University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

Systematic Testbed Apparatus for Thermal Infrared Sensors (STATIS)

Approvals

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1.0 Problem or Need

Many space systems contain sensors and data acquisition devices crucial to mission success. These sensors need to be able to withstand four main types of stresses presented by the space environment. The trauma of launch, the vacuum of space, extreme temperature ranges, and electromagnetic interference from background radiation and the spacecraft itself.

Currently, contact based temperature sensors such as thermocouples take measurements on various surfaces of a spacecraft. The problem presented by contact based sensors is that they require complex wiring systems and flexible circuits that span over moving parts and joints on a space craft. The use of these complex wiring systems requires expensive and time consuming reliability testing, as they present opportunities for single-point failures that can compromise an entire mission. Contact sensors also do not allow for temperature measurements on surfaces where direct contact mares and reduces the overall effectiveness of the surface. Further explanation and examples are presented in Section 2 of this document. Based upon the risk factors presented by contact sensors, it can be deduced that the use of non-contact infrared temperature sensors would be highly beneficial.

The intent of STATIS is to design, build and validate the functionality of a test bed that will characterize a range of commercial off the shelf (COTS) non-contact infrared temperature sensors, by testing their accuracy and precision over variable distance and on different target surfaces when compared to contact based temperature sensors, in a simulated space environment.

The test bed will be integrated into a Thermal Vacuum Chamber[1], which will represent the vacuum and temperature environment of space. The temperature of 5 different target surfaces will be controllable in the range of 250-350 K, and 4 different COTS non-contact infrared temperature sensors will record measurements over this range. The test bed shall provide the capability to increase the temperature of the target surfaces by 20K/hr and decrease it by 5K/hr through the designed user interface. The test bed shall also provide the capability to vary the distance (0-TBD cm) between the sensors and target surfaces through the designed user interface.

The 5 different target surfaces that will be tested are, Chromated Aluminum, Anodized Aluminum, Glass, Graphite Composite (TBD), and Emissive Paint. These target surfaces are being tested because they represent common surfaces on spacecraft, which have different emissivity values. The 4 sensors will be bought with funds directly from STATIS' own budget. The prices of COTS non-contact infrared temperature sensors range from 20 to 10,000 dollars (Optris Gmbh, 2014), due to STATIS' budget restrictions only 4 will be utilized. The infrared measurements will be compared to data from a contact based temperature sensor.

2.0 Previous Work

Infrared (IR) radiometry allows for the measurement of an object's temperature, above absolute zero, from the electromagnetic radiation emitted (emissivity) from its surface. The emissivity depends on the material, its surface properties and geometry, temperature, wavelength, and the measuring arrangement.

IR temperature sensors are the preferred temperature measuring device when the temperature of moving objects is required; it is difficult to design a wiring configuration – a by-product from conventional contact temperature sensors such as thermocouples – compatible with a system involved with a dynamic event: assembly lines, rotating joints, etc. Infrared temperature sensors are being employed in robotic welding where by its very nature the melting point exceeds the temperature of all metals (Luma Sense Technologies, 2014). Additionally IR sensors have found their way into mechanized food production where items pass by the sensors moving at several miles per hour, leaving only a fraction of a second for the sensor to check temperature (Thermo Works, 2014).

For aerospace applications, conventional contact temperature sensors, such as thermocouples, increase production times because the wiring attaching the sensors must be properly designed to prevent fraying and meet military/NASA specifications (Crimping, 2011).

The Visible Infrared Imaging Radiometer Suite (VIIRS) could have benefited from a non-contact IR temperature sensor (Visible, 2014). VIIRS has a rotating telescope assembly and a half angle mirror mechanism whose temperature is desired in order to validate optics outputs and other data. Because of the

[1] Thermal Vacuum Chamber: Provides a vacuum environment of 1e-5 Torr while maintaining a temperature that allows the sensors to be tested within the suppliers recommended operating range. The size specifications of this Thermal Vacuum Chamber are still to be determined until a specific chamber is chosen.

dynamic circumstances involved with the rotating telescope and half angle mirror mechanism, an IR temperature sensor could have reduced the risk of the mission by validating temperature tests in vacuum chambers, on-orbit temperature monitoring, or validate component capability (temperature tolerance verification, mechanical optimization, etc.). Reducing risk would have reduced the cost of the project, or would have allowed for the allocation of resources to be placed elsewhere.

3.0 Specific Objectives

Levels of success were created in order to break down different aspects of the test bed, these are shown below in Table 1. While STATIS will be designing the components to achieve Level 3 success, should unforeseen issues arise, the project has the ability to be scaled back to still achieve Level 2 or Level 1 success. The project is being designed to go into a TBD thermal vacuum chamber at Ball, therefore, Level 3 revolves around the fact that everything must comply with the provided Integration Control Document (ICD). Should STATIS not be able to acquire time in the thermal vacuum chamber, success can still be achieved for all criteria by demonstrating the functionality in ambient conditions.

Table 1: Levels of Success

Criteria	Environ-ment	Data Acquisition	Temp Control IR Sensors	Temp Control Target	Distance Control	Target Selection	IR Sensors
Level 1	Ambient	Acquire data from temp sensors (Contact sensors at both IR and target plus data from IR sensors themselves)	Uncontrolled	Command temp to range of ambient - 350K	Manually be able to change and measure distance from IR sensor to target in between each test series	Manually change the five targets in between test series	One IR sensor per test series with the capability of collecting temp data from given target
Level 2	-	Acquire data from temp, distance, and target selection sensors	Command and control sensor temp to set values between 275-325K to within ±1 K	Command and control target temp to set values between 250-350K to within ±1 K	-	-	-
Level 3	TVAC	Electronic ICD compliance of all sensors	Command and control sensor temp to set values between 275-325K to within ±1 K with a stability of ±1K	Command and control target temp to set values between 250-350K to within ±1 K with a stability of ±0.1K	Using software, mechanically change and digitally measure the distance from IR sensor to target from 7-76mm as part of the test series.	Using software control, mechanically switch between five targets during the test series	Four IR sensors per test series with the capability of collecting temp data from given target

4.0 Functional Requirements

4.1 Functional Block Diagram

Once the test bed is installed inside and the thermal chamber has been pumped down to a pressure less than 1.0e^{-5} torr, the tester will initiate a set of commands from the control software of the test station computer. The commands will consist of a target temperature and sensor temperature commands (in the range of 250-350 K and 275-325 K respectively), a target selection (5 target materials), and a separation distance command in the range of 0-TBD cm. This information will travel by wire to the digital-to-analog converter (DAC) through the test chamber cable port. The DAC system will take the temperature, target, and distance commands and supply the corresponding voltage inputs to the heaters (target and sensor), target selection system, and distance control system, respectively. The target and sensor housings will connect to the TVAC chiller plate (TBD °K) to dump heat and maintain a constant temperature. Once the selected target material is at the commanded temperature and distance, measurements will be taken from the IR sensor at a frequency of TBD Hz and sent to the analog-to-digital converter (ADC). Contact temperature sensors on the IR sensor and on the target material will also send reference temperature data to the ADC at a rate of TBD Hz. The distance control system will provide distance measurements at the same TBD Hz rate. The local ADC will continuously convert and communicate the acquired data back to the test computer, where the data will be processed and stored. This data will be analyzed by the control software to provide closed-loop feedback control of the target and sensor thermal control systems, distance control system, and target selection system. Once 300 seconds of data are collected from the sensor at a set temperature, distance, and target, (sufficient time to monitor sensor drift) the tester will modify any one of these parameters via an input command to the control software, and data collection will repeat. A depiction of this process is shown in Figure 1.

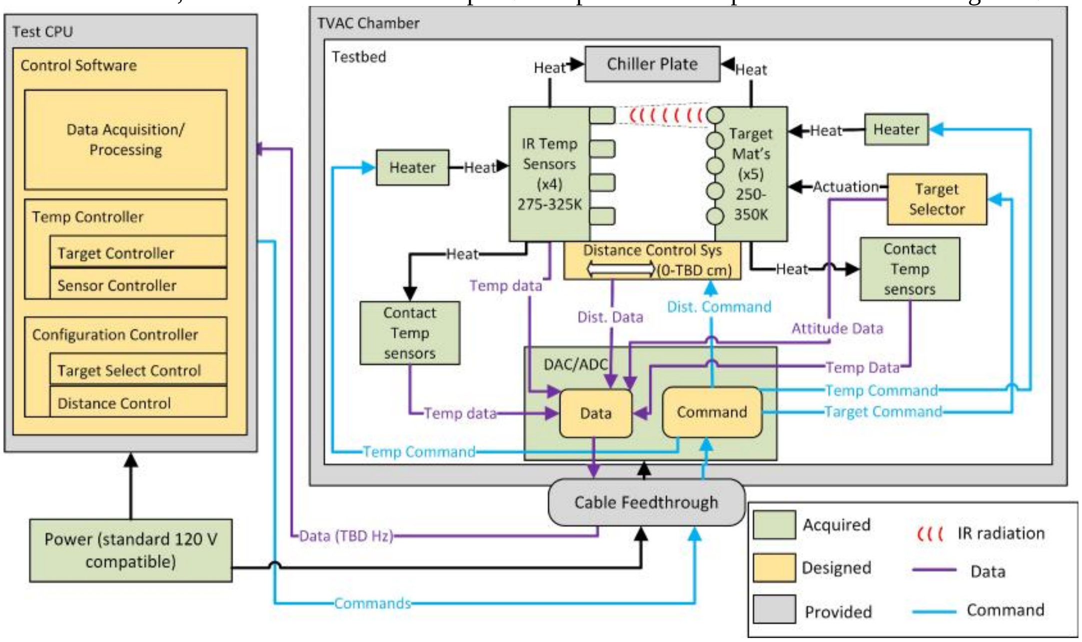

Figure 1: Functional Block Diagram

4.2 Concept of Operations

The concept of operations depicted in Figure 2 shows the testing procedure involved in operating STATIS and the future goals of the product upon completion. The test bed will be loaded with 4 sensors (exact models TBD) and 5 target surfaces aforementioned in Section 1 and integrated into the thermal vacuum chamber. Integration requires wiring into the thermal vacuum, exact requirements TBD based on specifications of the TVAC to be used at Ball's facilities. The chamber will be de-pressurized, and the user will initiate temperature data collection. Each sensor will be tested simultaneously. The materials will be cycled such that each sensor will record data from each material. Distance between the sensors and materials will be altered and temperatures of the materials will be modified from 250 K to 350 K based on the rates provided in Section 1. A contact based sensor will supply a 'temperature truth reference' of the materials which will provide a benchmark from which comparisons can be made to the experimental data recorded. The data will be compared based on a common clock to ensure data corresponds directly to the truth reference. Upon completion of the STATIS project, a test report summarizing the results and possible sensor recommendations will be delivered to the customer. Additional tests will be performed by the customer to further research sensor capabilities for space use.

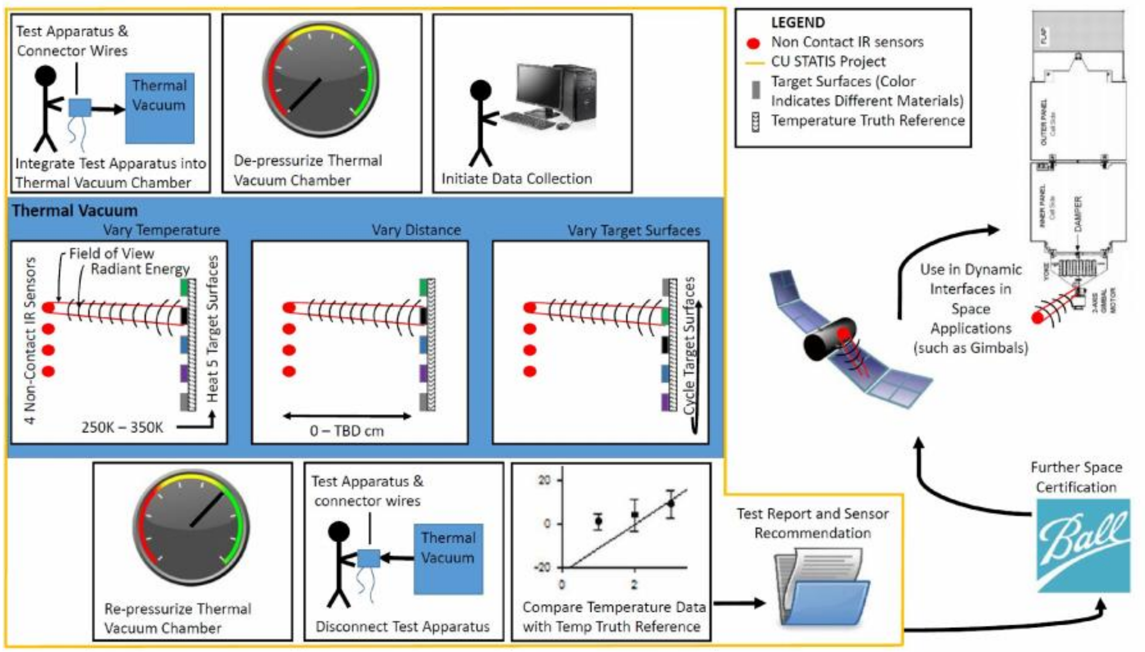

Figure 2: Concept of Operations

5.0 Critical Project Elements

CPE.1 Data Collection: The test bed must be able to collect and store useful data while testing the IR temperature sensors. If the test bed is unable to store data about the IR sensors' performance then the test bed provides little functionality to the customer.

CPE.2 Sensor Selection: An important part of the project is selecting off-the-shelf IR temperature sensors that meet initial requirements to be tested in the TVAC environment. The sensors must meet the resolution and accuracy requirements set by the customer. This also means they will have to withstand the manufacturer operating temperature limits and TVAC outgassing requirements.

CPE.3 Test Bed Functionality: The test bed must be able to give accurate performance metrics of the IR sensors including accurate and precise temperatures of the target materials and IR sensors and also accurate measurements of the distance between the targets and the IR sensors. These metrics need to be accurate so that the customer can effectively assess the performance of the IR sensors under test.

CPE.4 Thermal Model: Since the target materials temperature must change within a specific timeframe, a thermal model must be developed to determine what hardware is necessary to meet the requirements for heat exchange.

CPE.5 Electrical Model: The electrical system must be able to handle the data needs of the test bed in terms of sample rates and feedback control. An electrical model must be created to determine what hardware can handle the requirements of the system.

CPE.6 Thermal Control: The test bed targets must be heated at certain rates which may require difficult to design hardware to meet these requirements.

6.0 Team Skills and Interests

Critical Project Elements	Team Members and Associated Skills/Interests
Thermal Control	**Ashley:** experience in theoretical thermal control and interested in the thermal aspect. **Sarah:** Interested in the design and implementation of feedback/control loops in aerospace applications. **Dylan:** Experience in control system design and thermal system modeling.

Thermal Models	**Maria:** theoretical experience with thermal models. **Dan:** Experience with CAD software, interested in developing 3D model of test bed components for thermal modeling. **Dylan:** Experience in analytical modeling of dynamic systems.
Electrical Models	**Smith**: Interested in financials as well as electronics. **Dylan:** Interested in electronic design and hardware control systems. **Evan:** two years of designing cubesat avionics, internship with Ball Aerospace working on EMI susceptibility analysis **Sarah:** Passion for electronic component design previous experience with micro-avionic component design. Eager to learn more about electronics and data budgeting.
Sensor Selection	**Maria:** Interest in trade studies and research into IR sensor capabilities **Smith:** Interested in financials and sensor implementation. **Alexander:** Interest in finding/using/modifying commercial off the shelf IR sensors for use in space applications
Data Collection	**Cameron:** minoring in computer science and have an interest in developing embedded systems **Dylan:** Interested and experienced in software development and data analysis. **Evan:** two years of designing cubesat avionics including data budgeting, internship with Ball Aerospace working on EGSE software
Test Bed Functionality	**Ashley:** one year full time job experience creating, testing and operating test beds for rockets and multi-mission software. **Dylan:** Interest in system integration. Experience in multi-system sequencing. **Dan:** Interested in systems integration and testing. **Cameron:** have experience in fabrication and like to get my hands dirty **Alexander:** Interest in mechanical component design, studying structures for BS/MS.

7.0 Resources

Critical Project Elements	**Resources Needed**	**Sources Available**
Thermal Control	Control system for maintaining and controlling the temperatures of the sensors, TVAC, and the target surfaces.	Dale Lawrence, Shane Brown, XinLin Li.
Thermal Models	Access to Thermal Modeling software. Understanding of heat transfer between components in a vacuum.	Guidance from customers (Hansford Cutlip, Shane Brown), CU faculty (Xinlin Li, Jelliffe Jackson).
Electrical Models	Access to circuit analysis software. Understanding of proper DAQ protocol.	ITLL Lab Stations and Software. Interface Control Document of TVAC provided by Shane Brown (TBD). Trudy Schwartz.
Sensor Selection	Understanding of current infrared sensor technologies available on the market today.	Guidance from customers (Hansford Cutlip, Shane Brown, Joe Lopez) Sensor data sheets and list of materials from manufactures.
Data Collection	Understanding of the data budget for each component, DAQ software.	ITLL Lab Stations and Software. Interface Control Document of TVAC provided by Shane Brown (TBD). Trudy Schwartz.
Test Bed Functionality	Control system for maintaining and controlling the distance between sensors and target materials. Subsystem integration between project components. Control system for target selection.	Dale Lawrence, Shane Brown, Matt Rhode, Joe Lopez.

8.0 References

Crimping, interconnecting cables, harnesses, and wiring. (2011, March 29). Retrieved September 14, 2014, from http://www.hq.nasa.gov/office/codeq/doctree/87394.pdf

Luma Sense Technologies. (2014, 09 10). Retrieved from Luma Sense Technologies: http://www.lumasenseinc.com/EN/solutions/industrial/metal-processing/induction-tube-welding.html

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Thermo Works. (2014, 09 10). Retrieved from Thermo Works: http://www.thermoworks.com/products/ir/

Visible Infrared Imaging Radiometer Suite (VIIRS). (2014, September 14). Retrieved September 15, 2014, from http://npp.gsfc.nasa.gov/viirs.html