of liquid nitrogen to slow the heat transfer process. Maintaining vacuum is critical to keeping the liquid helium for as long as possible. I had to determine whether or the Dewar had any leaks, and if so, find where they were located and diagnose them

III. Methods

Before I could modify the programming I had to learn XC and Python. This allowed me to both understand the existing code and make my own improvements. Once I had gained an adequate level of proficiency I began altering the code to allow for a Restart button. The trick was not only getting the Python GUI to send the command to the XC code, but to change the XC portion to reset everything as if it had just been initiated and allow for multiple restarts in a single run. This was a challenge because, as I mentioned, the Initiate and Stop buttons were only available for one-time use. To overcome this I first created a button on the GUI using Python. I then said anytime this button is clicked send a certain signal to the XC code. Once the XC code got the signal, it would need to know what to do with it. Thus I altered that code as well, making it revert back to its initial location when clicked, and automatically beginning the new scan cycle. Furthermore I ensured it had the ability to restart as many times as necessary, so that it would not be a one-time click like the Stop and Initialize buttons.

My next modification was to immediately store the desired parameters in the system for the experiment upon start-up. This was relevant because motors would forget their identifying character and have to be re-programmed. Re-programming required connecting the motor to a different computer and performing a series of steps including disconnecting and reconnecting ground. It was a laborious process but was the only way to give them back their name. The external computer could be used to individually give each parameter its designated value, but the process would be ultimately tedious. Therefore it was imperative they be given their rotational velocities, home positions, and other necessary quantities automatically before the scan cycle began. To do this I ran a loop at the beginning of the XC code that fed each motor its specific quantities and saved them. This allowed us to get the proper timing we needed with the scan cycles. Another reason these parameters had to be fed was because the existing code did not appropriately find home on the switching mirror. Although throughout the scan cycle rotational positions were periodically given to the switching mirror, these were based on relative positions with no sense of absolute scale. Since the switching mirror was not axially symmetric this would create problems during testing and in the field as the light would not be appropriately reflected. The only way to ensure the switching mirror was at the correct position was to have it move very slowly until it found its home position. Its home position is a unique location that allows the switching mirror to know exactly

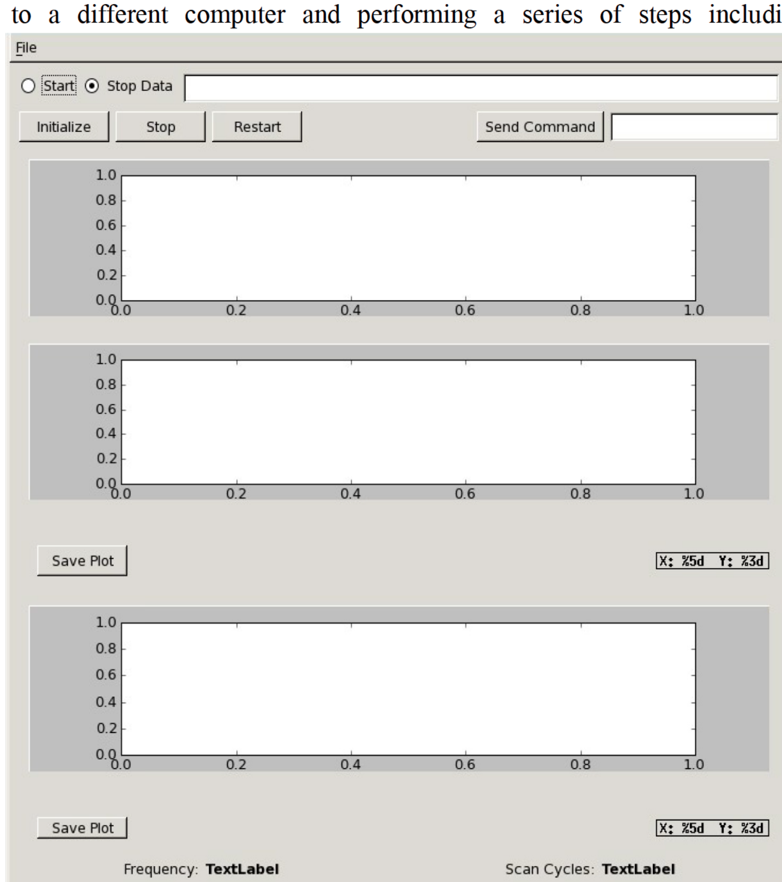

Figure 3: SMLS GUI to initiate and run the control mechanism

where it is. Once the home position is found all other positions to which the mirror moves are taken relative to it and thus they are always the same.

While possible to re-program the motors, this tedious process became all too frequent and would ultimately stall my work on the gyroscope. There was no good reason this should be happening, and we spent countless hours trying to figure out the cause. The company who made the motors had never heard of this before and was unable to provide any sort of assistance. Finally we speculated the motors forgetting their names was due to electrical surges between cables, as wires were long and disordered on the table bench top. We are still unsure if this is the true cause, as these occurrences happened rather sporadically, but are currently putting the motors in their final positions on the SMLS and remaking cables of the appropriate lengths. It is unlikely this task will be done by the end of my internship, so the responsibility of testing it will fall on the person who takes this over next.

In addition to the four components governed by motors the SMLS control mechanism needed a gyroscope. This would allow the exact orientation of the system to be known at a given time, and would be useful for determining where in the sky data came from. There existed some code for the gyroscope, but it was essentially useless. As a result any data it was getting from the gyroscope was irrelevant and dramatic changes had to be made. To combat this I first read the manual on the format of the output. This alerted me to what to look for when data was coming through to see if we were on the right track. Next we wanted to look at the spacing between data packets. Since there was a large enough space (approximately the same size as the entire data packet) I wrote my code to look for a sequence of over a hundred ones in a row. The chances of this occurring in the data packet are next to nothing so we can be sure this will only work between packets. Then I told it to wait until the first 0 (since that is how the start pins begin) and begin recording data there. Since we know each byte is 8 bits plus a start bit and the fifth byte of the packet always gives the packet's length, we can successfully read in the entire packet without any problems. When the data packet is done there should be another long series of ones while it waits for the next packet to be read. This is easily accomplished with a while loop, and gives the XC code access to everything the gyroscope can tell us.

My last task for the SMLS control mechanism was to develop a method to record data from the four motors as well as the gyroscope so that it could be later used to better analyze the spectrometer data. As mentioned above, there existed an attempted system to do this but resulted in a failure of the entire program. To fix this I automated a recording of a data sheet to be stored in the DIRECTORY/SMLS_data/DATE where DIRECTORY refers to the path to the folder that stores the Python code, and DATE refers to whatever date the data is taken on. Inside each date folder lies all SMLS runs from that date, labeled by its date and time of commencement. This way all the information on the control mechanism for every run is stored and can be looked at later. It was also useful in debugging as I could look up the text file and see what each of the components were doing when it worked or didn't work. The difficulty came when trying to incorporate the gyroscope data into the record sheet. Because the data is read in through the XC code, it then has to be transferred seamlessly to the Python program, re-converted to hexadecimal digits, and transcribed onto the output file. I began by modifying the code to allow for the first two bytes to be transmitted to the Python and it worked successfully. However, upon finishing the code to transfer the entire gyro data packet it was much to my dismay to discover several motors had forgotten their names once again. I reprogrammed them but found that was not the problem. They still had their names and would not function properly. When I would run the program sometimes some of them would work and other times others would work – there was no discernible pattern to which would or wouldn't work. I had never before encountered this problem, and Bob Jarnot and I decided it was likely due to the wiring pattern. In addition to the sloppy cabling throughout the surface of the table the motor boxes themselves contained a somewhat messy wiring job. We decided to halt work until everything had been rewired to allow for optimal positioning and minimal electromagnetic interference. We put the motors where they would be on the final flight run, measured the

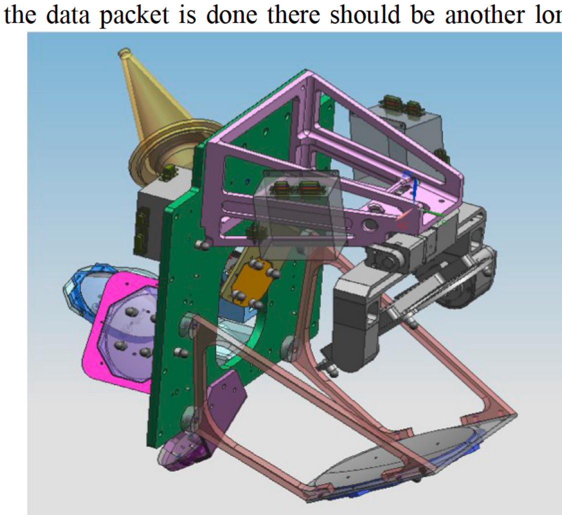

Figure 4a: Front of flight-ready SMLS control system (without cables)

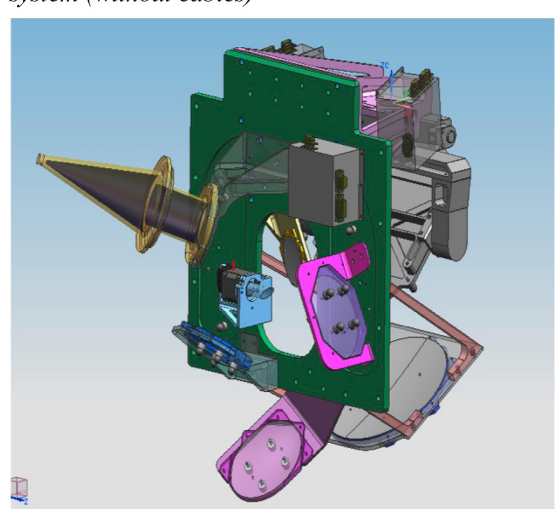

Figure 4b: Back of flight-ready SMLS control system (without cables)

distances the cables had to be, and sought to make it mission-ready. The cables are still being rewired and it is likely they will not be finished until after my internship has ended, so it will be the next person's responsibility to get things going and make sure the gyroscope data is being channeled properly from the XC to the Python programming.

Because of the low energy microwaves contain it was necessary to use a Dewar to minimize internal contamination and that the Dewar not contain any leaks. To test how long the Dewar would stay cold for I was in charge of filling both the nitrogen and helium compartments with liquid nitrogen. Unfortunately the Dewar was soon frozen solid before either of the compartments could be sufficiently filled, signifying there was a substantial leak. My task became then to locate the leak and figure out how to fix it. I used a helium gas mass spectrometer to identify probable leak locations. The problem was there appeared to be several leaks, and we could not figure out what the cause was. I talked to the company that made the Dewar but they were uncertain as well, and tried sending us o-rings of different material. The next step will be to get steel flanges and see if they are more sturdy under disproportionate pressures, but that is likely to be after I am gone as well. We are also trying to obtain leak sealant to help us further narrow down the exact location of any leaks.

IV. Results and Conclusion

Although i ran into several time-consuming problems I was still able to produce effective results and improve the SMLS control mechanism to near-flight readiness. Once the gyroscope transcription code is finished the program should be ready to run as I do not know there to be any caveats or other jobs that need completion. I have modified the code to automatically write data, incorporated a gyroscope into the system, implement an automatic feeding of the parameters to all four motors, and instituted a restart button that is both efficient and reliable. I additionally have worked fiercely on solving the problem of the Dewar leak, and as a result have made substantial progress in that area. Along the way I have also worked with and resolved a number of smaller issues relevant to the SMLS, but have omitted them from this report as they were relatively minor in comparison, such as testing a bias board with a dummy load and changing the code to look for the optimal magnetic current or coming up with creative solutions to engineering dilemmas. In short, this internship was a rewarding experience and I enjoyed contributing to research that will hopefully help us understand human impact on climate change.

V. Acknowledgments

I would like to thank Dr. Paul Stek and Dr. Robert Jarnot for their assistance throughout the internship and allowing me to be part of the Microwave Limb Sounder team. I would also like to thank Dr. Robert Thurstans, Dr. Sharmila Padmanabhan, Tony Guarnera, Mario Loo, and all of the MLS team. Finally, I would like to thank NASA's Undergraduate Student Research Program and the Jet Propulsion Laboratory with the Student-Faculty Programs Office from Caltech to allow me to have this opportunity.