

COLLIDE-3: Avionics Module

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Abstract — Dr. Colwell, a planetary researcher at UCF, has been running the COLLIDE experiments for over decade.

The most recent iteration of the experiment is COLLIDE-2, which was originally designed to fly aboard a rocket (called New Shepard) provided by Blue Origin, an emerging sub-orbital rocket flight company. He asked us to make an AVM for another experiment. To understand what we are trying to achieve through the implementation of our AVM, and to comprehend the vocabulary that will be used regularly throughout this paper, it is important to have a firm grasp of the experiment that our AVM is being designed around to control. However, before we get into that, it is equally important to know the scientific reason behind COLLIDE-3 existing in the first place.

Index Terms — Aerospace electronics, microcontrollers, Electronic components, accelerometers, displays

I. INTRODUCTION

Dr. Colwell is a planetary researcher in the Physics Department at UCF. One of his labs focuses on low-velocity particle collisions in microgravity environments. The formation of a planet occurs in multiple stages. First, dust particles come together to form planetesimals. Once planetesimals grow enough in size, they are considered protoplanets. Finally, a protoplanet can become large enough to be considered a planet. Much is known about planet formation once it reaches the planetesimal stage, since from that stage on the body is large enough to attract particles through its own gravitational force.

However, before this stage, it's unclear how enough particles come together to develop into something with its own gravitational force. This is where Dr. Cowell's research comes in. Through observing collisions of tiny dust particles in a space-like environment (vacuum chamber, microgravity) we can actually see the types of reactions that are likely to lead to planetesimal formation. Dr. Colwell specializes in low velocity impacts, specifically in ranges around 20cm/second. Not only is a microgravity environment essential for reasons of watching the collision occur without gravity moving the particles, but the presence of gravity makes creating a

collision at 20cm/second virtually impossible. What we hope to see in these collisions is particles starting to stick together.

II. OUR EXPERIMENT

COLLIDE-3 houses all of the necessary functions for a controlled collision experiment. Shown in Figure 1 are two of the main components of COLLIDE-3; the IBS module, which is where the actual collision occurs, and the vacuum

chamber, in which the IBS module resides inside. The vacuum chamber is pumped down through the connection circled in yellow in Figure 1. A gauge (orange circle) connects to the same place so that the level of vacuum on the inside can be read. Once a vacuum is achieved, COLLIDE-3 is loaded onto a suborbital rocket. A suborbital rocket is just that; it flies up into the area above Earth's atmosphere, outside the pull of Earth's gravitational forces. Through not having to leave the actual orbit of the Earth, the rocket can be made much simpler and cheaper than those designed to leave orbit, while being able to achieve the same environment for scientific experiments.

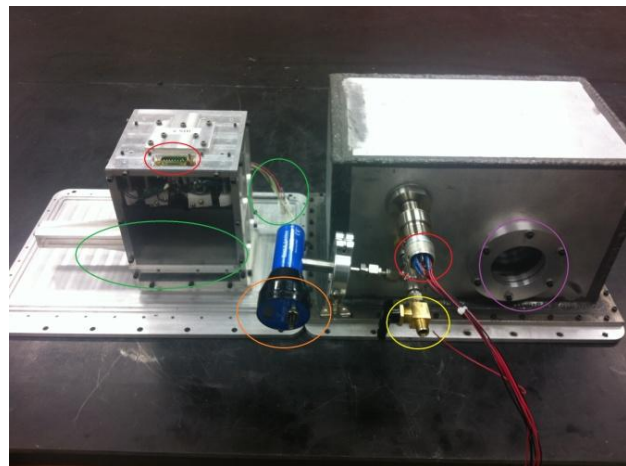


Figure 1. COLLIDE-3 IBS and Vacuum Chamber. The electrical connections circled on the left feed through the box, coming out on the red circle on the right.

Once the rocket reaches its peak altitude and has achieved a microgravity state, COLLIDE-3 runs its experiment. First, the lights activate, allowing the now-recording camera looking in through the viewport (purple, Figure 1) to witness the contents of the vacuum box. The microstep driver (yellow, Figure 2) activates, running the stepper motor (purple, Figure 2) and moving the door down the track on the IBS (green, Figure 1). This door

reveals a payload of dust particles to be collided into. Shortly after the door opens, a current is passed through the muscle wire, which activates the launcher located between the LEDs. The launcher propels a quartz marble into the dust payload basin, all of which is recorded. After 30 seconds, the door is closed, the lights turn off, and the camera stops recording.

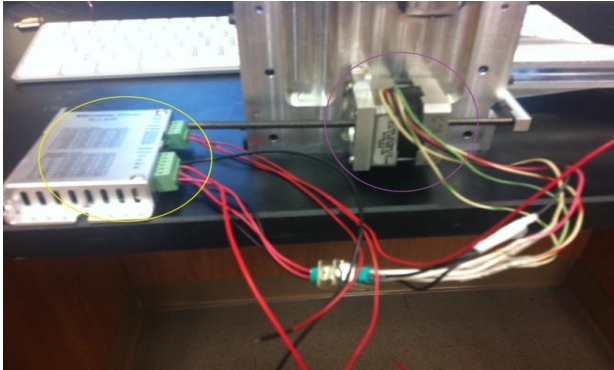


Figure 2. Microstep driver connected to stepper motor

Not shown is the CPB in which the vacuum box, camera, and circuit board (Figure 3) is housed in. This is because the CPB is property of Blue Origin, and we are under a Non-Disclosure Agreement which prevents us from picturing it anywhere. It's a fairly straightforward box though, simply providing threaded holes to mount our boxes and room for electrical feedthroughs. The DC to DC converters shown in Figure 3 are for regulating the voltage sent into the IBS module. Blue Origin's AVM, and the one we are replacing it with, only provided 28V DC. The lights and power of the microstep driver require 12V DC, while the PWM of the microstep driver and the muscle wire require 6V DC. The middle chip in Figure 3 is the 28-12 converter, with the two chips flanking it acting as 28-6 converters.

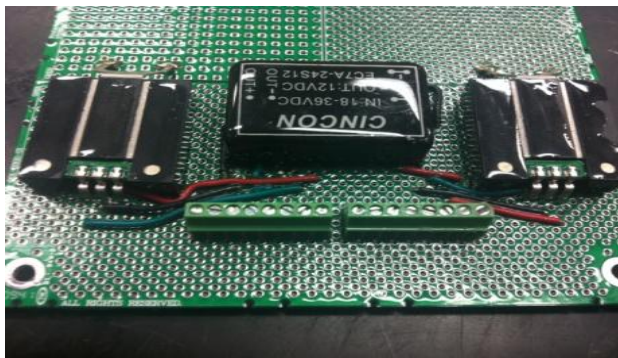


Figure 3. DC to DC converters for IBS components

III. ACCELEROMETER

In order to start the mission, the accelerometer have to sense that it is in mid air or in micro gravity which will simulates the same condition as out of space. The accelerometer will be used to start up many other components like the LED lights, muscle wires, the microcontroller, solid state hard drives, and the camera. Thus, the accelerometer is very important to our project and should be researched and implemented correctly.

Our project is designed to simulate how the universe was created by putting the Collide 3 AVM into space to conduct our experiment with a spherical object and dust particles. This can not be demonstrated because we are not in spaces. For our senior design project, we will be simulating the micro gravity in space by using a drop tower. This drop tower is provided for us by Dr. Josh Colwell which is our sponsor. We will be using his lab to conduct our experiment which will sense micro gravity instead of the conventional space beyond our earth. The drop tower is basically a structure that is about ten to twelve feet tall and made out of PCP pipes and other metal materials. The drop tower also has soft cushions at the bottom to hold the object so it would not break our project when it hits the bottom. We will be lifting our project up to the top of the tower and then we will drop it. Once our project is being dropped in mid air, the accelerometer will detect the micro gravity in that very instance.

Once our accelerometer sense micro gravity from the free fall with the help of the drop tower, it will basically flag a switch which states that it is in space or free fall. Most likely we will have to test it out in the drop tower first to make sure the accelerometer actually senses the micro gravity and activates the switch to flag it on. We will be modifying the code to work during our presentation with just a tilt because we might not be able to present it in the lab. Thus, our presentation will probably start with a tilt of the AVM which will turn the accelerometer on. Of course, we will have some kind of documentations that shows that the accelerometer actually working either on paper or video.

When the accelerometer sense micro gravity, it will initially turn on the LED lights which will provide the Collide 3 AVM with visibility in space. After that, it will initiate the muscle wire by letting current go through it. The muscle wires will squeeze the hinge which will open the door to release the bigger spherical object. It will also open the doors to release some dust particles. The dust particles will most likely orbit around the bigger object. Here is when the camera shines. The camera will start to take pictures and it will store these images onto the solid state hard drive or drives, we have not decided how many

solid state hard drives will be implemented into our project. Essentially, everything will proceed after the accelerometer detects micro gravity.

The reason we are using an accelerometer for our project is because we need a device that will measure active acceleration which is the force due to the gravity of the Earth. We can experience this force during freefall. An accelerometer in a gravitational freefall will measure its force to be zero because its reference to the earth is weightless during this timeframe. Even though the speed is increasing with every second during the fall, there is no normal force to push back which is used to determine the weight. With no weight on the accelerometer, it is essentially weightless. This is the reason why we will be using the accelerometer to simulate micro gravity in out of space.

There are lots of different types of accelerometers out there. The Collide 3 AVM is suppose to go into space as well, thus it might be better to explore our options of accelerometers by getting a more advance one. Some of them even sense the direction and the magnitude of the accelerations in vector and quantity respectively. The advance accelerometer models with these features can be used to detect vibration and shock during the flight. The Collide 3 AVM does not care of the orientation of itself nor does it care about the angles it is in compared to the Earth. Even though those features are not important, most accelerometer will be able to sense them anyways, we just won't use it.

We only need it to sense micro gravity and handle the shock and vibration while it is on its way into space. Most accelerometers are small and is able to handle vibration. This is essential to our project because if it is big and bulky, then the vibration from the flight might shake it and make it not function correctly. The smaller the accelerometer is, the more secure and safe it can be integrated into our Collide 3 AVM.

We are going to be using the Hitachi H48C 3-Axis accelerometer as shown in Figure 4. This accelerometer also has a very low powered consumption feature. It's STBY (standby) mode operates are only 1 micro ampere. It is high shock durable which is also relevant to our project because of the flight into space. It also have different sensitivity mode. The H48C accelerometer description for each pins are also very easy to learn and code as shown in Table 1. All in all, we used the H48C because it fullfill our requirements and it is very easy to used and operate.

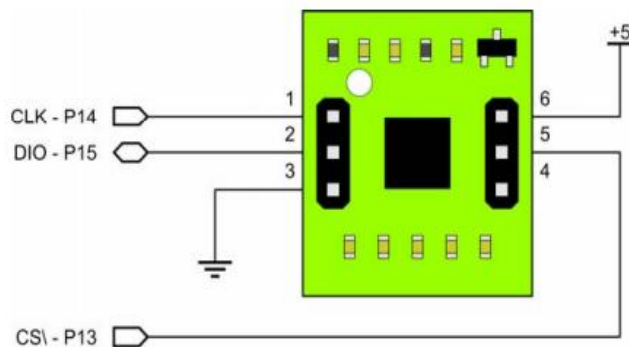


Figure 4. Shows the pin layout of the Hitachi H48C

Pin	Label	Definition
1	CLK	Synchronous clock input
2	DIO	Bi-directional data to and from the host
3	Vss	Power supply ground which is 0v
4	Zero-G	“Free-fall” detection output; active-high
5	CS\	Chip select input; active-low
6	Vdd	+5 vdc

Table 1. Connection pin layout definition

IV. MICROCONTROLLER

COLLIDE-3 consists of many components, which when activated in the right sequence, forms a microgravity experiment. To go about activating these components in the right sequence, we decided to integrate a system of a microcontroller driving various relays. This was done because a microcontroller gave us a way to send signals to various devices at very accurate times, and the relays allowed us to give more current to these devices than the microcontroller would be able to output itself. Specifically, we needed to be able to read an input from an accelerometer, and send outputs to relays which will be controlling LEDs, muscle wire, microstep drivers (both with a flat DC level and a PWM line), and a camera. Important features of the microcontroller for us included: Flash memory available, number of I/O lines, clock speed, package type, operating voltages, output voltage levels, power consumption, robustness, temperature ranges, and ease of programming. The I/O lines currently had to be at least 7-8, but we knew future iterations of the experiment had the possibility of adding more devices to be

controlled, so we set the minimum ideal range to be 14 I/O pins.

A quality of life decision for us was the package type. A DIP style pin layout is more intuitive and something we had more experience creating than a QFP/QFN package style. Also, while it obviously wouldn't be ideal, it is possible to modify a DIP style pin on a PCB board with last minute wirings, while nearly impossible to do the same with a QFP/QFN.

After quite a bit of research, the obvious choice for us was the ATmega328, as seen in Figure A. This microcontroller is fairly popular, being the same one driving the Arduino Uno.

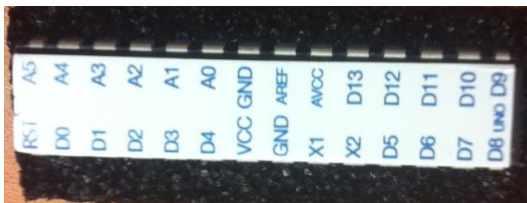


Figure 5. AtMega 328

This meant that there was plenty of support for it, not just through example codes and such, but through the vast DIY groups found throughout the internet. The specs for it were very alluring too, offering 32kb of flash memory, a temperature range far exceeding expected values, 23 I/O capable pins (6 of which had PWM capabilities), and an input voltage range of 1.8-5.5VDC. Not only that but the chip has a very small footprint, with an easy to integrate through hole pin style.

Aside from specs, its power consumption was obviously optimized greatly by the manufacturer. The chip consumes barely .2mA while in its active mode, and lowers that number to .75uA when in power save mode, and lowers it even further to .1uA when in power down mode. In total, the ATmega328 boasted four unique modes, each with successively lower power consumption.

A huge draw for us for the ATmega328 was its ease of programming. The chip itself came pre-burned with a bootloader, which meant it was ready to have code uploaded to it without the use of any external hardware programmers. As for the creation of the actual code to be uploaded to control the experiment, the ATmega328 utilizes the Arduino 1.0 software, which is an open source language of C/C++ functions that can be called. For example, to make pin 6 go high (thus activating a relay), you would simply type "digitalWrite(6,HIGH);". This is not only easy, but also intuitive, which made any debugging fairly simple.

The integration of the ATmega328 with our relays is seen in Figure B. The relays (Axicom Relay 220VDC 2A

SPST) have four pins, two of which are control and two of which are load. Since these are "normally open" relays, meaning the circuit is usually broken, no current may pass through the load side until the control side is activated.

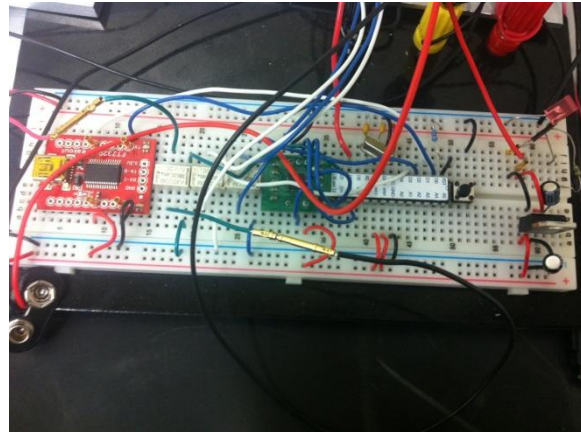


Figure 6. AtMega Micro-Controller

The ATmega328 is capable of activating the control side of the relays through a high signal. Through this setup, an external power source then sends its power through the load side of the relay. Thus, while the ATmega328 itself can only supply around 40mA of current by itself, the relays allow it to control the distribution of the 4A of current the experiment will experience in total.

V. USER INPUT MODULE

A convenient way to both view and change experimental variables was desired so we wanted to include some kind of basic display and several buttons to carry this task out. Research brought us to CrystalFontz's website and to the CFA-735-TFK-KT module. This particular module included all physical features for a price (\$88) that was appropriate to our budget. The display is 20x4 (twenty characters per line, four lines). CrystalFontz has some software provided for both a Windows and Linux environment.



Figure 7. CFA-735-TFK-KT Display

CrystalControl is a Windows compatible software that is very user friendly and allows the end-user to display static text, scrolling text, and text from a file. The text from the file can be updated constantly at a desired interval of 30 seconds. CrystalControl is a very user friendly when creating multiple menus. The CFA-735 will be connected via USB to our primary microcontroller which will host our solid state drive. On the solid state drive will be a text document containing the experimental values that will be viewed and potentially changed.

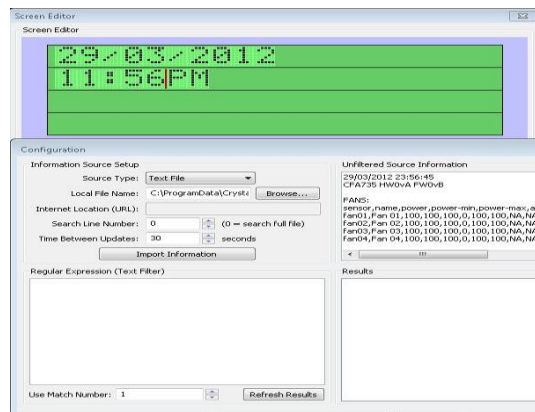


Figure 8. CrystalControl software reading text from a file

In addition to the changing or viewing of variables the user will also have the ability to select which camera will be used during the experiment. This selection will execute a specific set of batchfiles and scripts that will coordinate with the camera's software. Each camera is unique in ability and performance so this is an additional feature that was implemented to maintain the adaptability of the AVM.

The end user of the AVM has the ability to view predetermined experimental variables or change them (by incrementing or decrementing by a value of 1). Camera selection will be part of the menu however it won't be optional, rather mandatory so that the proper script files will run when the experiment begins. Once all of the above have been resolved the user will have a final choice of starting the experiment. Once executed a batch file will be called to run all necessary programs.

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VI. WINDOWS BOARD

The primary micro-controller must be compatible and sustainable for several connected devices, including the camera, the solid-state drive, and the AtMega micro-controller.

COLLIDE 3 will be initially ran with a consumer type camera and later with a high-end industrial camera. Dr. Colwell has several high-end cameras at his disposal so the goal was to choose a board that would be compatible to as many cameras as possible. Luckily we found one board has been compatible with all three cameras. EPIA branded P820-12 mainboard has a VIA Nano ULV processor (1.2GHz) which supports a Windows XP (as well as other versions of Windows and Linux) install. All three cameras have software that is only compatible to Windows XP and later versions, thus making a Windows based board a requirement. Since each camera's software will be installed it introduces the opportunity to create custom scripts and batch files to automatically run their software when needed by the experiment.

Due to the intense data stream coming down from the camera a board would have to be able to support the standard interface for a solid-state drive and the resources necessary to sustain the data transfer. The P820 has a SATA II connector. A SATA II connection can sustain up to 3.0 Gb/s (or 300 MB/s). Even with the highest resolution camera, after all settings (fps, resolution) have been made the transfer rate should only peak at no more than 110 MB/s; thus this will serve as more than needed to capture all images without having any issues. In addition to having a SATA II interface the P820 has been upgraded to include 2 Gigabytes of DDR2 RAM. Not only will this help in the data transfers but also with multitasking the camera software as well as the AtMega software (Arduino 1.0) and all necessary batch files and scripts written to automate the experiment.

Writing to the AtMega microprocessor is most utilized through the Arduino 1.0 software program. It is also compatible to Windows XP and later versions. The GUI of the Arduino 1.0 program is very user friendly and maintains a simple design interface. It is not resource

hungry and is required only to write the experiment procedure to the AtMega328. A batch file or script will be called when needed to start the program loaded with code where certain values have been loaded from the text file that was being used in connection with the CFA-735 (user input module). Again, since the board is Windows XP based a simple batch file or script can load the program with said file and execute the “Upload” button to write the code to the AtMega328.

Additional required components of the primary micro-controller included hardware interfaces for current and future peripherals. To support this the P820 sports two 2.0 USB ports (with the ability to add four more), a VGA interface, a HDMI interface, and a gigabit ethernet interface (see Figure 9 below). The gigabit Ethernet port will host the camera and the USB ports will be used for the user input module and to connect the AtMega micro-controller through a serial-to-USB breakout board. With the current setup there is only a one-way communication going from the P820 to the AtMega micro-controller, however if in the future the experiment calls for the micro-controllers to communicate back and forth with each other the P820 includes Watchdog timer; which is a software to help monitor and sustain stable communication between two micro-controllers.

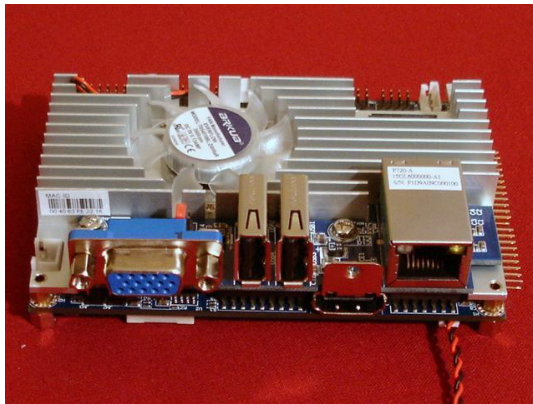


Figure 9. VIA Windows Board.

A final yet obvious requirement for the primary micro-controller is size. The COLLIDE-3 will house many parts and thus space will be limited. Fortunately the P820 has a

Pico-ITX form factor and is only 3.5” x 3.5” (see Figure 10 below). The size is incredibly small considering the software and hardware support from the board.



Figure 10. VIA Windows board form factor: Pico-ITX

VII. SOLID STATE HARD DRIVE

The camera will be shooting images at 200 frames per second at a resolution of 640 x 480. This has been tested to output data at approximately 100 megabytes per second (or 1 gigabytes per 10 seconds). With this in mind we knew the experiment would require a solid state drive to keep up with the data transfer rate. Additionally, since all components of the COLLIDE-3 will be under-going some tests to ensure they can handle the environment of the rocket (i.e. vibration test) the solid-state drive has no moving mechanical parts and undergoes both a shock and vibration test as part of its design. Luckily the cost and availability of solid state drives much better than they were just a few years ago.

Even with an average output of 100 megabytes per second the experiment run-time is only a few short minutes so storage capacity will not have to be that large, allowing us to focus more on speed than capacity when searching for a solid state drive. OCZ’s Vertex3 60 gigabyte solid state drive fits the needs of the experiment well. It used the latest SATA III interface which can have a potential data transfer rate of 600 megabytes per second. The drive itself can read up to 530 megabytes per second and write up to 480 megabytes per second. Solid-state drives are also small in form factor and will not take up much space in the COLLIDE-3 container (see Figure 9 below).



Figure 12. OCZ's Vertex3 solid state drive. under 4' x 3" in size.

VIII. CAMERA

The camera is arguably the most essential piece to the experiment. It has to have the ability to record at a resolution clear enough and a frame-rate fast enough to enable Dr. Colwell to dissect the effects of the experiment in micro-gravity.

Dr. Colwell has several high-end cameras at his disposal however for initial projects he will be using the StreamView-LR (see Figure 8 below). The StreamView-LR has a max resolution of 640 x 480 (VGA) which has sufficed on past experiments but also a pixel size of 7.4 x 7.4 μm . Even at this max resolution the StreamView can still maintain a 200 frames per second rate, maximizing visual data that will be retained onto the solid state drive. An additional ability of the camera is the integrated sensor can record in either 8-bit monochrome or in 24-bit color. Currently Dr. Colwell records the COLLIDE-3 experiment in monochrome however if that changes in the future this camera has the capability of adapting.



Figure 13. SVSI's StreamView-LR

At a resolution of 640x480 and a frame-rate of 200 frames per second the data transfer rate is about 100 mega-bytes per second. Recognizing this, the StreamView includes a gigabit interface to make such data acquisitions easier. The mainboard has a gigabit interface and the project will use a solid-state drive with a SATA II interface (capable of transferring data at 300 megabytes per second), thus the combination of both will compliment the StreamView-LR nicely.

The container that will house the entire COLLIDE-3 experiment has limited space so size was also an issue in deciding on a high-end camera. The StreamView, despite its many features, is only 1.5" x 2.0" x 3.2".

In the past Dr. Colwell has lost his experiment due to a rocket failure and thus lost a lot of grant money as well, most of which was spent on a high-end camera (the StreamView is on the cheaper end, it can be found for as little as \$6,000). This time he is planning ahead and has purchased a consumer camera which only cost \$200. The GoPro Hero is small, rugged, and can be easily be integrated into the experiment (see Figure 9 below). Its usual purpose is to be mounted on a helmet (skating, snowboarding, etc) and required a participant's action from a first-person view. In COLLIDE-3 it has good enough resolution and frame-rate to record the experiment on initial launches until the Dr. Colwell is comfortable that the rockets are stable enough to start implementing a high-end camera. Unlike the high-end cameras (which require a host computer and some sort of data storage) the Hero only needs a power signal to begin recording directly to its on-board storage. Although our AVM has a solid state drive and Windows mainboard, the Hero can still be integrated; it would just make the solid-state drive obsolete.



Figure 14. GoPro's Hero with original lens replaced with a non-fish eye lens.

IX. CONCLUSION

The Collide-3 AVM experiment will provide Dr. Josh Colwell another opportunity to study how planets were formed. The AVM part of the Collide-3 is designed to act as a “brain” or manager of the experiment. It will include a user input module for quick access to editing the configurations of the experiment. Overall, once the AVM is built and successfully integrated with the rest of the Collide-3 it will give the researchers and scientists at UCF another opportunity to study how planets were formed.

Our Collide-3 AVM finish project should be able to detect micro gravity when it is either in space or during a free fall. In our case, we will simply showcase it tilting to be activated. Follow by the LED lights turning on, then the dropping of the marble and moving of the micro-step driver. Once the micro-step driver opens the door completely, the particles should be released. The camera should now be recording data and that is the end of our experiment.

The research behind planetary formation is vast across the globe and it is a privilege to work towards any possible future discoveries in this field. This project is beneficial on several levels including academically and personally. The AVM will require skill in both electrical engineering and computer science. The project itself will require a high degree of teamwork from all individuals, including Dr. Josh Calwell.

ACKNOWLEDGEMENT

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We would also like to thank all the professors here today for agreeing to be a part of our senior design review committee. We hope you enjoy our presentation.

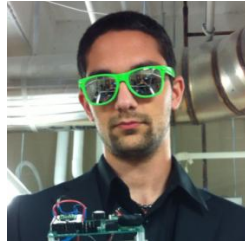
BIOGRAPHY



Walter Castellon is 26 years old doing dual major in Computer Engineering and Electrical Engineering. After graduating Walter plans to continue working at Infrared Systems Development as a design Engineer focusing on Analog Circuit Design.



Mohammad Amori is a 28 year old Computer Engineer currently interning at Lockheed Martin Lake Underhill location. He is an excellent friend and can pull the group together to get any task at hand done quick and swiftly. He is very family oriented and always helps out when needed.



Joshua Steele is a Computer Engineering student at UCF and a Brother of Theta Tau. He is a great leader and always gets things done when given a task. He is currently a Research Assistant for Dr. Colwell in the Microgravity Research Lab.



Tri Tran is a 25 year old Computer Engineer major. He is currently interning at Lockheed Marting Sandlake location. He plans on getting his Masters here at UCF after graduation. Great coder and likes testing and integration.

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