Critical Software

SOFTWARE REQUIREMENTS SPECIFICATION

SPACECRAFT THERMAL CONTROL SYSTEM

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1. INTRODUCTION

1.1. OBJECTIVE

The objective of this document is to provide a comprehensive and detailed specification of the software requirements for the Spacecraft Thermal Control System (STCS). This includes defining the functionality, performance, and constraints of the system to ensure that the final product meets the necessary criteria and provides a robust framework for implementation and testing.

1.2. SCOPE

The scope includes the development of the Temperature Simulation Library, Thermal Control Function and the Visualization User Interface. This document is intended to serve as a guide for the teams working on different modules and ensure coherence and integration between the modules.

1.3. AUDIENCE

The intended audience of this document is the team responsible for the implementation of the Spacecraft Thermal Control System modules.

1.4. DOCUMENT STRUCTURE

This document is structured to provide a comprehensive overview of the Spacecraft Thermal Control System project, detailing its objectives, scope, and requirements in a logical and organized manner:

- Section 1 (Introduction): Provides an overview of the document's objective, scope, intended audience, structure, and related documents.
- Section 2 (Project’s Domain): Describes the product's perspective, functions, and operating environment.
- Section 3 (Architecture): Outlines the architectural framework and design of the system.
- Section 4 (Requirements): Details the general structure of requirements, functional requirements, and performance requirements.

1.5. APPLICABLE DOCUMENTS

There are no applicable documents for this document.

1.6. REFERENCE DOCUMENTS

There are no reference documents for this document.

2. PROJECT’S DOMAIN

2.1. PRODUCT PRESPECTIVE

The Spacecraft Thermal Control System will simulate environmental conditions and maintain optimal temperature ranges using various control mechanisms. It will as well provide a user-friendly interface for real-time monitoring and visualization of the spacecraft thermal data.

2.2. PRODUCT FUNCTIONS

The Spacecraft Thermal Control System consists of several key functions or modules to manage the spacecraft's thermal environment effectively.

The Temperature Simulation Library (TSL) initializes the simulation environment, generates temperature data based on environmental conditions, provides an API for temperature data access and heater lines management. The simulated data is meant to be stored on a file for later processing, analysis or visualization.

The Thermal Control Function (TCF) implements algorithms to maintain optimal temperature ranges using heaters and radiators, controls the activation of thermal mechanisms, handles edge cases, and optimizes performance.

Finally, the Visualization User Interface (VUI) team designs and implements a user-friendly interface for real-time monitoring and creates comprehensive system documentation and user manuals.

2.3. OPERATING ENVIRONMENT

The only constraint regarding the operating environment is that all modules of the STCS must be able to be ran on an Ubuntu WSL environment.

The TSL and TCF modules must be developed using the C programming language and its standard libraries.

The implementation of the VUI is left to the discretion of the team involved in this module.

3. SYSTEM ARCHITECTURE

The overall system is composed by three modules: the Thermal Simulation Library (TSL), the Thermal Control Function (TCF) and the Visualization User Interface (VUI). These components interact with each other to form the Spacecraft Thermal Control System (STCS).

The TSL is responsible for generating simulation data (i.e., thermistor temperature values) and maintain these values both in program memory and in a file. This module also provides an interface for the TCF to obtain the temperature values of each of the thermistors. The thermistors values are controlled by individual heaters which can be powered on or off to increase or decrease a thermistor temperature. This interaction is possible via an interface.

The TCL is the module responsible for acquiring the temperature of each thermistor via the TSL-provided interface, decide, using the PID (proportional–integral–derivative) controller mechanism, whether to enable or disable a heater line and use the provided interface to do so. The heater lines can either be enabled or disabled which change the temperature values incrementally of a given thermistor. This process repeats itself again resulting in a stabilization of all thermistor temperatures.

The VUI is the tool which allows for the data visualization on an application with graphical user interface. This application reads the contents from the file constantly being written by the TSL and generates/updates the interface with the obtained information (e.g., plots, tables).

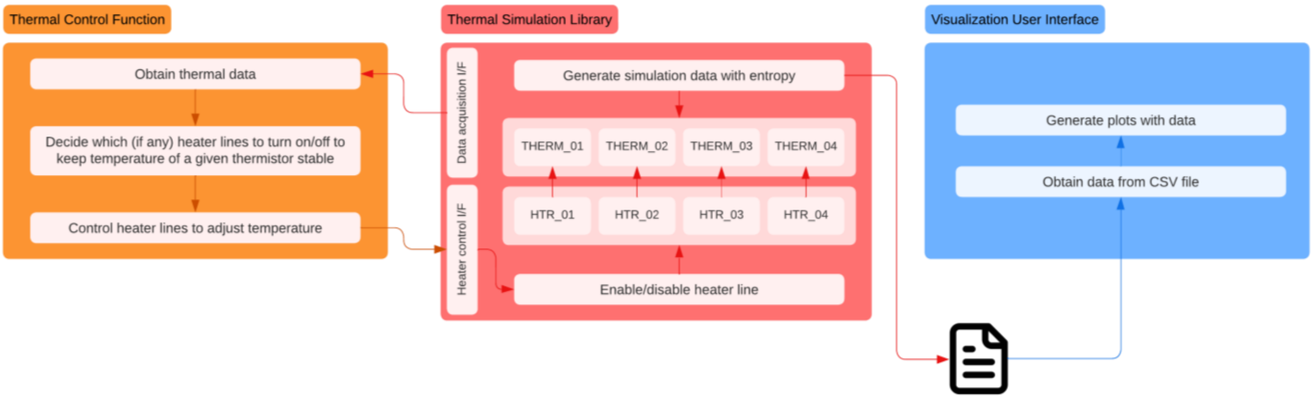
Thermal Control Function
Obtain thermal data
Decide which (if any) heater lines to turn on/off to keep temperature of a given thermistor stable
Control heater lines to adjust temperature
Thermal Simulation Library
Data acquisition I/F
Heater control I/F
Generate simulation data with entropy
THERM_01
THERM_02
THERM_03
THERM_04
HTR_01
HTR_02
HTR_03
HTR_04
Enable/disable heater line
Visualization User Interface
Generate plots with data
Obtain data from CSV file

Figure 1 - Spacecraft Thermal Control System high-level architecture

4. REQUIREMENTS

4.1. GENERAL

Each requirement includes a Requirement identifier, Requirement title and Requirement text.

Requirements are assigned with a unique identifier in accordance with the following policy:

[<product>-<document mnemonic>-<component>-<section>-<number>]

where:

REQUIREMENT ID ELEMENT	VALUE	REMARKS
<product>	STCS	Spacecraft Thermal Control System
<document mnemonic>	SRS	Software Requirement Specification
<component>	TSL TCF VUI	Temperature Simulation Library Thermal Control Function Visualization User Interface
<section>	FUNC	Functional Requirements
<number>	0000...9999	Sequential number in NNNN format

Table 1 - Requirement Identifier rationale

Verification Methods:

- **Inspection:** verification performed on a piece of code, to ensure that the code is correct and implements the required functionality.
- **Test:** execution of the verified software and the analysis of the execution results, to conclude whether the software behaves the expected way or not.

4.2. FUNCTIONAL REQUIREMENTS

This section presents the functional software requirements with a logical grouping per subsystem.

4.2.1. Thermal Simulator Library

The Thermal Simulation Library (TSL) is a software component designed to simulate the thermal environment of a spacecraft. This library generates temperature values for multiple thermistors, providing users with an accurate and dynamic representation of temperature fluctuations under various conditions. The TSL initializes the values of the multiple components and logs the data to a CSV file. Additionally, it provides interfaces for controlling heater lines associated with each thermistor, enabling users to actively manage and adjust the thermal conditions within the simulation. Eclipse periods are bound to happen which quickly reduce the temperature the thermistors. The inverse happens with extended exposure of the spacecraft to the sun which raises the temperatures of the thermistors.

STCS-SRS-TSL-FUNC-0010

Initialize Simulation Environment

The TSL shall initialize the simulation environment with the following parameters:

- Temperatures of each thermistor (in degrees Celsius):
  - THERM-01, THERM-02, THERM-03, THERM-04: <random value between -5 and 7>
- Status of each heater:
  - HTR-01: OFF
  - HTR-02: OFF
  - HTR-03: OFF
  - HTR-04: OFF
- Current period: NORMAL

STCS-SRS-TSL-FUNC-0020

Thermistor-Heater Relationships

The following relationships between thermistors and heaters shall be ensured:

- THERM-01 – HTR-01
- THERM-02 – HTR-02
- THERM-03 – HTR-03
- THERM-04 – HTR-04

Note: These relationships guarantees that when enabling/disabling a heater only one thermistor temperature is going to be affected.

STCS-SRS-TSL-FUNC-0030

System Monotonic Clock

The TSL shall maintain a monotonic clock on a 16-bit variable, incremented by 1 unit every simulation cycle.

STCS-SRS-TSL-FUNC-0040

Simulation Cycle Interval

The TSL simulation cycle interval shall be 5Hz.

STCS-SRS-TSL-FUNC-0050

Thermistor Values Update

STCS-SRS-TSL-FUNC-0050

The TSL shall update the temperature values for the 4 available thermistors every simulation cycle, based on environmental conditions such as solar exposure and eclipse periods.

Note: The thermistor IDs are as follows: THERM-01, THERM-02, THERM-03, THERM-04.

STCS-SRS-TSL-FUNC-0060

Normal Periods

Whenever the system's monotonic clock lower 8 bits are 0x00 to 0x1F or 0x60 to 0xFF, the TSL shall set the current period to NORMAL.

STCS-SRS-TSL-FUNC-0070

Normal Period Temperatures

Whenever the current period is set to NORMAL, the TSL shall update the thermistor values based on the associated heater power state:

- Heater ON: increase temperature of thermistor by 1 unit
- Heater OFF: decrease temperature of thermistor by 1 unit

STCS-SRS-TSL-FUNC-0080

Eclipse Periods

Whenever the system's monotonic clock lower 8 bits are 0x20 to 0x3F, the TSL shall set the current period to ECLIPSE.

STCS-SRS-TSL-FUNC-0090

Eclipse Period Temperatures

Whenever the current period is set to ECLIPSE, the TSL shall update the thermistor values based on the associated heater power state:

- Heater ON: increase temperature of thermistor by 4 units
- Heater OFF: decrease temperature of thermistor by 7 units

STCS-SRS-TSL-FUNC-0100

Sun Exposure Periods

Whenever the system's monotonic clock lower 8 bits are 0x40 to 0x5F, the TSL shall set the current period to SUN_EXPOSURE.

STCS-SRS-TSL-FUNC-0110

Sun Exposure Period Temperatures

Whenever the current period is set to SUN_EXPOSURE, the TSL shall update the thermistor values based on the associated heater power state:

- Heater ON: increase temperature of thermistor by 7 units
- Heater OFF: decrease temperature of thermistor by 1 unit

STCS-SRS-TSL-FUNC-0120

Provide Temperature Data API

The TSL shall provide an API to retrieve the current temperature of each thermistor.

STCS-SRS-TSL-FUNC-0130

Provide Heater Status Data API

The TSL shall provide an API to retrieve the current power status of each heater.

STCS-SRS-TSL-FUNC-0140

Enable Heater API

The TSL shall provide an API to set the status of a given heater to ON.

STCS-SRS-TSL-FUNC-0150

Disable Heater API

The TSL shall provide an API to set the status of a given heater to OFF.

STCS-SRS-TSL-FUNC-0160

Log Simulation Data

The TSL must maintain a detailed log of all temperature data generated during the simulation, including timestamps (monotonic clock), environmental conditions changes, heater status changes, thermistor temperatures and errors.

STCS-SRS-TSL-FUNC-0170

Error Handling and Reporting

The TSL shall handle errors gracefully by providing appropriate error messages for invalid API calls, corrupted data, or any other unexpected conditions. The system should log these errors and notify the user.

4.2.2. Thermal Control Function

The Thermal Control Function (TCF) is an essential software component responsible for maintaining the thermal stability of a spacecraft. It actively manages the temperature of various critical components by controlling the power to heater lines based on acquired temperature data from the TSL which will allow the TCF to adjust heating and cooling operations to ensure that all thermistors remain within specified temperature ranges, even under varying environmental conditions such as eclipses or extended sun exposure period. The TCF employs control algorithms, such as Proportional-Integral-Derivative (PID) controllers, to precisely regulate the temperature, by powering on/off a certain heater attached to only one thermistor, enhancing the spacecraft's operational efficiency and reliability.

STCS-SRS-TCF-FUNC-0180

Thermal Control Management Function

The TCF shall implement a Thermal Control Management Function to perform the thermal control based on a software Proportional-Integral-Derivative (PID) controller for each thermistor.

Note: A first version can be implemented using a “Bang-bang” controller approach, please see section X for the description.

STCS-SRS-TCF-FUNC-0190

Configure PID Parameters

The TCF shall allow the user to set the PID controller parameters (proportional, integral, and derivative gains) and the setpoint temperatures for the thermistors before the start of execution. This configuration should include:

- Proportional gain (Kp)
- Integral gain (Ki)
- Derivative gain (Kd)

STCS-SRS-TCF-FUNC-0200

Thermistor Setpoint Default Value

The TCF shall define a setpoint temperature for each thermistor. The default setpoint shall be 0 for all thermistors.

STCS-SRS-TCF-FUNC-0210

User-Defined Thermistor Setpoint Value

The TCF shall allow a user to change the setpoint temperature for a specific thermistor or all thermistors at runtime between the values of -20 and 20.

STCS-SRS-TCF-FUNC-0220

Thermal Control Enable

STCS-SRS-TCF-FUNC-0220

The TCF must provide an interface to enable its functionality. Upon enabling, the TCF should start reading temperature values from the TSL, feed them into the PID controller, and adjust the heater power status accordingly.

STCS-SRS-TCF-FUNC-0230

Thermal Control Disable

The TCF must provide an interface to disable its functionality. Upon disabling, the TCF should stop reading temperature values and cease controlling the heater power status, ensuring all heaters are switched off.

STCS-SRS-TCF-FUNC-0240

Heater Power Status Data Acquisition

The TCF shall, at the start of execution, acquire the power status of the following heaters: HTR-01, HTR-02, HTR-03, HTR-04.

STCS-SRS-TCF-FUNC-0250

Thermistors Data Acquisition

The TCF shall, every 5 Hz, acquire the values of the following thermistors: THERM-01, THERM-02, THERM-03, THERM-04.

STCS-SRS-TCF-FUNC-0260

User-Defined Thermistors Data Acquisition Frequency

The TCF shall allow the user to update, at runtime, the frequency at which the thermistors data is read from the TSL-provided interface between the values of 1Hz to 5Hz.

STCS-SRS-TCF-FUNC-0270

Heater Operation Based on PID Output

The TCF shall operate the heaters via the TSF-provided interface based on the output of the PID controller.

STCS-SRS-TCF-FUNC-0280

Maintain Nominal Temperature of Thermistors

The TCF must adjust the heater power status to maintain the temperature of each thermistor at the nominal value of 0 degrees Celsius.

4.2.3. Visualization User Interface

The Visualization User Interface (VUI) is a crucial software component designed to read and display temperature data generated by the Thermal Simulation Library (TSL). It processes data from CSV files to provide real-time and historical visualizations of temperature fluctuations across multiple thermistors. The VUI features interactive plots and dashboards that allow users to monitor and analyze thermal conditions, identify trends, and detect anomalies. By offering intuitive graphical representations and user-friendly controls, the VUI enables users to gain insights into the spacecraft's thermal behavior, facilitating informed decision-making and efficient thermal management.

STCS-SRS-VUI-FUNC-0280

Acquire Thermistors and Heater Status

The VUI shall acquire the following data from the CSV file:

- Thermistors Temperature Values
- Heater Power Status

STCS-SRS-VUI-FUNC-0290

Default Data Acquisition Frequency

The data acquisition performed by the VUI shall be done at a frequency of 0.2 seconds by default.

STCS-SRS-VUI-FUNC-0300

User-Adjustable Data Frequency

The VUI shall allow the user to adjust the data acquisition frequency between 0.2 seconds and 1 second.

STCS-SRS-VUI-FUNC-0310

Display Latest Thermistor Temperatures

The VUI shall display the latest temperature value for all 4 thermistors.

STCS-SRS-VUI-FUNC-0320

Display Current Heater Status

The VUI shall display the current power status of all 4 heaters.

STCS-SRS-VUI-FUNC-0330

Plot Thermistor Temperatures

The VUI shall display a plot with the acquired data for each thermistor temperature value from the past 5 seconds.

STCS-SRS-VUI-FUNC-0340

Plot Heater Status

The VUI shall display a plot with the historical power status of each heater from the past 5 seconds.

STCS-SRS-VUI-FUNC-0350

Adjustable Plot Time Range

The VUI shall allow the user to individually change the time range of the available plots between the values of 1 second and 75 seconds.

STCS-SRS-VUI-FUNC-0360

Synchronize Plot Ranges

The VUI shall allow the user to synchronize the time range for the two available plots (i.e., when changing the time range for one plot the same time range should be applied for the other plot).

STCS-SRS-VUI-FUNC-0370

Display Logged Error Messages

The VUI shall display a panel with logged error messages from the TSL.

STCS-SRS-VUI-FUNC-0380

Error Handling

The VUI shall handle errors gracefully, displaying appropriate error messages in case of missing data, corrupted CSV files, or issues during data acquisition.