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14. ABSTRACT

A GVR-BOT robot was tested to measure thermal effects of the design at different ambient temperatures. Thermocouples were placed on four subcomponents within the Main Electrical Housing: Radio, Main Processor, Left Motor Driver, and Right Motor Driver.
The system was tested at -20 C and +50 C ambient temperature while powered on and the results compared with a simulation of this environment. This testing confirmed that the system subcomponents did not exceed their designed temperature range.
Highly Accelerated Life Testing (HALT) was also performed for 15.8 hours total with no failures.

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GVR-BOT Thermal Testing

GVR-BOT Technical Report

Tyruss Valascho, Robert Sosin
2-1-2014

Executive Summary: A GVR-BOT robot was tested to measure thermal effects of the design at different ambient temperatures. Thermocouples were placed on four subcomponents within the Main Electrical Housing: Radio, Main Processor, Left Motor Driver, and Right Motor Driver.
The system was tested at -20 C and +50 C ambient temperature while powered on and the results compared with a simulation of this test. This testing confirmed that the system subcomponents did not exceed their designed temperature range.

Highly Accelerated Life Testing (HALT) was also performed for 15.8 hours total with no failures.

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Introduction

A GVR-BOT robot was tested to measure thermal effects of the design at different temperatures. Within the design, 4 subcomponents were identified as sources of heat:

- Radio
- Main Processor
- Left Motor Driver
- Right Motor Driver

The baseline thermal behavior of these parts was measured at different temperatures using thermocouples affixed to the subcomponents.

The GVR-BOT was designed to operate between -20 C and 50 C and these two points provided the upper and lower limits for the testing. Thermal modeling was performed first to estimate the expected behavior at the hot environment, then a completed prototype vehicle was measured.

In addition, an abbreviated HALT (Highly Accelerated Life Test) was also performed.

Baseline Temperature Measurement

Purpose

The Baseline temperature measurement testing is designed to verify modeled results and provide "real world" measurements of how hot the highest heat-producing components get at different ambient temperatures.

Baseline Test Procedure

For this test, the UUT (Unit Under Test) will be powered up and running during the test. Actuation is not necessary, just normal operation without user input.

All tested components are inside the main electrical enclosure of the robot, and the robot is operated at "idle" while maintaining communications with the OCU (Operator Control Unit). Thermocouples are attached to the subcomponents being measured inside the UUT and attached to a datalogger. The UUT is placed inside the thermal chamber and an additional "ambient" thermocouple is placed in open air near the center of the chamber.

The chamber is brought to the desired test temperature with the UUT inside – unpowered - and soaked for at least 1 hour before the test is started. Once the soak time has elapsed, the UUT is powered on and the test begins. During the test, the datalogger is monitored to see what temperature the measured subcomponents stabilize at. Stabilization occurs when all measured subcomponent temperatures remain within a constant temperature +/- 1 C for at least 30 minutes. Once stabilization occurs, the test can stop.

Baseline Test Results

Simulation Results

SPAWAR Systems Center Pacific ran a thermal simulation of the GVR-BOT design using the Solidworks 2013 thermal modeling package in July, 2013. To perform the simulation, the heat generation values in Table 1 were used.

Table 1 - Heat Generation Values for Simulation

Component	Manufacturer	Part	Heat Generation (W)
Motors	iRobot	N/A	12.50
Motor Drivers	Advanced Motion Controls	AZXB25A8	20.00
Main Processor	MSC	MSC Q7-TCTC-FD-104	4.50
GigE Switch	Diamond Systems	EPS-8000	0.81
Radio Router Board	Gateworks	GW2350	1.00
Radio	Ubiquiti	XR5	1.45
IMU (AHRS)	Microstrain	3DM-GX3-35	0.19

The simulation was performed using an ambient temperature of 48.9 C. The results of that simulation are provided in Table 2.

Table 2 - Thermal Simulation of GVR-BOT

Component	Max Temperature (C)
Radio	89.30
Main Processor	79.11
Left Motor Driver	93.12
Right Motor Driver	93.12

Testing Results

The UUT for temperature chamber testing was a Proto2 GVR-BOT[1] design. The vehicle was instrumented with J-type thermocouples as seen in Figure 1. The ambient temperature measurements were made using a K-type thermocouple.

[1] The design was called "Standardized PackBot" at the time of the testing, not GVR-BOT. The major design difference between a GVR-BOT and the Proto2 design was the use of the Ubiquiti XR5 radio instead of the GVR-BOT's XR2 radio.

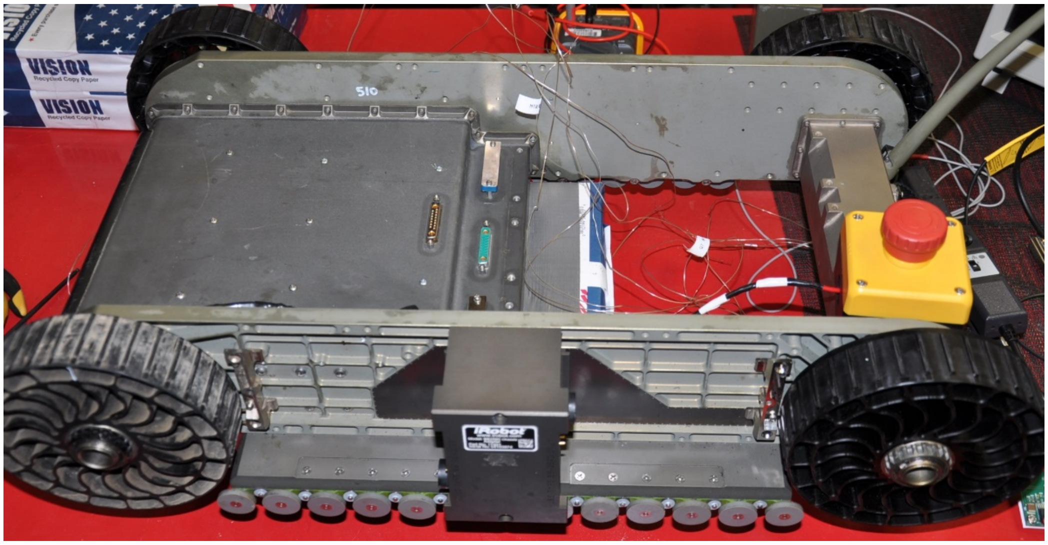

Figure 1 - Instrumented GVR-BOT for Thermal Testing

An image of the complete test setup is provided in Figure 2.

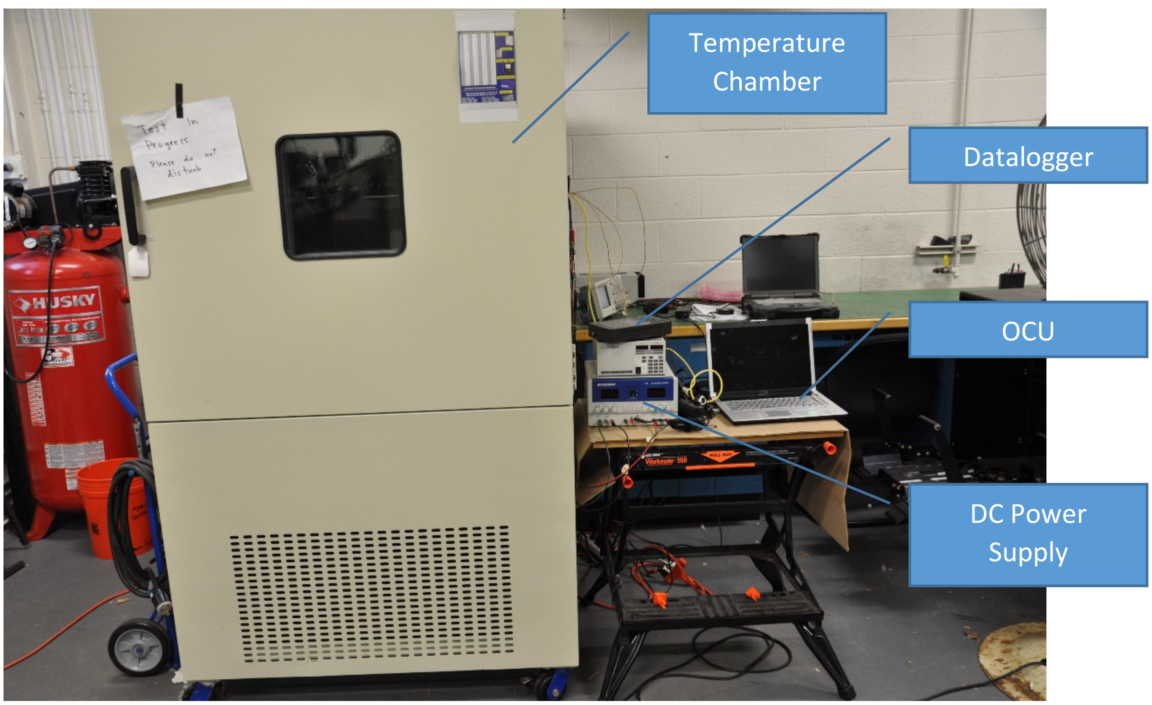

Figure 2 - Baseline Temperature Testing Setup

The testing was performed at chamber temperatures of -20 C and +50 C with data being logged at a rate of 1 Hz. The robot was powered by a DC power supply, not the robot's batteries.

Plots of the test results at -20 C and +50 C are provided in Figure 3 and Figure 4, respectively.

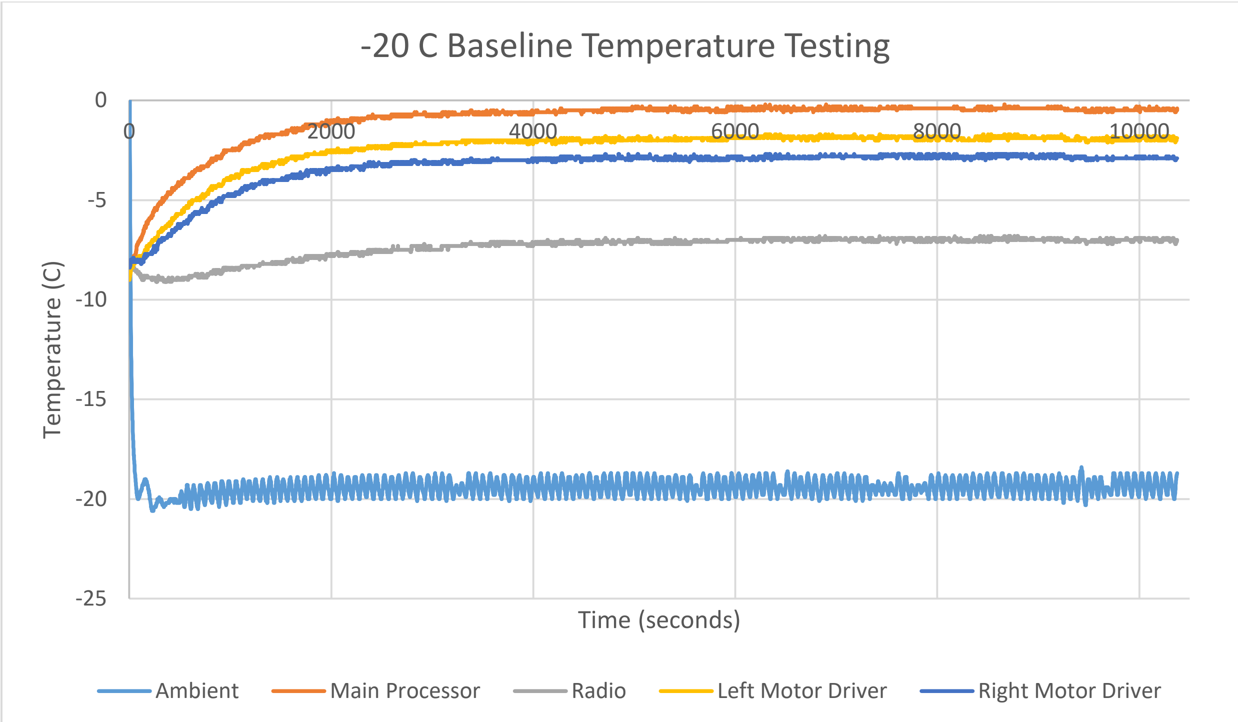

Figure 3 - Baseline Temperature Test Results, -20 C

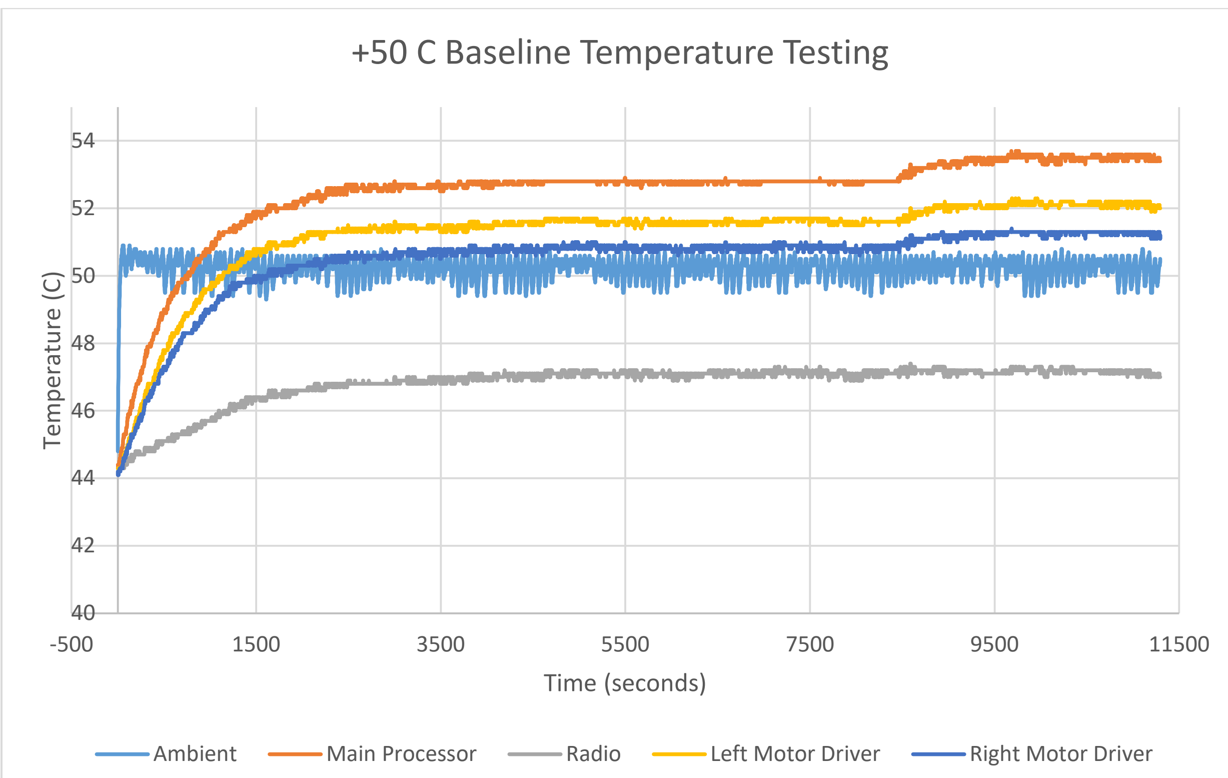

Figure 4 - Baseline Temperature Testing Results, +50 C

An unexplained increase in the temperature of 3 components occurred at 8500 seconds into the test. Their measured temperatures increased by about a degree and re-stabilized.

Summaries of the test results at -20 C and +50 C are provided in Table 3 and Table 4, respectively, with Table 4 including a comparison with the simulation results as well.

Table 3 - Summary of Results at -20 C Ambient

Component	Max Temperature Actual (C)
Radio	-7.03
Main Processor	-0.45
Left Motor Driver	-1.91
Right Motor Driver	-2.85

Table 4 - Summary of Results at +50 C Ambient

Component	Max Temperature Simulated (C)	Max Temperature Actual (C)
Radio	89.30	47.18
Main Processor	79.11	53.50
Left Motor Driver	93.12	52.13
Right Motor Driver	93.12	51.28

HALT Test

Purpose

Artificially age the hardware to simulate years of usage in days. HALT testing is usually performed until a failure occurs, if time permits.

HALT Procedure

For this test, the UUT will be powered up and running. Actuation is not necessary, just normal operation without user input. Because the test will be run continuous for multiple days, a wall supply can be used to provide power to the UUT instead of the batteries. Some method of knowing when failures occur and capturing relevant data is necessary, whether external to the UUT or self-diagnosis / reporting.

The following is a 6 hour cycle which may be repeated as many times as necessary, with 4 cycles occurring in a 24 hour period.

1. Place powered and running UUT in temperature chamber and soak at lowest point of specified temperature range for 2 hours.
2. Ramp from lowest temperature to highest temperature over 1 hour.
3. Soak at highest point of specified temperature range for 2 hours.
4. Ramp from highest temperature to lowest temperature over 1 hour.
5. End of cycle.

HALT Results

The HALT was performed in December 2013 and consisted of three cycles of hot to cold, with 1 hour time periods at each temperature extreme. Using 1 hour dwell times did not result in temperature stabilization, so an abbreviated test was run in February 2014 of only one hot to cold cycle.

The results of both test events are provided. The testing results from December 2013 are shown in Figure 5.

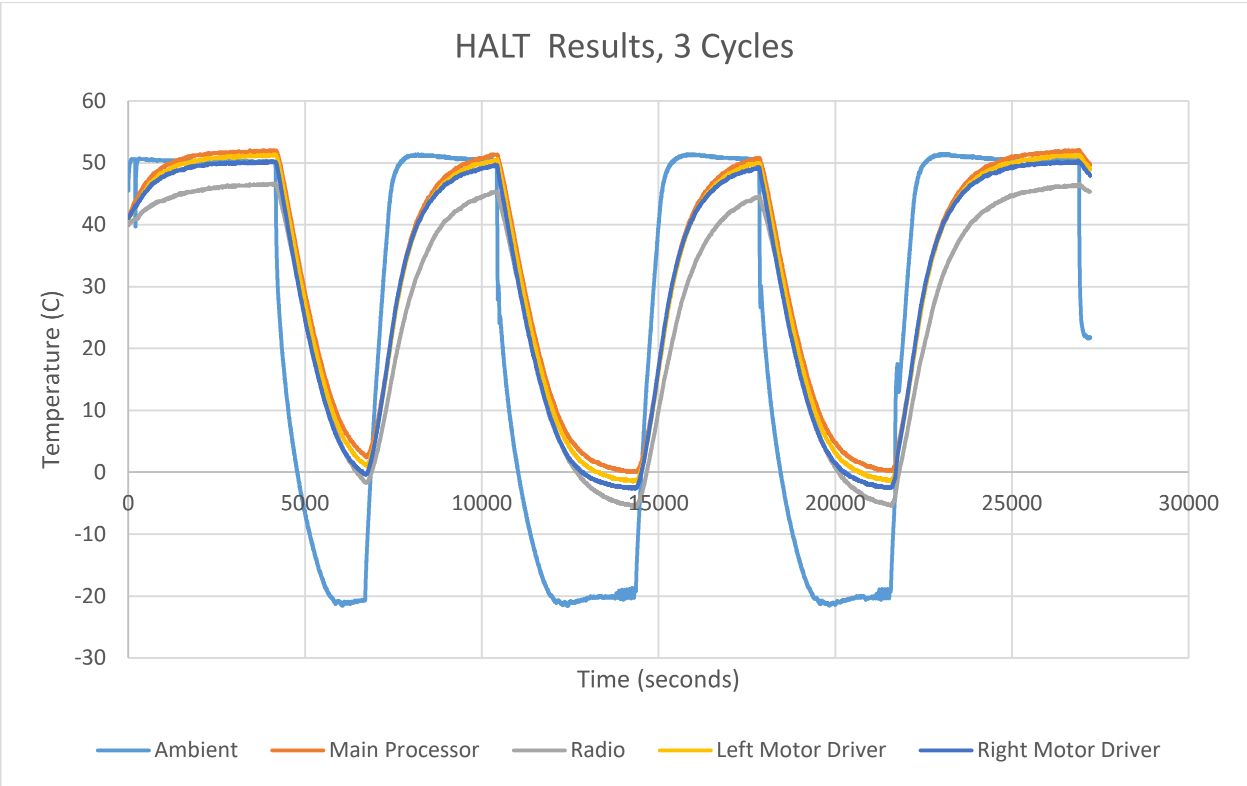

Figure 5 - 3 HALT Cycles

Figure 6 contains the results from the February 2014 testing.

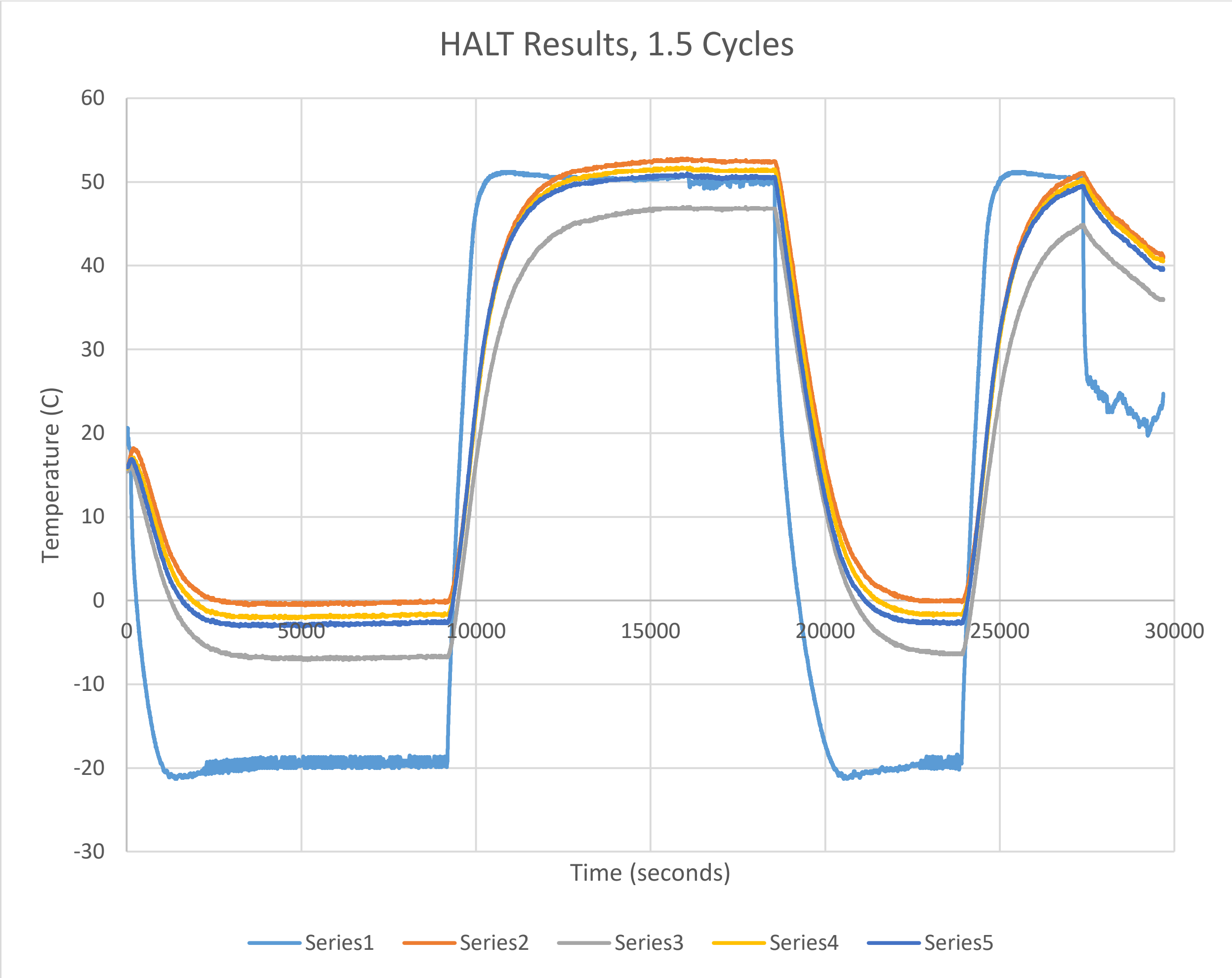

Figure 6 – 1.5 HALT Cycles

During both tests there were no failures.

Conclusions

All components within the GVR-BOT Main Electrical Housing are rated for a temperature range of -40 C to 85 C.

During temperature testing, the subcomponents of the GVR-BOT did not exceed their rated temperature ranges. The simulation predicted that the radio and both motor drivers would exceed 85 C, but the testing results showed no subcomponents rose above 53.5 C. It is felt that the simulation was not given complete initial conditions. In particular it was not known if the electrical housing was correctly modeled. It is made of aluminum and should allow steady heat flow out of the electrical housing in all directions.

The UUT performed satisfactorily during HALT, with no failures after 15.8 hours of severe temperature cycling.

Recommendations

The soak time for the testing should have been longer to ensure all subcomponents are at the desired temperature point before testing. In both Figure 3 and Figure 4 it can be seen that the subcomponents being tested did not have adequate time to reach the chamber temperature. Since the testing was mostly interesting in a baseline steady state temperature value, this likely did not impact the results.

The simulation should be improved and validated so more simulation can be performed in the future.

Appendices

Abbreviations and Acronyms

HALT: Highly Accelerated Life Test

OCU: Operator Control Unit

UUT: Unit Under Test