Embedded Systems Hardware Integration and Code Development for Maraia Capsule and E-MIST

Emmanuel S. Carretero
Embry-Riddle Aeronautical University, Daytona Beach, FL, 32114

The cost of sending large spacecraft to orbit makes them undesirable for carrying out smaller scientific missions. Small spacecraft are more economical and can be tailored for missions where specific tasks need to be carried out, the Maraia capsule is such a spacecraft. Maraia will allow for samples of experiments conducted on the International Space Station to be returned to earth. The use of balloons to conduct experiments at the edge of space is a practical approach to reducing the large expense of using rockets. E-MIST is a payload designed to fly on a high altitude balloon. It can maintain science experiments in a controlled manner at the edge of space. The work covered here entails the integration of hardware onto each of the mentioned systems and the code associated with such work. In particular, the resistance temperature detector, pressure transducers, cameras, and thrusters for Maraia are discussed. The integration of the resistance temperature detectors and motor controllers to E-MIST is described. Several issues associated with sensor accuracy, code lock-up, and in-flight reset issues are mentioned. The solutions and proposed solutions to these issues are explained.

Nomenclature

E-MIST	=	Exposing Microorganisms in the Stratosphere
GPS	=	Global Positioning System
IPR	=	Ice-Point Resistance
ISS	=	International Space Station
JSC	=	Johnson Space Center
KSC	=	Kennedy Space Center
NASA	=	National Aeronautics and Space Administration
OEM	=	Original Equipment Manufacturers
RTD	=	Resistance Temperature Detector

I. Introduction

A. Maraia Background

The Maraia Capsule is a small, unmanned capsule designed to bring samples from experiments aboard the ISS back to earth. The project is a collaboration between KSC and JSC. The design of the outer shell, heat shield, and lid were done at JSC, KSC was responsible for building these components. KSC was also responsible for the avionics, flight software, ground station, and telemetry. JSC is currently developing the control algorithm and designing the internal hardware layout for the prototypes being developed. The full-scale version of Maraia will have a diameter of about [redacted] and weigh approximately [redacted].

Two small-scale and a full-scale version of Maraia have previously been created and tested at subsonic speeds. The purpose of all 3 flights were to test aerodynamic stability at subsonic speeds. The 2 small-scale flights were used to validate the avionics hardware, parachute deployment system, and flight code leading up to the large-scale test.

There is currently another small-scale prototype of Maraia being developed. This test article is intended for supersonic testing. In addition, the new prototype will contain a full set of hardware and software for a more in-depth test of the entire system. In order to achieve supersonic testing the capsule will be dropped from an altitude of [redacted], this should allow testing at speeds up to approximately Mach [redacted]. The small-scale, supersonic article is nearing completion; most of the hardware (GPS, altimeter, cameras, RTD, pressure transducers, thrusters) have already been incorporated prior to, or as a result of, the work described here.[1]

B. E-MIST Background

E-MIST is not a capsule nor a rocket, it is a payload for conducting scientific experiments. This system is designed to attach to a high altitude balloon via connections to gondolas on the balloon. The target altitude for these experiments is in the range of [redacted] above sea level.[2] The technology has previously been applied to an experiment.

There are four chambers where samples can be held. The samples themselves are mounted on four "skewers", one for each chamber. These "skewers" can be rotated to expose the samples to the environment. During the previous mission it was observed that there were issues with the opening and closing of the chambers (rotation of the skewers). It was determined that the improper opening and closing of each "skewer" stemmed from how the motors were controlled. The "Considerations" section of this report describes the issue and how it was resolved.

E-MIST employs a number of sensors to observe the environment in which the tests are conducted, these sensors are: radiometer (1), GPS receiver (1), Altimeter (1), RTD (3).[2] The GPS was not operational for the 1st flight so this system was fixed for the 2nd flight. The current condition of E-MIST did not require modification of any of these subsystems, but it was determined that improved accuracy could be achieved on the temperature measurement of the RTDs. This project supported modification of the circuits for the RTDs via design and testing of the new circuits. Improvements were also done in the motor control to reduce error in the rotation of the "skewers".

II. Setup

C. Maraia Hardware Setup

1. *Cameras*

The two cameras are oriented such that one is facing upward, through the top of the capsule, and the other faces to the side. Figure 1 shows the location of these cameras on the capsule. The upward-facing camera is intended to capture the deployment of the parachute. The side-facing camera allows for verification of the capsule orientation (can get a visual comparison with the horizon).[1]

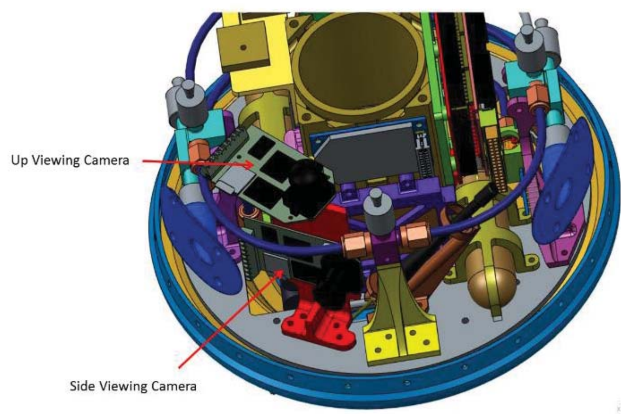

Figure 1. View of internal capsule components showing position of cameras[1]

2. *RTD*

The purpose of the RTD is to measure the temperature on the heat shield during atmosphere re-entry. The sensing portion of the RTD is attached to the heat shield, and the female connector end is joined to a male connector on the avionics board. This allows for ease of replacement, should the RTD be damaged and need to be replaced. The setup also simplifies debugging when testing with various resistors in place of the RTD.

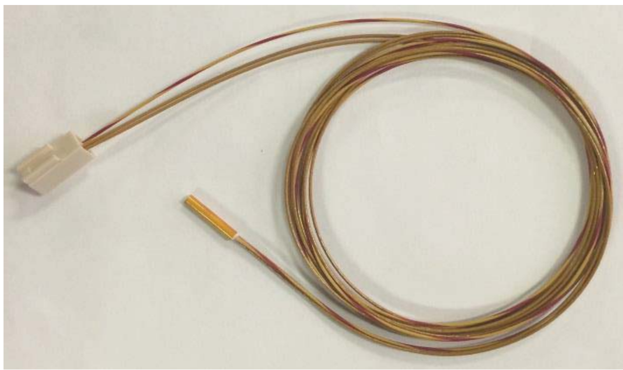

Figure 2. RTD used on Maraia

The RTD is setup in a voltage divider circuit so that an analog input on the microcontroller can read in the voltage across the RTD. The voltage can then be used to solve for the resistance of the RTD and thus obtain the temperature measurement. The supply voltage for the voltage divider is 5V, and the resistor has a value of 2 kΩ. The resistor value was obtained such that the voltage at the analog input would not exceed the allowable ADC input voltage throughout the temperature range.

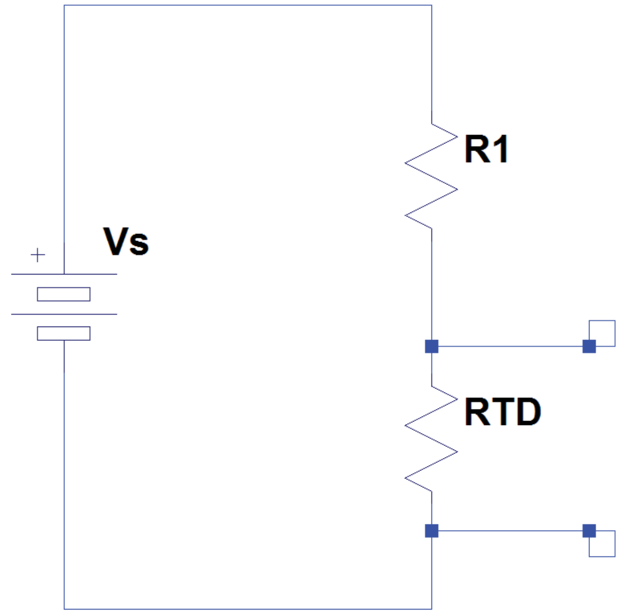

Figure 3. Voltage divider circuit for RTD[3]

3. *Pressure Transducers*

Two pressure transducers are used to measure the pressure on the high [redacted] and low [redacted] sides of the propulsion system. The high side is at the CO2 canister, and the low side is after the relieve valve and before the thrusters.[1] Figure 4 depicts the propulsion system and the areas of high and low pressure where the pressure transducers are to be used.

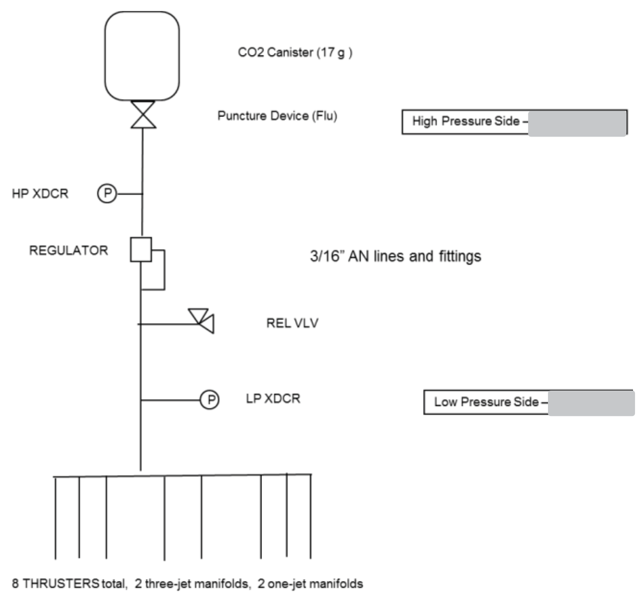

Figure 4. Propulsion system for Maraia[1]

D. E-MIST Hardware Setup

4. RTDs

The three RTDs are located at the battery, radiometer, and the inside of a test coupon mounted on the outer wall. The circuits were designed to be able to read temperatures as low as [redacted]. There are heaters at the battery and radiometer, so these RTDs should read well above that temperature.

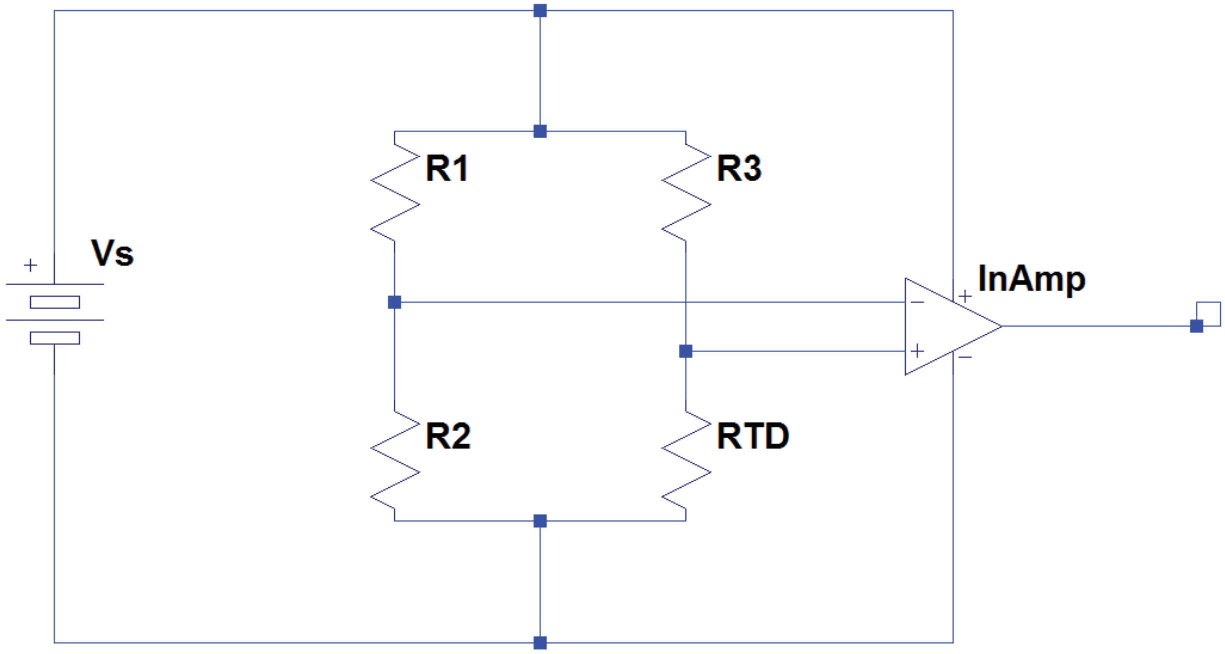

Figure 5. RTD with Wheatstone Bridge and instrument amplifier[3]

Each RTD is set up in a Wheatstone Bridge circuit with an instrument amplifier, as shown above in Figure 5. An analog input on the microcontroller reads in the voltage output from the instrument amplifier. The voltage is used to solve for the resistance of the RTD, which is then used to obtain the temperature measurement. The supply voltage for the RTD is 5V. The resistor values are listed in Table 1. The resistor values were obtained such that the voltage at the analog input would not exceed the allowable ADC input voltage throughout the temperature range. In addition, the following conditions were met: the instrument amplifier output would not be clipped, the voltage output from the instrument amplifier would have the largest range as possible, and the inputs to the instrument amplifier were within limits. The maximum output voltage was limited by the common mode voltage of the supply. Table 2 lists the limitations which were dealt with.

Table 1. Wheatstone Bridge Resistor Values

Label	**Value (Ω)**
R1	2000
R2	68
R3	2000

Table 2. Instrument Amplifier Limitations[4]

Variable	**Voltage (V)**
$V_{OUT\ (G > 1)}$	0.05 to 4.5
$-V_{IN\ (min)}$	0.15
$+V_{IN\ (max)}$	1.5
V_{SOURCE}	3 to 12
$*V_{OUT\ (CMV)}$	< 1.5

* NOTE: This was obtained from tests (not a reference)

5. Motors

As previously mentioned, the four motors control the rotation of the "skewers" (each gets a motor). The rotation of the "skewers" allows for opening and closing of the chambers. Figures 6 and 7 depict the arrangement of the "skewers" on E-MIST and the setup with the motors. The samples are mounted on the "skewers" and the chambers in which they are contained are formed by the "skewer" and the walls around them.

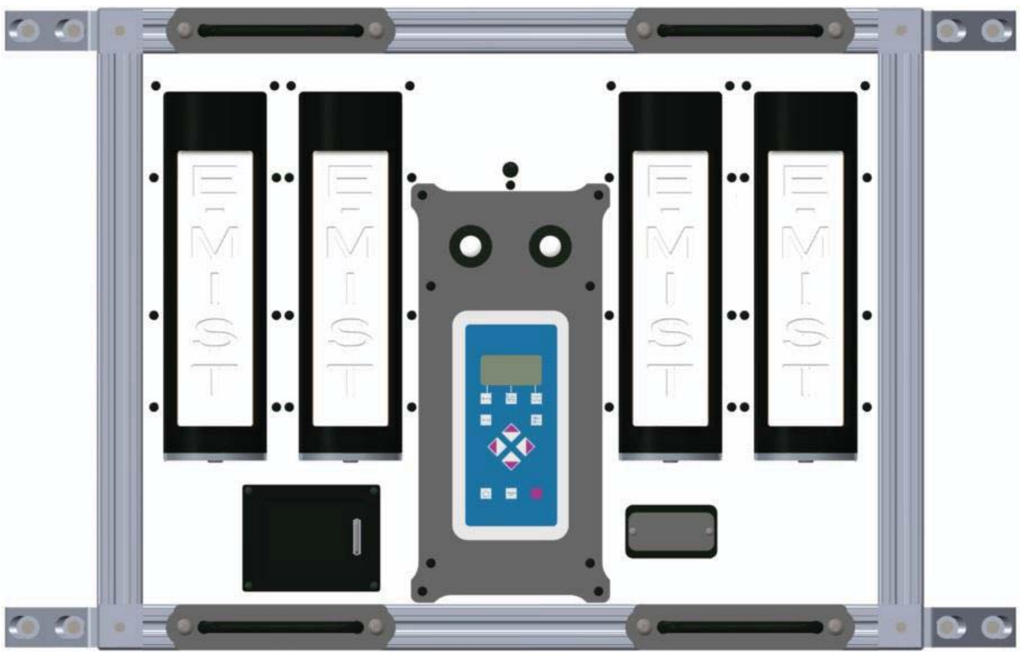

Figure 6. Front view of E-MIST showing locations of skewers[5]

(a) (b)

Figure 7. Front (a) and back (b) views of a skewer assembly[5]

The motors each have 6 pins, these are: Motor (-), Motor (+), Hall VCC, Hall GND, Channel A, Channel B. Two of these pins (motor +/-) are connected to the motor driver, the Hall VCC and GND are connected to 5V and GND, and Channel A is connected to the microcontroller. Channel A and B are quadrature wave outputs from the encoder. Only one channel is used, as the direction of rotation will be known at all times.

For each motor, the driver is connected to the motor +/- and three connections to the microcontroller (motor pin 1, motor pin 2, and motor speed control). In addition, the power supply for the motors and the power supply for the driver must also be connected.

The operation of the four motors requires a total of eight I/O, four PWM, four CN, one 5V, one 3V, and one GND pin on the microcontroller.

III. Considerations

E. Resolving camera shutoff on reset on Maraia

The cameras start recording on automatic mode as soon as launch is detected and will continue to record throughout the flight until the capsule has landed. Since the cameras require a push button to turn on and off, there is risk that an in-flight reset will cause the cameras to turn off and stay off for the remainder of the flight. A solution to this problem would be to have a reset flag trigger off a check to determine if the cameras are already on or not, this would prevent them from shutting off and turning on every reset. This solution hasn't been applied, as there are no remaining available pins.

F. Improving accuracy on Maraia and E-MIST RTDs

There are a number of errors which can arise in the temperature measurement. Some of these issues are listed below:

- Improper mounting of the RTD sensing element
- Lead resistance changing as temperature changes
- Inaccuracy in the ADC
- Accuracy with which any resistor in the circuit was measured
- Accuracy of the power supply

There were studies on how to reduce the error of the measurement, but these were not applied on Maraia, as the RTD is a non-critical component for the spacecraft. However, measures were taken to reduce the error in E-MIST.

The Wheatstone Bridge with Instrument Amplifier combination, mentioned earlier, was implemented on E-MIST to improve accuracy. In particular, the circuit decreases the effect of inaccuracies in the ADC. Though this is the only source of error that was reduced, the accuracy of the measurement was still drastically improved, as the ADC was the major source of error.

G. Eliminating Maraia pressure transducer lockup

The I2C data and clock lines require pull-up resistors in order for the communication protocol to work. These resistors were not integrated into the board and instead had to be placed externally. Both the high side and low side sensors use I2C to communicate with the board. The sensors have the same slave address, so they were placed on separate I2C busses.

Since the I2C protocol has the master wait for an acknowledgement bit from the slave, there is a risk of the code getting stuck should one of the sensors be disconnected while I2C communication is executing. To eliminate this issue, a flag to check sensor connection was implemented to the I2C library. This flag also makes the code more efficient, since code used to run disconnected sensors will not be executed, should those sensors be flagged.

H. Reducing error in motor positioning on E-MIST

Previously, the four motors controlling the "skewers" were rotated based on a predetermined period of rotation, which depended on a consistent motor speed. The issue with this was that the motor speed varied as the battery voltage decreased during flight. To resolve this issue, motor encoders were implemented to determine position, and a control algorithm using position, rather than motor speed and time, was developed.

IV. Conclusions

The cameras on Maraia were connected to the harness and are operating properly. The issue with cameras shutting off at reset is still in the process of being resolved; an adequate solution would be to connect the LED output from one of the cameras to an input pin on the board, checking the voltage on the pin would allow the code to determine whether or not the camera is on or not. For the time being, the issue is being avoided by temporarily eliminating one of the reset flags.

A voltage divider circuit was used with the RTD to allow an analog input on the board to measure the voltage across the RTD. The RTD circuit for Maraia is fully operational and requires no additional work. Although there is error in the temperature measurement, the measurement is non-critical and the magnitude of the error is acceptable.

The pressure transducers used on Maraia were tested and found to be working. There was an issue with the high side pressure transducer, but it was resolved by using different pull-up resistors than those mentioned on the datasheet. After making the appropriate connections to the board, both sensors are running smoothly.

A Wheatstone Bridge and instrument amplifier circuit where used with the RTDs on E-MIST to help minimize error in the ADC. The circuit is not yet implemented into the board but it was tested externally and found to operate as expected; the Wheatstone bridge and instrument amplifier are producing the correct outputs. It is still necessary to test the integrated circuit to determine whether or not the measurement error has been reduced.

The control algorithm for the motors and the code to run the encoders were developed and tested on the motors. These are ready for implementation on E-MIST.

As a result of this work, the cameras, RTD, and pressure transducers have been successfully integrated to Maraia, the improved RTD circuits were designed and tested for E-MIST, and the “skewer” system with motor control is ready for implementation. The ongoing work will focus on integrating the remaining hardware onto Maraia and E-MIST.

Acknowledgments

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