Smart Moon Transportation System

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Internet of Things

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Contents

Chapter 1

Smart Moon Transportation System

The goal of this project is the design and implementation of an intelligent wireless sensor network used to monitor and control a regolith transport solution for the Moon. Lunar regolith is one of the most common resources present on the moon and it is an important material used for different ISRU activities, but also mineral processing and construction.
For the extraction, excavation, and transportation of lunar regolith, a distributed system of transport solutions can be used.
One of the most relevant key issues of this process is the presence of an extremely dusty environment that may hazard the equipment, and the same holds for the temperature. The idea behind this project is to develop an IoT telemetry and control system used to turn a set of regolith transport solutions into a set of smart transportation systems that can be used to monitor and control the extraction and transportation process while minimizing dust hazards, possible errors in the amount of regolith transported, and considering the typical moon's temperature extreme conditions.

1.1 Environmental Conditions

Considering the deployment of the solution to the lunar environment, different environmental problems have to be addressed.

- Energy Resources: Resource energy available on the Moon is limited.
  A typical source of energy that can be used in this environment is solar energy. A set of solar cells can be used as a harvesting system, though considering that the maximum and minimum solar flux depend on the Earth and Moon positions and that the slow rotation period implies long periods of night and days on the Moon.

- Temperature: Because of the absence of an atmosphere, the surface temperature ranges from -130° to 120°.

- Dust: Particles smaller than 20 microns in size of fine lunar dust are present overall in the lunar environment.
  This dust is very abrasive for the equipment and can be electrostatically charged.

- Radiation: A harsh radiation environment is present in the Moon due to the absence of a layer of magnetosphere protection.
  A radiation protection solution could be considered.

1.2 LunaNet

NASA developed LunaNet, an 'Internet' network for the Moon and the Artemis missions allowing to bring Internet and the IoT protocols to the Moon, just started the last November.
Artemis is NASA's program to establish a long-term human presence on this satellite.

Chapter 2

Design

The solution proposed is composed of the following components:

- A network of IoT devices, including sensors collecting data from the physical environment and actuators. Part of the IoT devices uses the MQTT protocol, while the other part uses the CoAP protocol.
- A border router, deployed in order to provide external access to the Internet.
- A Java collector, that collects data from sensors, stores them in a MySQL database, and sends commands to the actuators realizing the application logic.

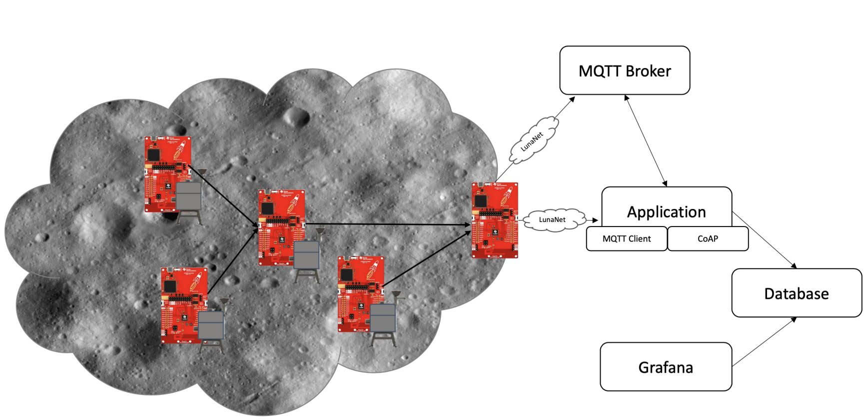

Figure 2.1: Architecture

2.1 IoT Nodes

Each IoT device is a Contiki-NGCC2650 Launchpad equipped with the Contiki-NG operating system.
The reference network is a low-power lossy network (LLN) exploiting the 802.15.4 and IPv6 protocols.
Multi-hop communication is implemented by the RPL protocol.

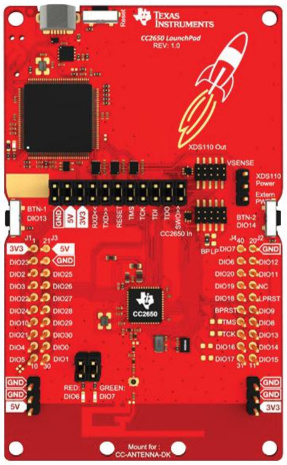

Figure 2.2: Contiki-NGCC2650 Launchpad

Each node is equipped with three different sensors used to monitor the important metrics of the application domain, an alarm system implemented through a set of LEDs, and a button used to shutdown the alarm.

2.2 Monitored metrics

The metrics monitored by the different sensor nodes are the following:

- Temperature, monitored to deal with the extreme possible values, which are possible due to the absence of atmosphere.
  To allow the transportation system to properly work, the system will shutdown in case the temperature range goes beyond the range [-10°, 65°].
  Since the distributed system is thought to be used overall the moon surface, some transportation systems will continue to be operative, while the rest will stop working.

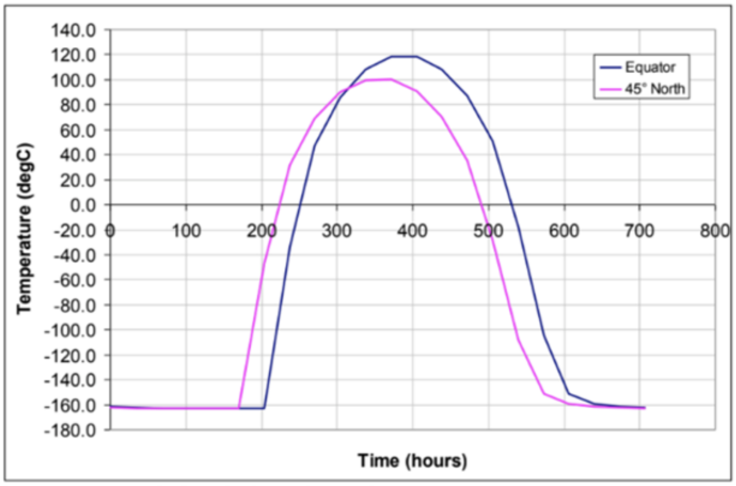

Figure 2.3: Temperature variation in a lunar day

- Dust, considered to monitor and control the amount of dust level experienced by each transport system.
  A high level of dust may hazard the system, and also induce the system to transport dust together with regolith.
  An onboard sharp GP2Y1010AU0F dust sensor can be equipped to the device, able to detect very fine particles.
  If the amount of dust overcomes a certain threshold, the rotation speed of the motor can be decreased or the system can be shutdown.

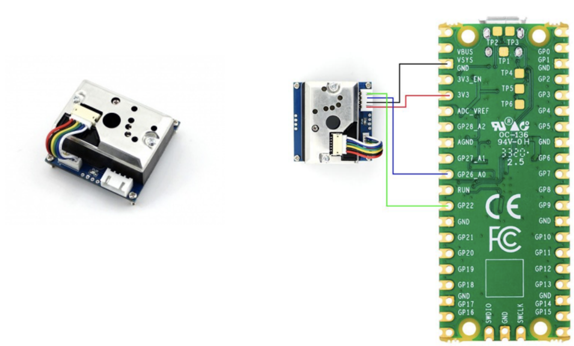

Figure 2.4: Onboard sharp GP2Y1010AU0F dust sensor

- Solid particle mass flow meter, used to monitor the regolith level processed by each transport system.
  If the regolith level overcomes a proper threshold, the system may be carrying rocks or other kinds of materials.
  Since the transportation system can tolerate a maximum weight, in case the threshold is overcome, the system will shutdown.
  An astronaut can manually handle the problem reaching the proper transportation system, and click the launchpad button to shutdown the alarm.

2.3 Collector node

The collector node implements the application logic based on the data collected from the MQTT and CoAP nodes.
If one of the sample values monitored by the sensor nodes does not range among the pre-established thresholds, an alarm system is triggered, eventually using actuating capabilities in order to come back in the standard range.
In this way, the collector is able to detect and eventually solve anomalies regarding the temperature, dust level and mass flow measurements.

2.4 IoT nodes lifecycle

The workflow followed by the different IoT nodes is described below.

1. Each node tries to establish a connection to the network

2. Once connected to the network, the MQTT sensor nodes try to register with the MQTT broker, while CoAP nodes send a registration message to the collector

3. If the previous cases successfully occur, the sensor nodes will periodically acquire data and send them to the collector node (simulated in the project using random values)

4. The sensor nodes will listen for potential alarm messages provided by the collector in case of anomalies.
   In case an alarm message is received, the sensor stops sending period updates and turns on the red LED, otherwise the green LED will be used in case of

normal operations.
A specific actuator system is used in case of anomalies regarding the dust level. No actuating capabilities are considered for the temperature, since this cannot be controlled on the lunar environment.
In case of anomalies in the mass flow meter, the astronaut may deal with the possible problems involving the weight carried by the transportation system, then clicking the Launchpad button.
Once the problem is solved, the sensor will return to its operational state and trigger the shutdown of the alarm.

2.5 MQTT network

Each MQTT node connects as a client to an MQTT broker publishing and subscribing to dedicated topics in order to communicate with the collector.
The node publishes data on the following topics:

- /temperature, /dust, /regolith to notify the collector of the current values of these metrics.
  The format of the message is {"id": node ID, "t": type, "v": value, "u": unit}.
  The collector will subscribe to this topic.

The collector will publish on the topic:

- /alarm/node_ID, in order to send an alarm to a specific MQTT monitor in front of a value not in the standard range.
  The message will contain the type of the error.
  Each monitor will subscribe to the topic involving its identifier.

2.6 CoAP network

Each device in the CoAP network will register with the collector, issuing a POST request to the registration endpoint.
After the registration, the collector will set up the observe relations to receive samples from the sensors, in order to update the database.
The resources exposed by the sensor nodes use the following endpoints:

- /temperature, /dust, /regolith, endpoints accepting GET requests and holding the last corresponding value sampled by the sensor. The same endpoints also accept POST/PUT requests, used to receive alarm messages from the collector.

2.7 Data encoding

The data exchanged between IoT nodes and the collector are encoded in JSON using a proprietary format.
This decision has been taken because of the more lightweight communication, faster processing times, and simpler information representation with respect to XML.
For this project in fact, interoperability is not required.
A binary encoding like CBOR has been considered, but not used since it is not supported by Contiki OS.

2.8 Database

The data captured by the sensors are stored in a MySQL database in order to be visualized with the Grafana tool.
The database contains a specific table for each type of considered metrics, maintaining the sample measurements taken by the sensors, and a table containing information about the sensor nodes.

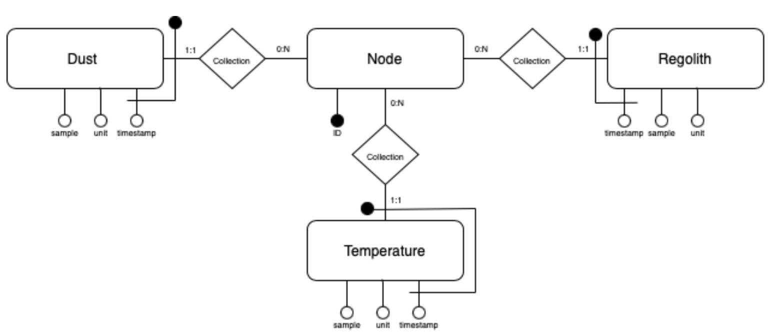

Figure 2.5: E/R Diagram

2.9 Grafana

A web-based UI developed using the Grafana web interface shows the data stored in the database by the collector node.
A different section is considered for each node, with a panel for each metric measured. Proper thresholds are also shown in order to show the normal operational range.

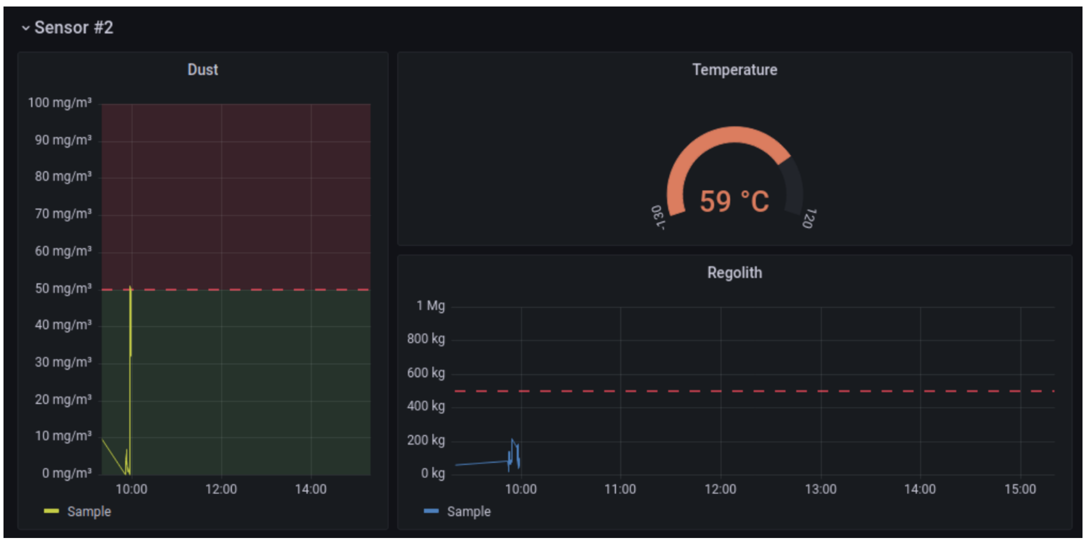

Figure 2.6: Grafana dashboard of a specific node

Chapter 3

Testing

To test the application, sensing and actuating capabilities have been simulated using random values and proper application logic.
The actuating system has been simulated as the following:

- the dust level will periodically decrease of a certain quantity until the alarm will shutdown.
- the temperature will not be modified since we have no actuating capabilities on the temperature of the moon environment.
- the regolith level will periodically decrease of a low quantity, in order to simulate the time needed to push the button and shutdown the system.

3.1 Cooja

A first test of the Smart Moon Transportation system was performed using the Contiki Cooja Simulator. The test was performed deploying all the components on the same Ubuntu virtual machine and using the default configuration.
A single LLN has been created with the presence of a border router, CoAP nodes and MQTT nodes.

3.2 Contiki-NGCC2650 Launchpads

A second test of the Smart Moon Transportation system was performed using three Contiki-NGCC2650 Launchpad nodes, used respectively as border router, CoAP node, and MQTT node.

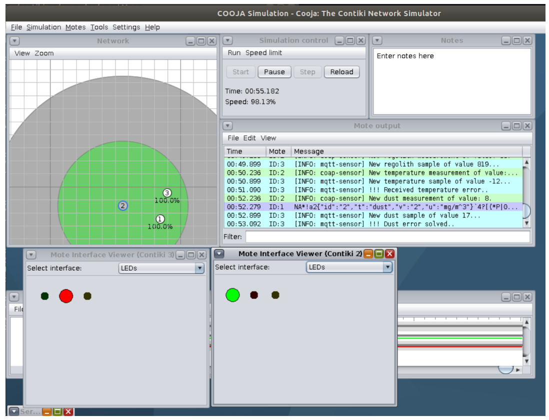

Figure 3.1: COOJA Simulation

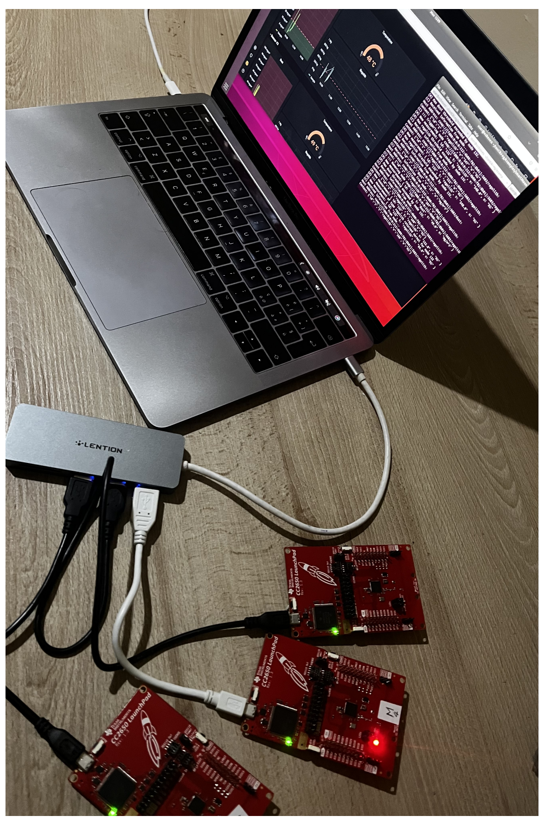

Figure 3.2: Contiki-NGCC2650 Launchpads deployment