Revision: 1.0

CS4360 High Altitude Balloon

Software Design Document

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October 20, 2016

Contents

1 Introduction

1.1 Purpose

This document will describe the design implementation of a high-altitude balloon (HAB) controller. The controller will facilitate data collection and remote management of the payload.

1.2 Scope

The scope encompasses both software and hardware design:

- The High Altitude Balloon controller requires combining multiple hardware systems in a compact and lightweight payload. This entails a custom motherboard with separate data collection daughter-boards containing sensors, break-out headers and a fail-safe cut-down system.
- Software ties the hardware to the ultimate aim of data collection.
  - Sensor data is recorded and acted upon in the controller logic.
  - A radio system to facilitate tracking, command actions and improve payload retrieval after flight termination.
  - An adjustable cut-down mechanism that releases the payload after a predetermined amount of time or radio signal.

1.3 Audience

The intended audience of this document includes the client and supervising managers. It provides feedback and an overview of the intended system.

2 Design Overview

2.1 Description of the Problem

The scientific community performs experiments and gathers data from high altitudes, typically from flying a weather balloon. At high enough altitudes, the atmosphere can be termed *near-space,* and is of interest scientifically due to the benefits of low atmospheric disturbances in experiments—such as gathering cosmological data—at a fraction of the cost of a real-space launch.

Such flights require the ability to gather and record sensor data, such as temperature and pressure, as well as whatever experiment is primarily of interest on the individual flight. In addition, tracking and recovery of the equipment when a flight has ended is important, in light of the cost and time savings associated with equipment reuse.

Lastly, flights are unpredictable and require fail-safe ways to terminate a misbehaving flight for a variety of reasons:

- Unfavorable flight path characteristics.
- Balloon will fail to reach bursting altitude, and thus the payload may not be recoverable.
- Problems with equipment or experiment.

2.2 Assumptions

It is assumed that the primary user will have an understanding of computers and electronics at a daily-life level. The user will understand how to install software, identify and plug in common ports (including battery connections and USB), know basic arithmetic and follow and understand instructions.

It is further assumed that the primary users of this system will include the typical middle school to college level students and teachers. Therefore, while every effort is made to build a reliable system, the current implementation does not implement various system reliability methods that would further complicate and increase the projects costs and time-to-deployment.

2.3 Constraints

The general constraints around HAB flights involve weight, size, cost and ruggedness.

A weather balloon can typically lift a certain amount of weight based on the size of the balloon. Regulatory agencies also limit the payload weight. Thus the controller and related systems should minimize weight to allow cheaper and light balloons, and allow more free payload capacity for other experiments.

Coupled with weight battery capacity. Higher capacity batteries increase run-time, but at the expense of weight. Hence, conservation of energy is important to allow long flights, or extended payload retrieval.

Additionally, the desire for a compact system to allow room for other experiments and data collection technologies limits the controller size. While size is an important consideration, weight is the overriding constraint due to the hard regulatory limit placed on balloon payloads.

Any system is also constrained by budgetary boundaries. This is especially true outside of the government funded studies in academia. Hence, a low cost solution is desirable.

Ruggedness is also important. The payload is subjected to accelerations and torque upon liftoff and payload landing that require a secure means of attachment to both the balloon and the payload container.

Lastly, a short time-frame of three weeks between the undertaking of the controller and the scheduled launch is a major constraint on development.

2.4 Goals

The goals of the HAB project are derived from and similar to those in the constraints section (section 2.3 on page 4.)

They consist of:

- Low weight
- Small volume
- Energy efficiency

3 Architectural Strategies

3.1 Software Environment

The software used during development will include the standard Arduino IDE[1] with various sensor libraries included with many sensors boards upon purchase. The Arduino framework is written in C++ and inline assembly. Custom software will be designed to provide logging and control of the sensors.

Software reuse is an important consideration due to the tight time frame. Many sensors and third party libraries are available to interface with the Arduino software framework. These libraries save time and energy in writing interface code and debugging of software problems. Additionally, future maintaince is enhanced due to the ease of programming and understanding the more simplistic Arduino programming language, which is a subset of C++.[2]

3.2 User Interface

The controller interface is straight forward. During launch the user will apply power by plugging in the battery and observing if a GPS signal is aquired through the built-in LED indicator. After successful recovery, the user will remove power to the unit, reapply power and hold the interface button to exit recovery mode. Upon exiting recovery mode the user will plug in a serial cable to the appropriate on-board header and use a terminal program and commands to download the raw data from the SDCard.

3.3 Data Storage

Data is stored on an SDCard for ease of availability and large storage capacity. Data integrity is important and is accomplished by detecting and correcting errors during data logging.

Successful detection of errors is done through CRC16 checksums coupled to every SDCard write. Every potential block of data to be written to the card is first checked if empty. If the SDCard block is empty, data is written to that block and immediately read back into a separate area of memory. This is then compared with the valid sensor data to ensure successful data writes and retrieval. If no match is found, the controller will continue to attempt to write and check subsequent blocks. Each block is written in a raw format to guard against file system corruption if power loss or a watchdog reset occurs.

[1] The Arduino IDE can scarcely be called an IDE. However, time shortages do not allow migration to a more full featured IDE, or distancing from the Arduino core libraries.

[2] Though, except for the standard libraries, all C++ functionality is available.

If a reset occurs, the controller finds the tail, or end, of the log (where data was last written) and continues to log data. This protects against overwriting of previous data.

3.4 Hardware

The mother and daughter board prototypes are hand made to reduce time to deployment.[3] PCBs are hand laid out and soldered.

[3]Typical turn-around time for affordable custom PCB boards are 3–4 weeks.

4 System Architecture

4.1 Hardware

The HAB controller will be based on:

- An Atmel ATMEGA2560 microcontroller. This is a small system-on-a-chip (SOC) that allows communication with various sensors without needing additional components.
- Various sensors such as,
  - Magnetometer
  - Gyroscope
  - Accelerometer
  - Geiger counter
  - Temperature
  - Barometric pressure
  - Humidity
  - Light level
  - Global Positioning System (GPS)
- Recordable medium such as EEPROM and SDcards.
- Resistive heaters to control sensor and experiment temperatures while in flight.
- Payload retrieval components,
  - A siren or buzzer to allow auditory location of payload once on the ground.
  - LEDs to attract attention getting visually.

The cut-down unit will include,

- A nichrome resistive wire that will cut through the nylon payload supporting cord.
- A microcontroller that will implement a timer and react to barometric pressure.
- A spring loaded housing to provide force to pull the nichrome wire through the payload line when activated.

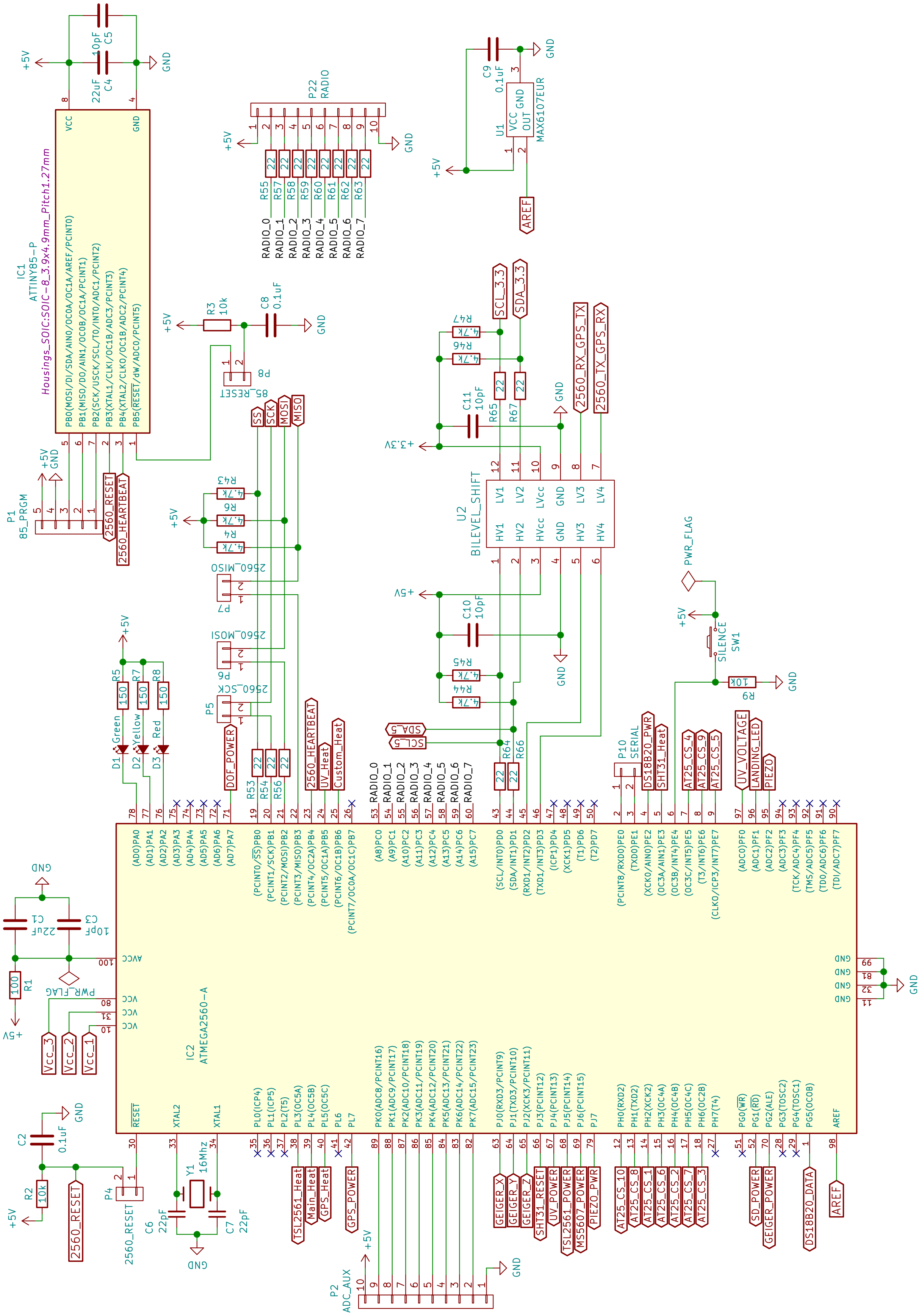

Figure 1: Main HAB controller schematic.

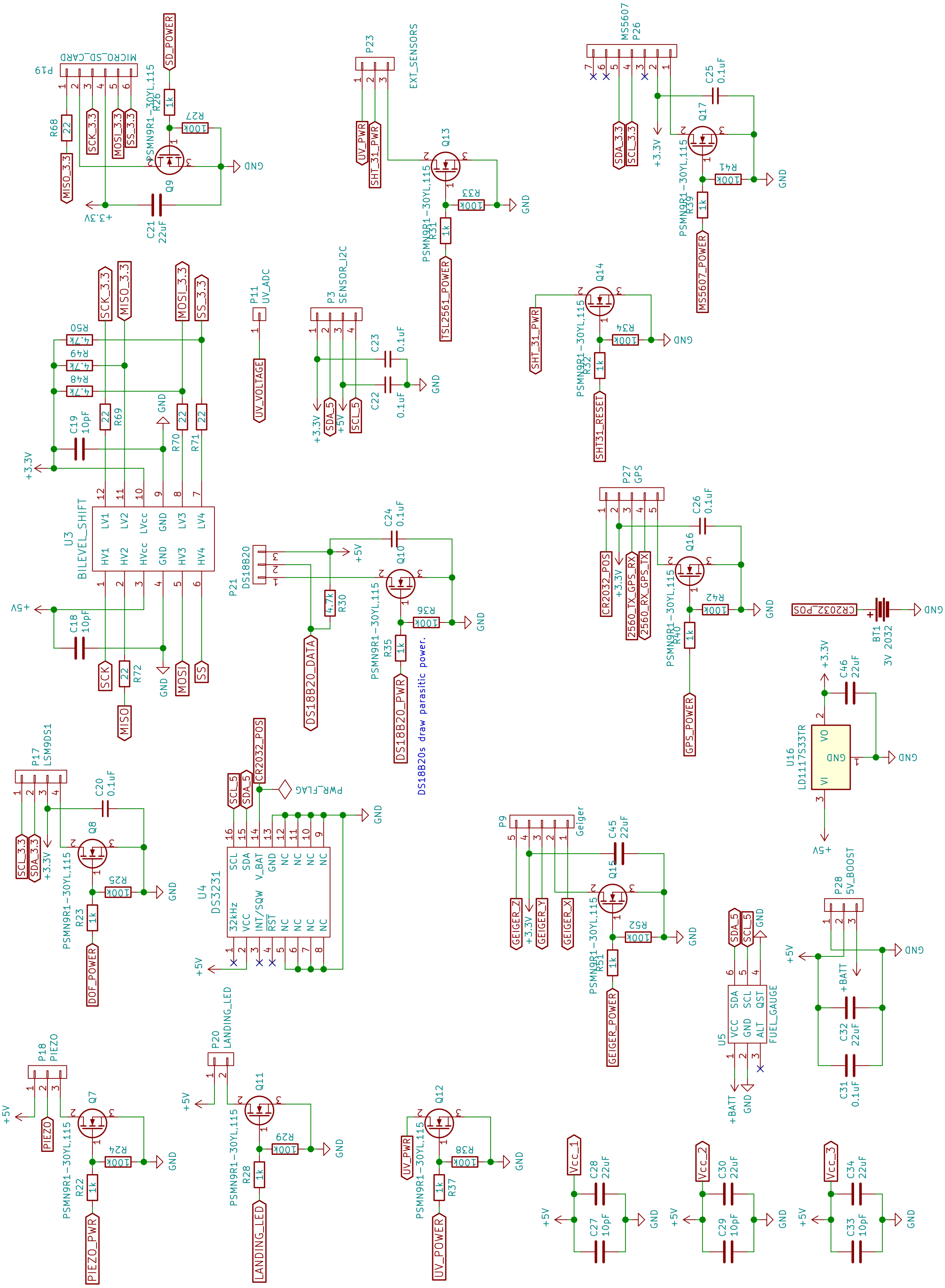

Figure 2: Schematic detailing the auxiliary connections from motherboard. Controls various aspects of the controller such as power and communications.

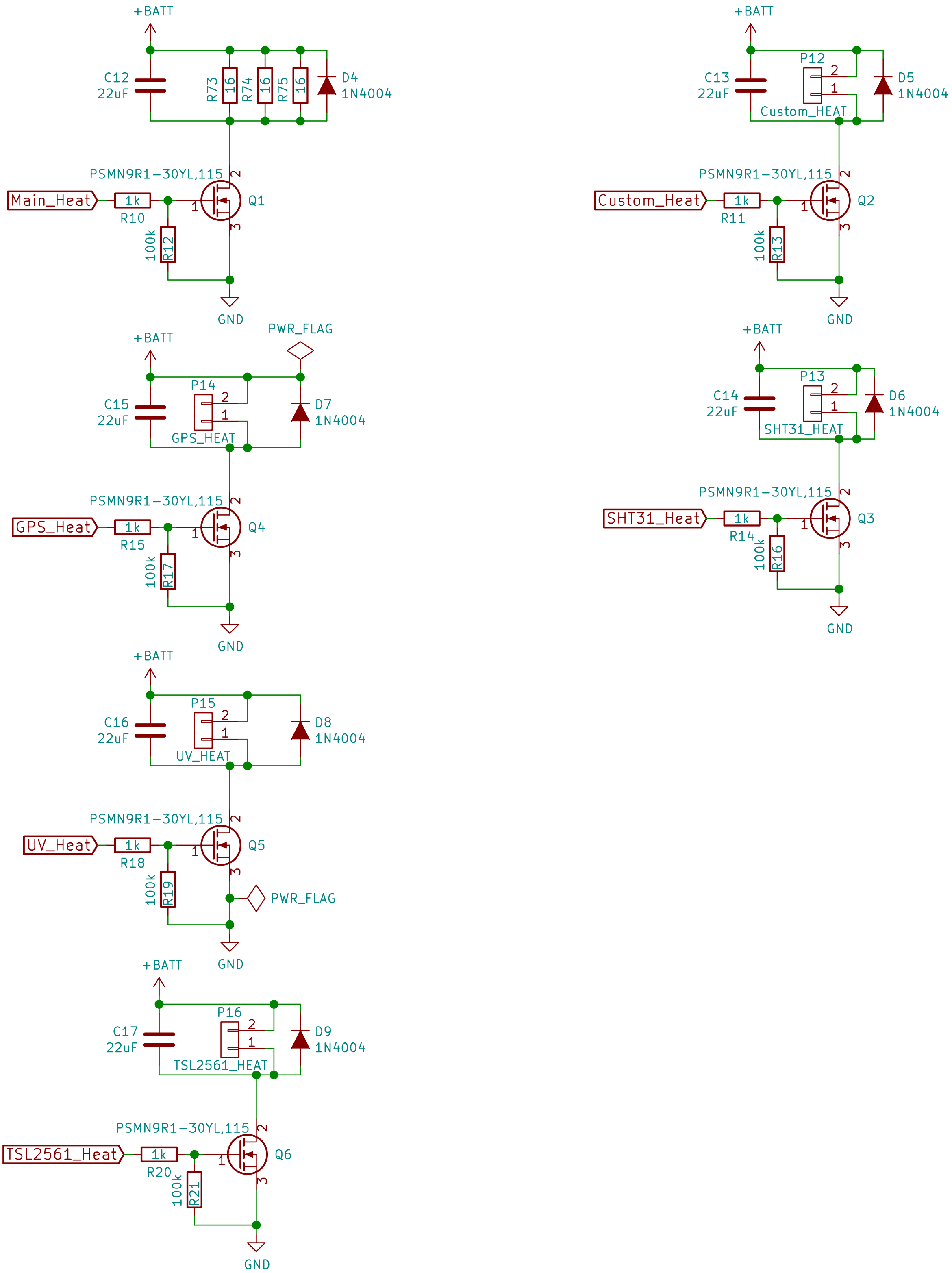

Figure 3: Heat control schematic.

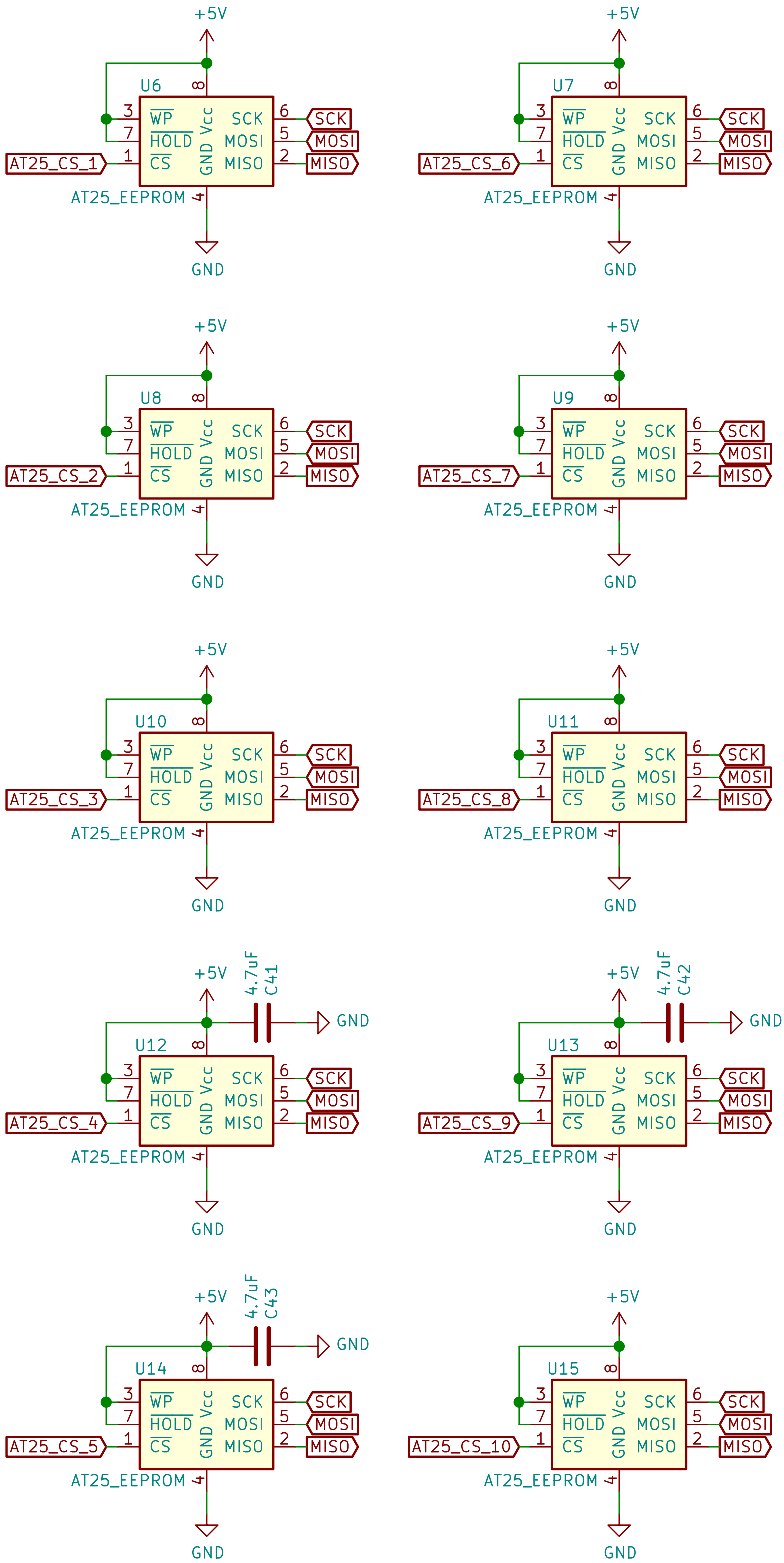

Figure 4: Proposed EEPROM schematic for backup datalogging.

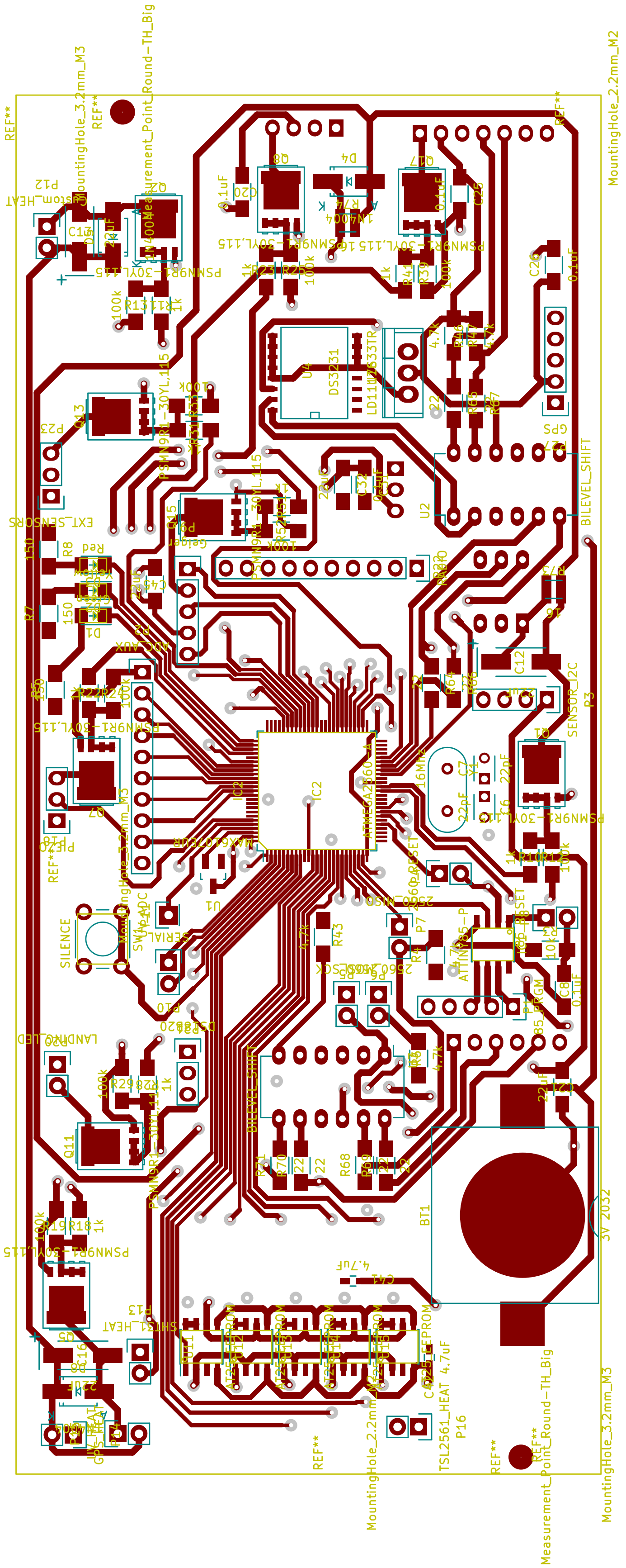

Figure 5: Front PCB routing layout.

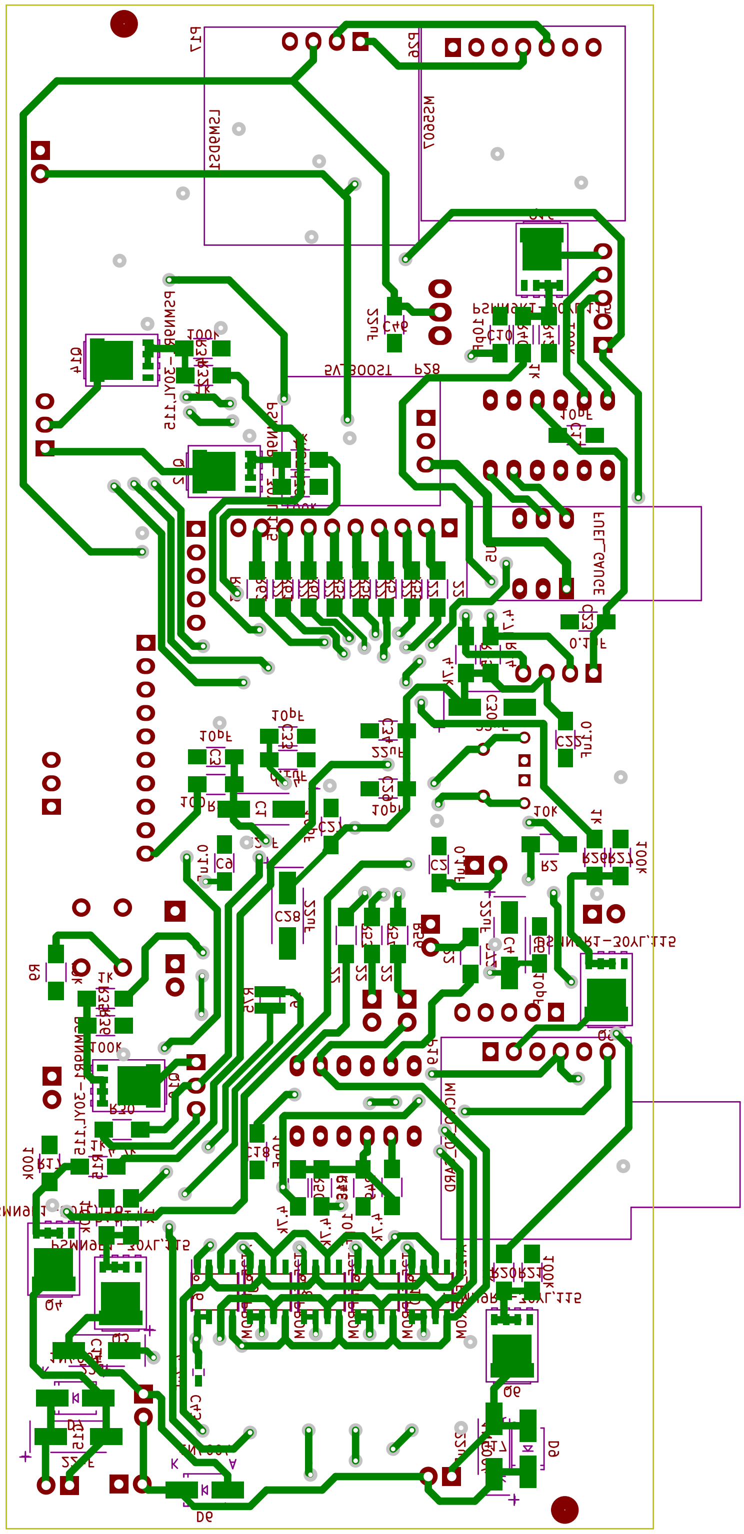

Figure 6: Back PCB routing layout.

4.2 Software

The software of the HAB controller is primarily responsible for polling various sensors and recording the data for later analysis.

The controller communicates with the following sensors:

- Temperature sensors
    - Dallas Semiconductor DS18B20s mounted on the following sensors or locations:
        - GPS Receiver
        - ML8511 UV light sensor
        - TSL2561 Lux light sensor
        - SHT31 Humidity and temperature sensor
        - Internal header break-out board
        - Free hanging outside the payload container (external temperature)
    - Additionally, the DS3231 Real time clock contains a temperature sensor that is designated the motherboard temperature for thermostatic regulation.
- Humidity through SHT31
- Light levels
    - TSL2561 Lux and Broadband light level sensor
    - ML8511 UV sensor
- Ionizing radiation through a modified MightyOhm Geiger counter board
- Barometric pressure via a MS5607
- LSM9DS1
    - Magnetometer
    - Gyroscopic
    - Accelerometer

The controller also communicates with a microSD flash card to record the relevant data.

Lastly, the controller is responsible for flashing LEDs and an acoustic alarm to aid in payload retrieval once it determines it has landed.

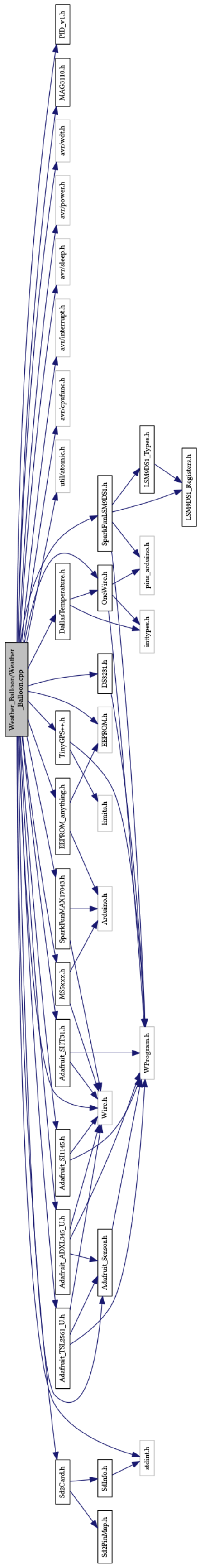

Figure 7: Include files for the HAB controller main program.

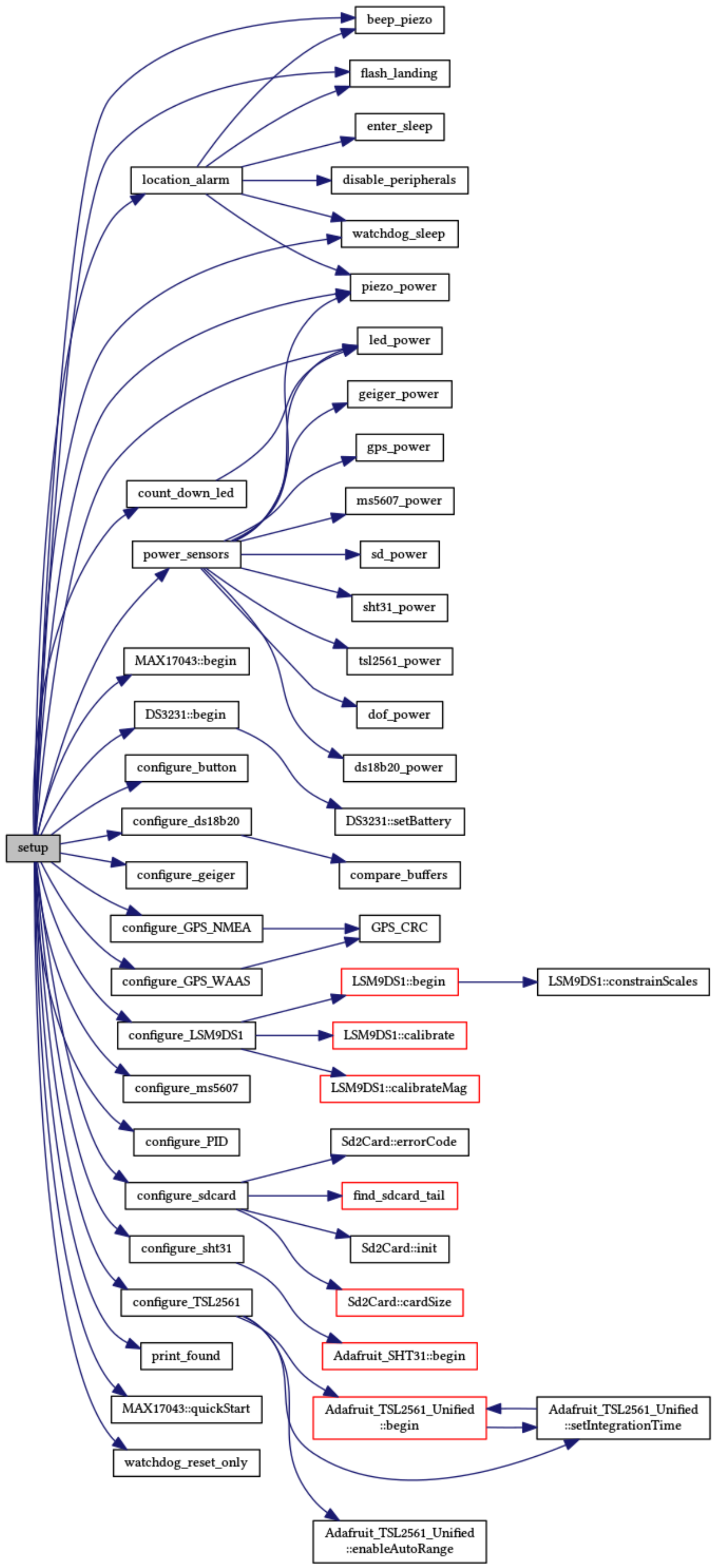

Figure 8: Overview of the function calls from the initial setup function.

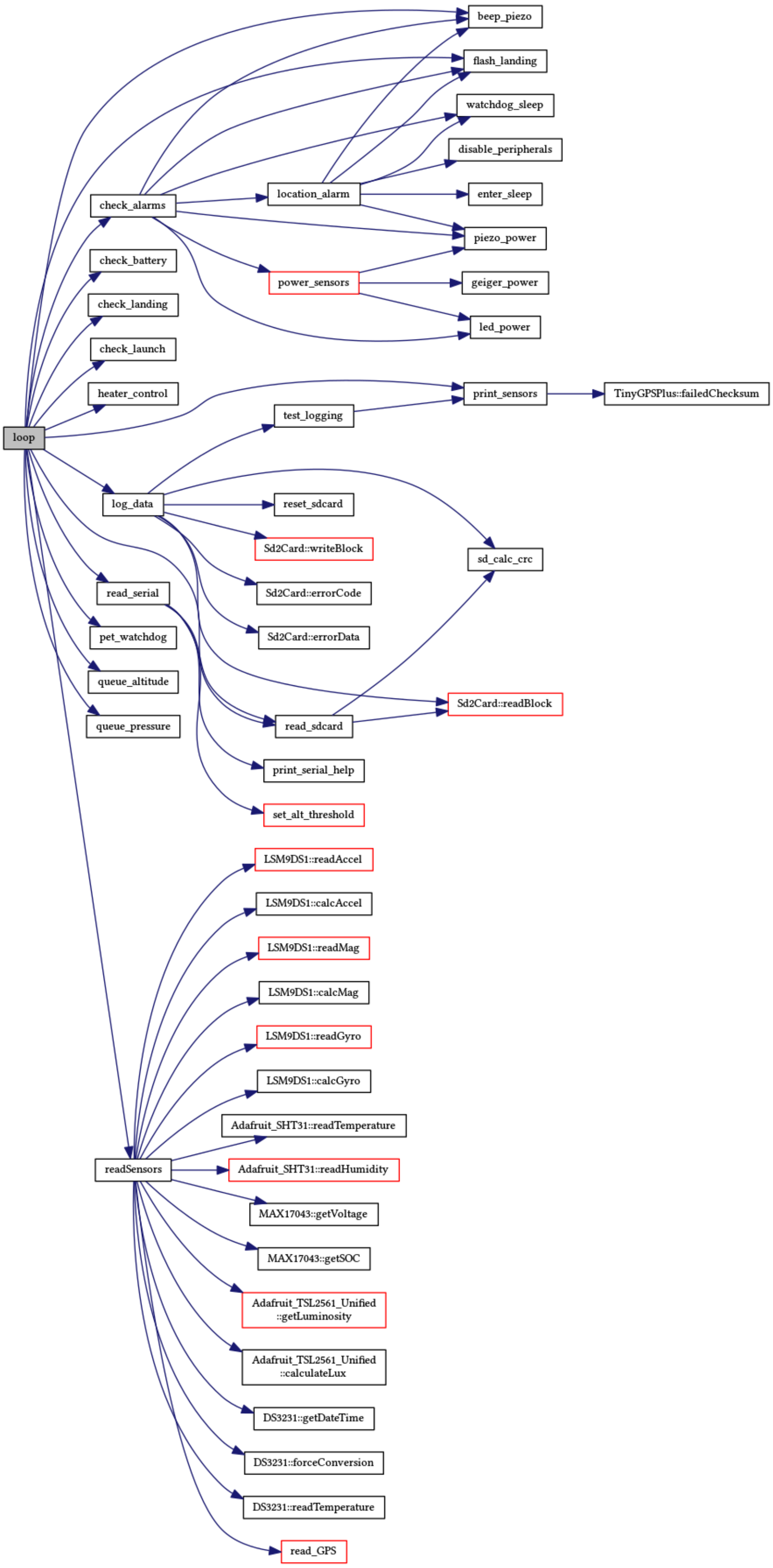

Figure 9: Function calls from the main loop function.

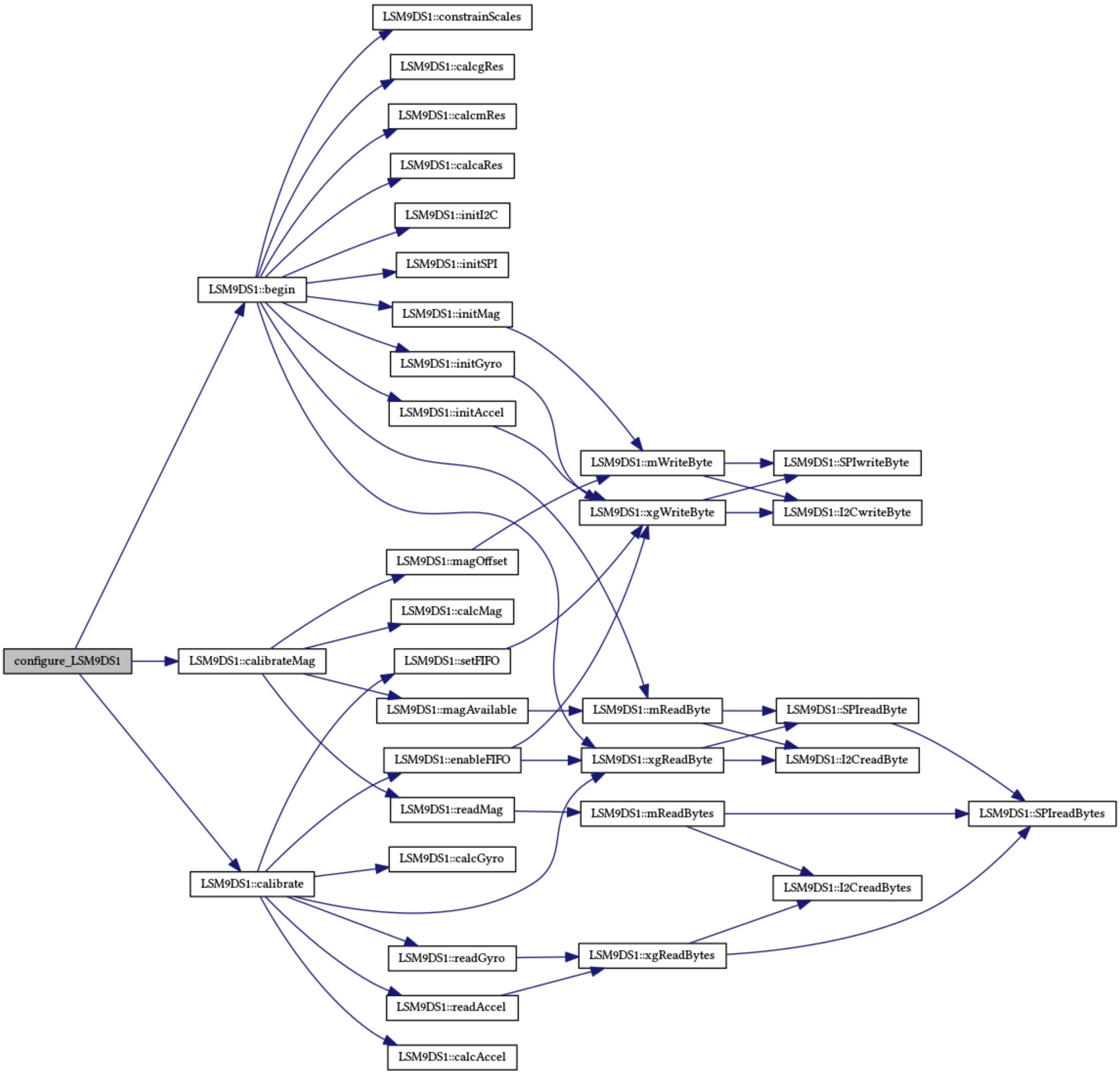

Figure 10: Function calls to configure the LSM9DS1 acceleration/gyroscope/magnetometer sensor.

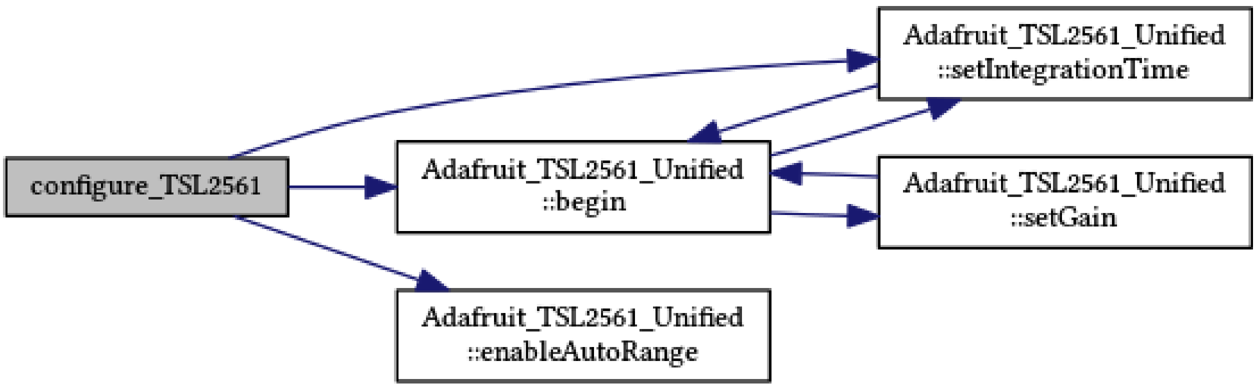

Figure 11: Function calls to configure the TSL2561 light sensor.

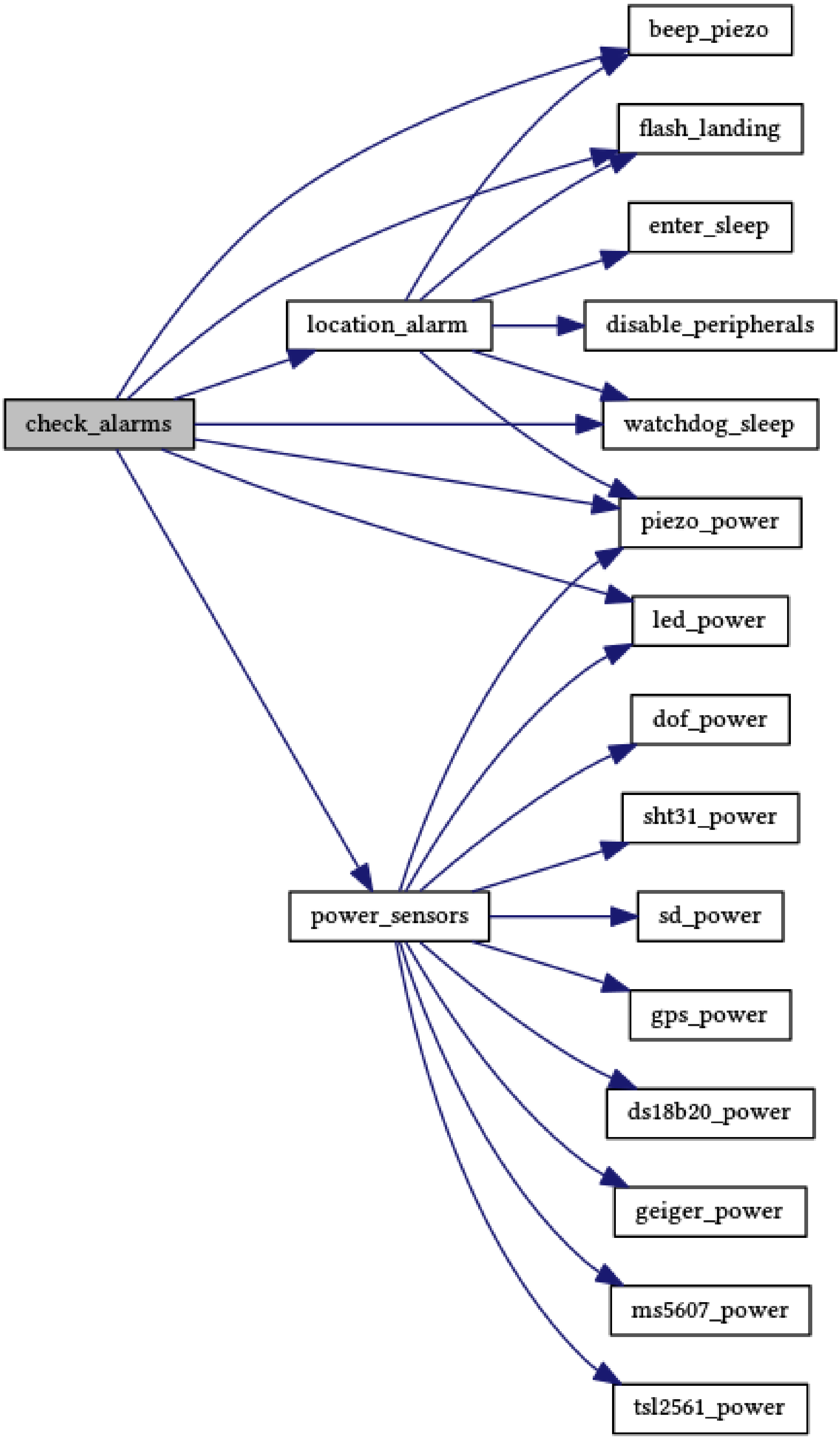

Figure 12: Function calls for the check_alarms function.

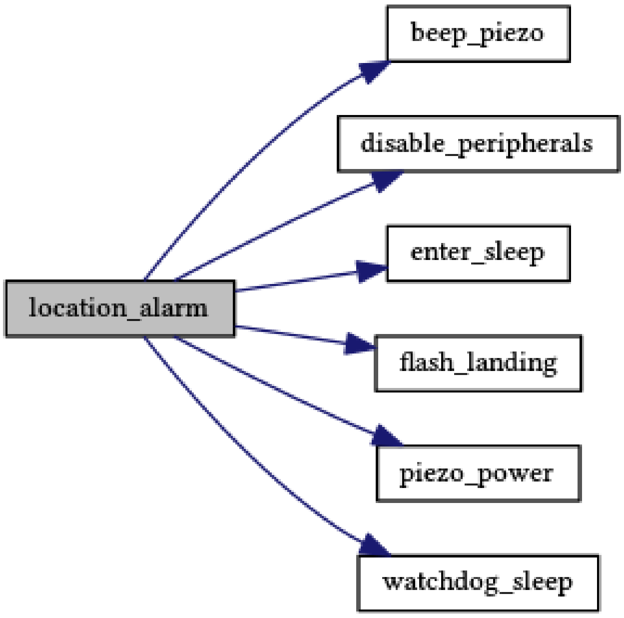

Figure 13: Function calls from the location_alarm function.

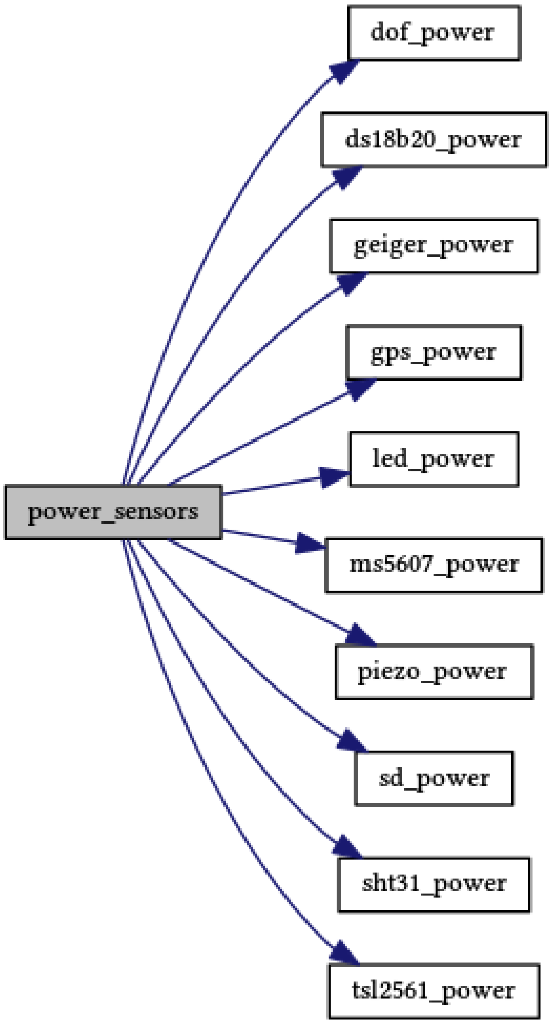

Figure 14: Function calls from the power_sensors function.

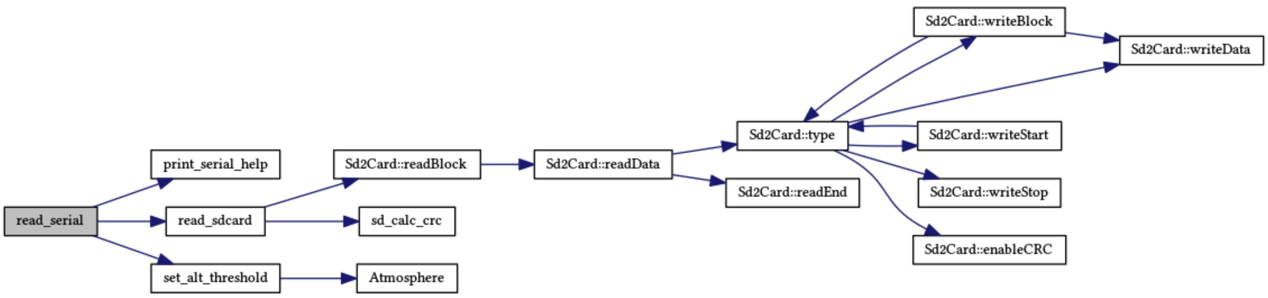

Figure 15: Function calls from the read_serial function.

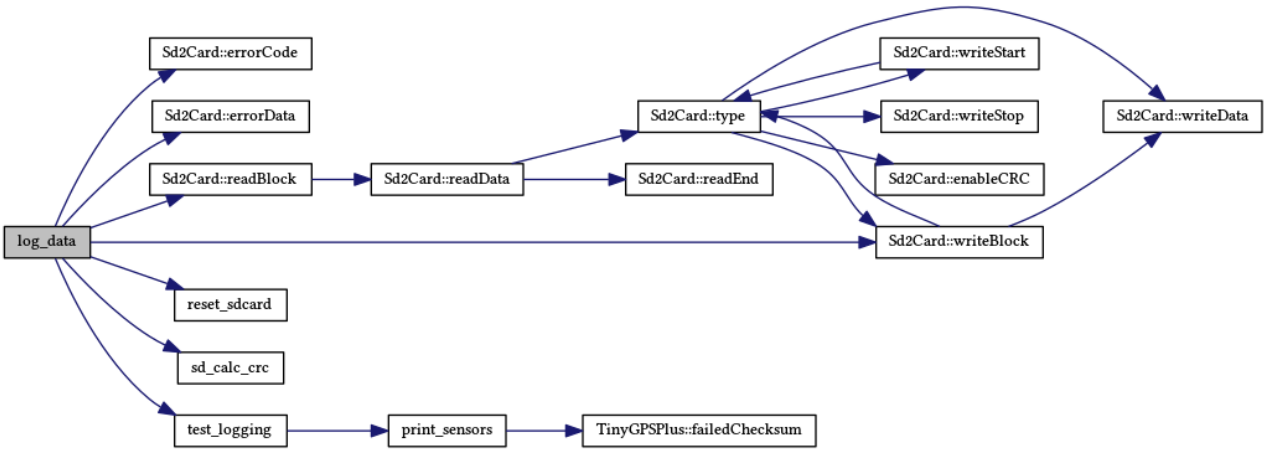

Figure 16: Function calls from the log_data function.

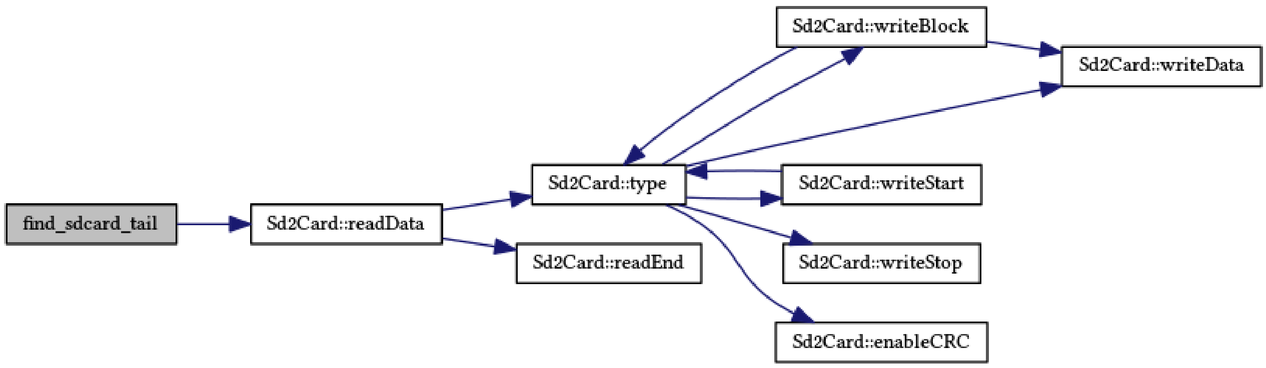

Figure 17: Function calls from the find_sdcard_tail function.

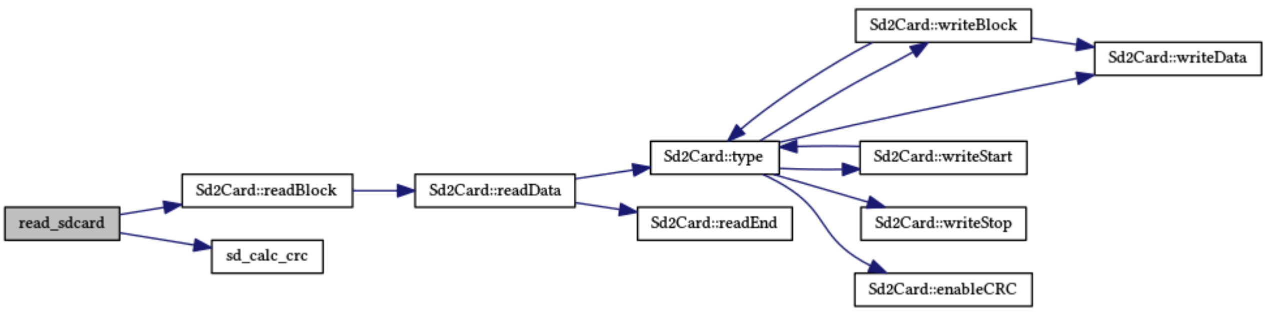

Figure 18: Function calls from the read_sdcard function.

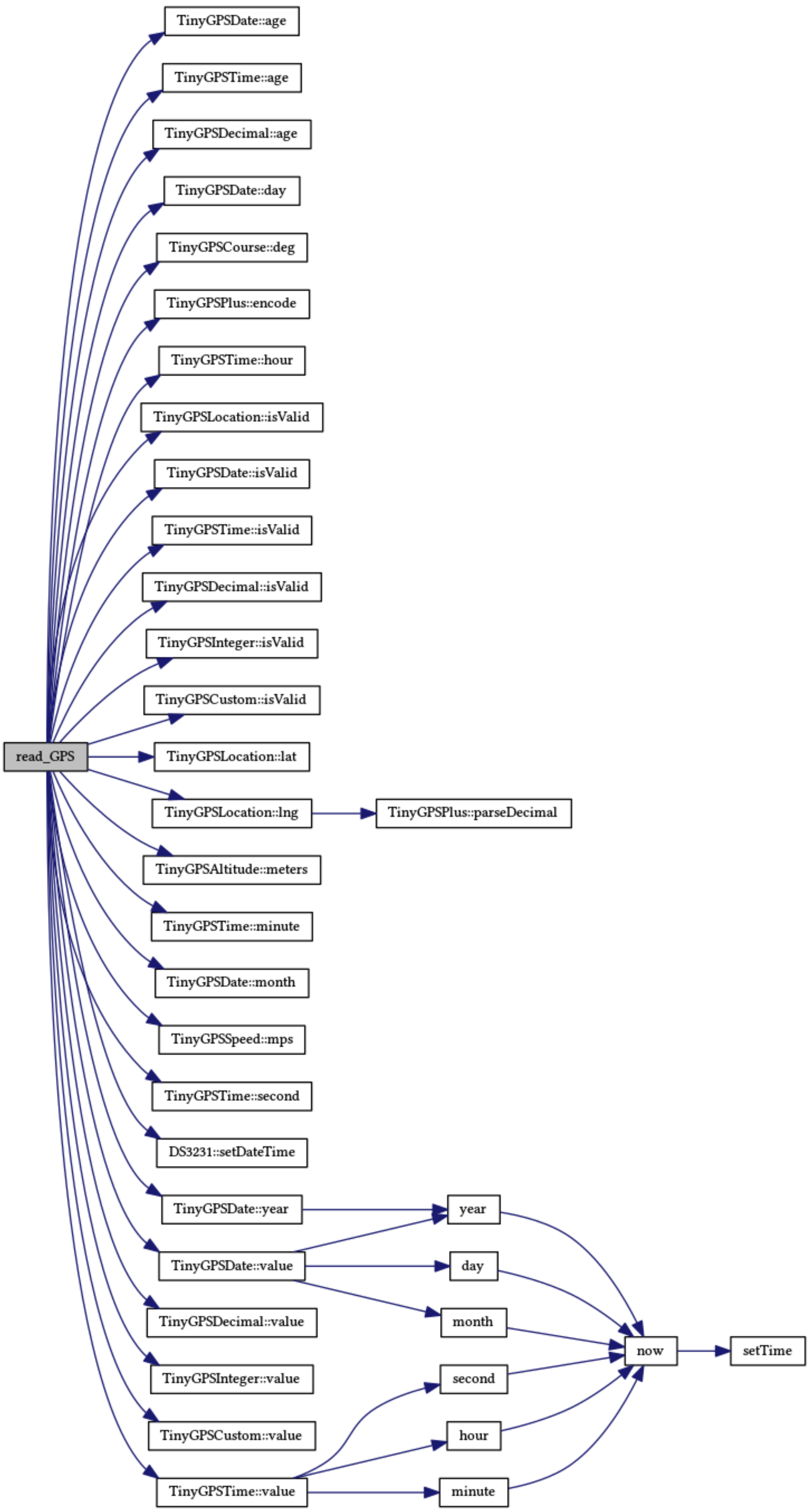

Figure 19: Function calls from the read_GPS function.

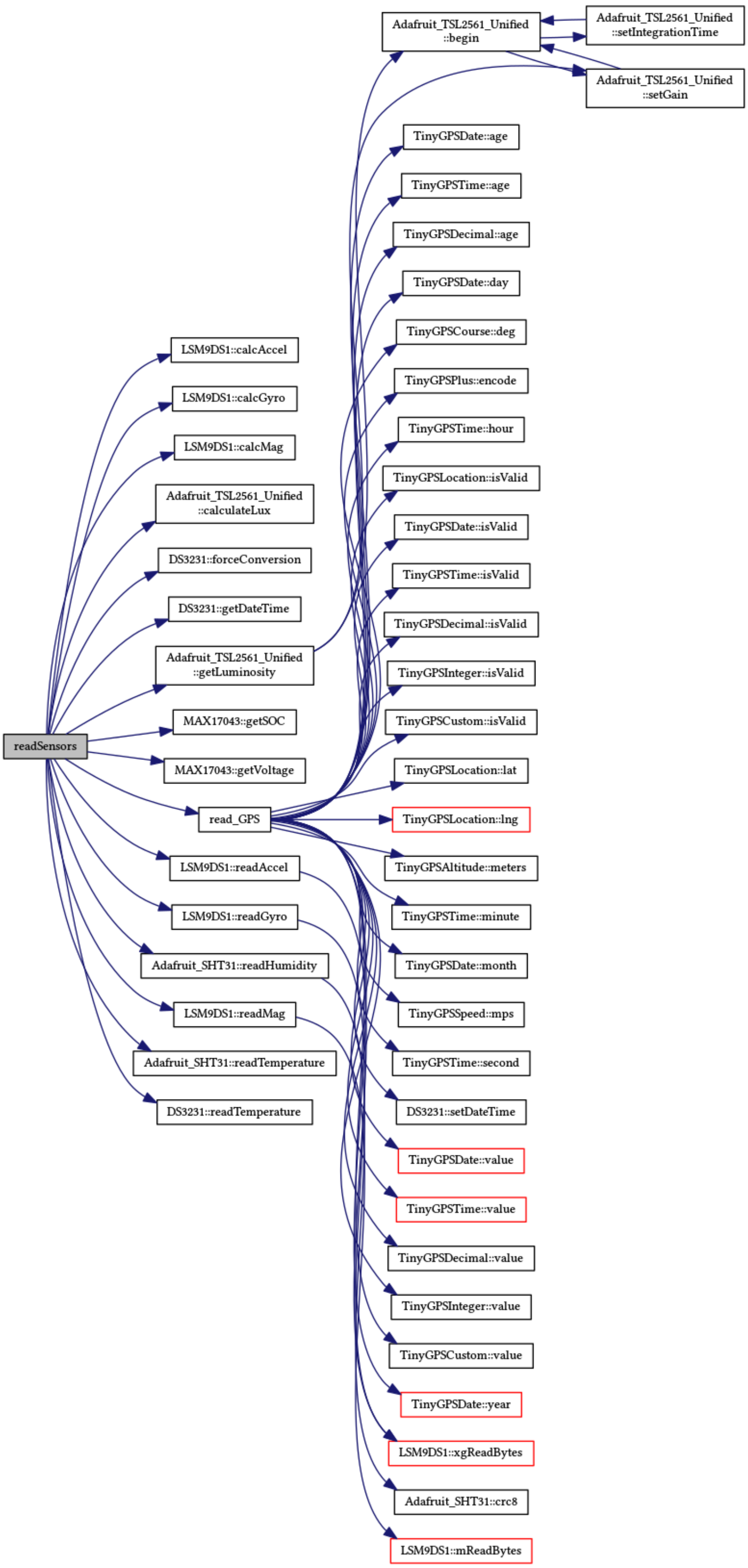

Figure 20: Function calls from the readSensors function.

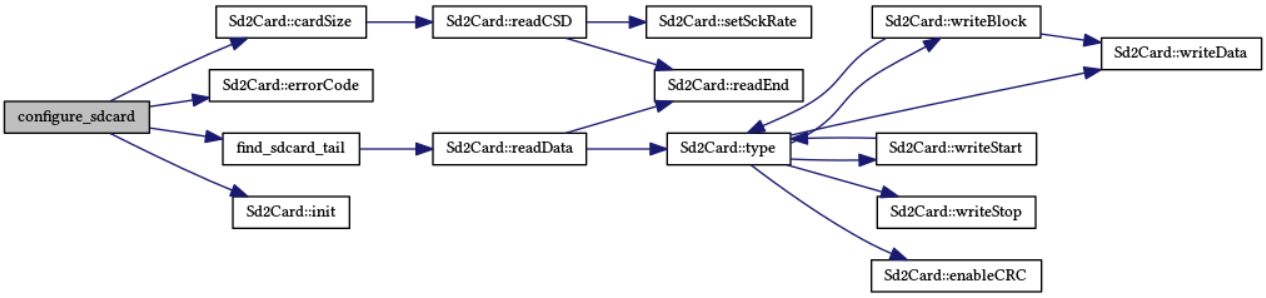

Figure 21: Function calls from the configure_sdcard function.

Nomenclature

Accelerometer	An accelerometer is a device that measures acceleration.
Barometric pressure	The local pressure of the atmosphere as measured by a sensor or instrument.
Controller	Generically, the HAB data collection and payload control system.
Cut-down	A device that releases the payload from the balloon upon a specific signal. Eg, time, altitude, GPS coordinants, radio signal.
Data collection	Gathering and logging data retrieved from electronic sensors for later retrieval and analysis.
EEPROM	Electrically Erasable Programmable Read-Only Memory and is a type of non-volatile memory used in computers and other electronic devices to store relatively small amounts of data.
Flight termination	Ending of a flight, either naturally through a balloon bursting at high altitude, or through the mechanical means of a cut-down device.
Geiger counter	An instrument used for measuring ionizing radiation.
Global Positioning System	A global navigation satellite system that provides geolocation and time information to a GPS receiver in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites.
GPS	Global Positioning System.
Gyroscope	A sensor that measures degree of rotation of a body due to the gyroscopic effect of a spinning mass. Electronic versions are offered today that result in the same function.
HAB	High altitude balloon. A platform tethered to a balloon, designed to achieve a high altitude, allowing scientific experiments and data collection.
Header	A place on an electronic board where related signals are routed to allow a cable to connect, thus interconnecting seperate boards or devices.
IDE	Integrated development environment (IDE) is a software application that provides comprehensive facilities to computer programmers for software development.

LEDs	Light Emitting Diodes. Small electronic components that emit light when receiving electric current.
Magnetometer	An instrument that measures magnetism, such as the strength and direction of the magnetic field at a point in space.
Microcontroller	A small computer; the lower end on the system-on-a-chip spectrum.
Motherboard	The main board in charge of a system. Connects to smaller and more specialized daughter-boards, headers, sensors, etc.
Near-space	Tthe region of Earth's atmosphere that lies between 20 and 100 km (65,000 and 328,000 feet) above sea level, encompassing the stratosphere, mesosphere, and the lower thermosphere.
Nichrome resistance wire	A wire designed to heat up when an electric current is passed through it. Nichrome wire provides oxidation resistance which is important for wire reuse.
Payload	The packages attached to the balloon. Typically does not include items such as the parachute and cut-down unit.
Payload retrieval	Retrieving the payload after it has landed on the ground.
PCBs	Printed Circuit Boards.
Remote management	Allows communication from a ground station to the HAB controller via radio link. This allows remote control of certain settings and issuance of commands.
SDcard	A Secure Digital card is a small form factor memory device containing a microcontroller and flash memory.
Sensor	An electronic device designed to transform a physical property into an electronic representation to allow recording and analysis.
SOC	System-on-a-chip.
System-on-a-chip	A single integrated circuit containing a processor core, memory, and programmable input/output peripherals.
Tracking	A HAB flight is typically tracked in real-time so that the payload may be recovered after it parachutes back to Earth. Tracking is typically done with radio and direction finding equipment or transmission of GPS coordinants.
Watchdog	An electronic timer that is used to detect and recover from computer malfunctions. A timeout is used to initiate corrective action, typically by resetting the system.