ARDUSAT, AN ARDUINO-BASED CUBESAT PROVIDING STUDENTS WITH THE OPPORTUNITY TO CREATE THEIR OWN SATELLITE EXPERIMENT AND COLLECT REAL-WORLD SPACE DATA

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ABSTRACT

Short for "Arduino Satellite", ArduSat is an open-source Nanosatellite, based on the CubeSat standard. The extensive Arduino sensor suite on board gives students the opportunity to create their own satellite experiments and collect real-world space data using the Arduino open-source prototyping platform. From March until May 2014, two undergraduate physics students from Hasselt University used the downloadable ArduSat Software Development Kit which allowed them to design the command sequences they used to conduct their experiments.

1. ARDUSAT, A SHORT HISTORY

Four graduate students from the International Space University, with a Central Campus located in Strasbourg, France, founded in 2012 the aerospace company NanoSatisfi Inc. The successful launch of the ArduSat crowdfunding campaign on KickStarter resulted in a first design of the ArduSat payload prototype in August 2012 and a first high-altitude test in October that same year.

A big day for the newborn company was November 20, 2012, on which an agreement was signed with entrepreneurial company Nanoracks LLC to coordinate the deployment of the first two ArduSats via the NASA and JAXA (Japanese Space Agency) satellite deployment program.

On August 3, 2013, the Japanese cargo transfer vehicle HTV-4 was launched from the Tanegashima Space Center in Japan to the International Space Station (ISS), carrying two ArduSats among 3.6 tons of science experiments. Six days later, the HTV-4 was successfully berthed by the ISS' robotic arm Canadarm 2 to the ISS.

ArduSat-X and ArduSat-1 were finally launched together with the Vietnamese PicoDragon CubeSat on November 19, 2013 from the Japanese ISS experiment module Kibo using the Poly Picosat Orbital Deployer or P-Pod. This standard deployment system helps in the effort to reduce costs and development time for CubeSat developers.

Figure 1. CubeSats ArduSat-X, ArduSat-1 and PicoDragon launched from the ISS module Kibo on November 19, 2013

Both ArduSats stayed in a low Earth orbit (LEO) until re-entering the atmosphere on April 15 and April 16, 2014 respectively.

ArduSat-2 is a double-unit (2U) CubeSat and an improved version of the single unit ArduSat-1 satellite. It was deployed on February 28, 2014 from the Kibo airlock of the ISS but no signals were received. ArduSat-2 re-entered the atmosphere on July 1, 2014.

2. ARDUSAT UNCOVERED

ArduSat-X and ArduSat-1 are two single unit (1U) CubeSats, with sides of 10 cm and a total mass of approximately 1 kilogram. The tiny spacecraft's structure and power subsystems are based on the CubeSat standard, an open-source specification created in 1999 which defines a standard platform for low-cost space research. Both satellites carry roughly 20 sensors, including an optical spectrometer and a camera. The overall architecture is shown in Fig. 2.

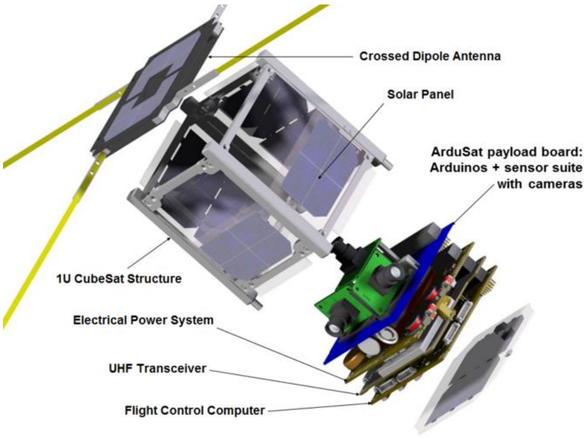

Figure 2. Architecture of a single unit ArduSat

The brain of the ArduSat-1 is the ArduSat Payload Processor Module (ASPPM), represented in Fig. 3. It features one supervisor processor consisting of an ATmega2561 (similar to an Arduino Mega) plus 16 processor nodes each running an ATmega328P just like an Arduino Uno.

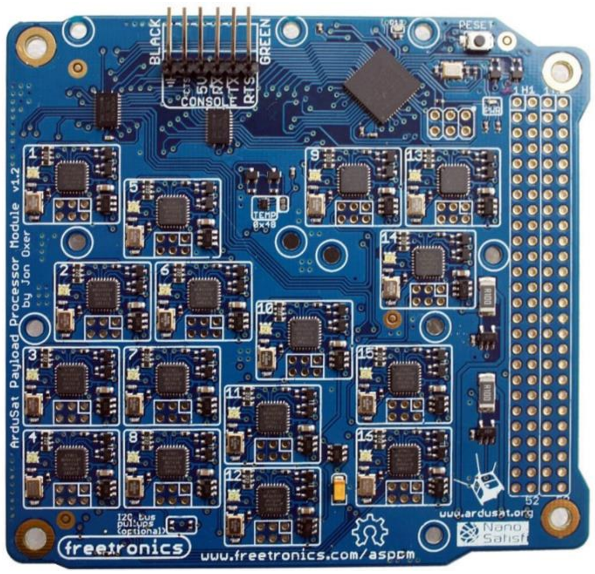

Figure 3. The ArduSat Payload Processor Module

The role of the supervisor is to provide mass storage on the Micro SD card for all processor nodes; power down any nodes not in use; receive new sketches to execute on nodes, and send them to the appropriate node via the serial connection; provide debug information on the serial debug console; and monitor power consumption on the 5 V and 3.3 V rails. The processor nodes are dedicated to computing the experiments, each on one node.

To communicate with the ground, ArduSat is equipped with a half-duplex UHF transceiver, operating in the 435-438 MHz amateur radio satellite band.

3. CODING FOR SPACE

The starting point for talking to sensors is Arduino, an open-source electronics prototyping platform.

The Arduino programming environment is easy to use for beginners, yet flexible enough for advanced users. It is based on the Processing programming environment and can be expanded through C++ libraries.

Open-source technology made it possible to enhance Arduino's baseline Integrated Development Environment (IDE) with the ArduSat Software Development Kit (SDK), available for download on GitHub since May 2013.

Undergraduate physics students from Hasselt University used an Arduino Uno to upload their code because the processor nodes of the ASPPM in the ArduSat run a similar microcontroller. To test the sensors all together, a little demo CubeSat has been built using K'NEX, as can be seen in Fig. 4 and Fig. 5.

The whole idea behind the working process is to create code; submit code for review via email or through ArduSat's website; do code testing on a development satellite; upload the program to the satellite; download the resulting data from the satellite; and examine the gathered data.

4. TESTING THE SENSOR SUITE

Because of the prototype nature of ArduSats-X/1 and the failure of ArduSat-2, the code has never been uploaded to the satellites. Nevertheless, as-if experiments have been carried out on a test satellite showing that the results obtained from the different electronic devices aboard are reliable and ready to be carried out in space.

Seven sensors of the ArduSat sensor suite have been tested, the first six of them exactly the same as those in the original ArduSat sensor suite.

Figure 4. Side view of K'NEX CubeSat

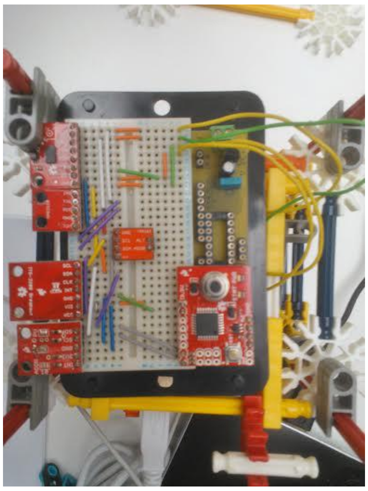

Figure 5. Top view of K'NEX CubeSat

4.1. Luminosity sensor (TSL2561)

Illuminance or ambient light level is a very complex measurement to make because it involves both the human eye's response to color – i.e. frequency – and the concentration of that light. The TSL2561 manufactured by AMS-TAOS is not a true luxmeter, but rather a light-to-digital converter that transforms light intensity to a digital signal.

The device combines one broadband photodiode (visible plus infrared) and one infrared-responding photodiode on a single integrated circuit. Two integrating analog-to-digital converters (ADCs) convert the photodiode currents to a digital output that represents the irradiance measured on each channel. This digital output is sent to a microprocessor where illuminance in lux is derived using an empirical formula to approximate the human eye response. This makes the TSL2561 far superior to simpler photoresistors and photodiodes for illumination measurement.

The human eye has a huge dynamic range, far more than most electronic sensors. Real-world conditions can range from 0.0001 lux in starlight, to over 100,000 lux in direct sunlight. The TSL2561 has features that allow it to handle this huge dynamic range. These settings are similar to a camera; one can change both the sensitivity, which is like an ASA film rating, and the integration time, which is like the shutter speed. Like a camera, you can balance those measurements for the best results.

Illuminance values of a white LED measured by the TSL2561 were compared to values obtained by a Vernier Light Sensor giving percent differences of about 6 %.

4.2. Three-axis accelerometer (ADXL345)

The ADXL345 from Analog Devices is a small, thin, ultralow power, 3-axis accelerometer with high resolution (13-bit) measurement at up to ±16 *g*. Digital output data is accessible through an I²C digital interface.

The device measures the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion or shock. Its high resolution of 3.9 m*g*/LSB enables measurement of inclination changes less than 1.0°. Several special sensing functions are provided. Activity and inactivity sensing detect the presence or lack of motion by comparing the acceleration on any axis with user-set thresholds. Tap sensing detects single and double taps in any direction. Free-fall sensing detects if the device is falling.

To test the accelerometer, the K'NEX CubeSat was put in free-fall and used as a simple pendulum (Fig. 6), giving percent errors of approximately 6% for the theoretical period of the pendulum.

4.3. Digital 3-axis gyroscope (ITG-3200)

The ITG-3200 from InvenSense is a triple-axis Micro-Electro-Mechanical Systems (MEMS) gyro integrated circuit.

The device features digital-output X-, Y-, and Z-axis angular rate sensors or gyros on a single chip with a sensitivity of 14.375 LSBs per °/sec and a full-scale range of ±2000 °/sec as well as a fast mode I²C interface up to 400 kHz. Three integrated 16-bit ADCs provide simultaneous sampling.

To test the gyroscope, the K'NEX CubeSat was put on a turning plate (Fig. 7) rotating at a constant angular velocity. Measured Z-axis values corresponded to chronometer obtained data with percent differences of about 11 %.

Figure 6. Experimental setup to test the 3-axis accelerometer

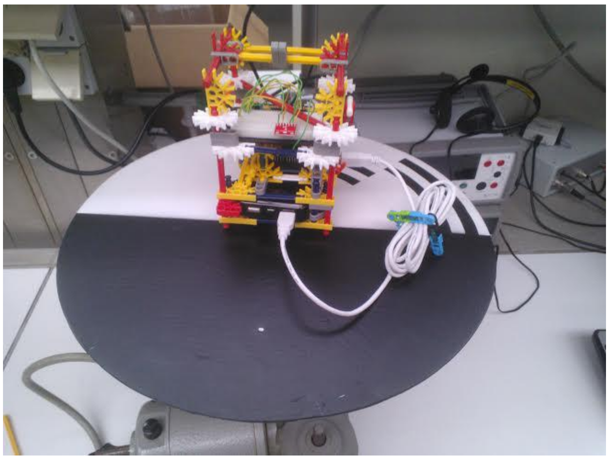

Figure 7. Experimental setup to test the gyro

4.4. Digital temperature sensor (TMP102)

The TMP102 device from Texas Instruments is a silicon bandgap digital temperature sensor, offering an accuracy of ±0.5 °C. The device is specified for operation over a temperature range of -40 °C to 125 °C. Communication with the TMP102 is achieved through a two-wire serial I²C interface.

A temperature experiment was run on the "AS-IF" development satellite, located in Paris, France. A hot and cold cycle were executed in a clean room testing environment that acts *as if* it is a real satellite.

4.5. Digital 3-axis magnetometer (MAG3110)

Freescale's Xtrinsic MAG3110 is a small, low-power, digital 3-axis magnetometer. The device measures the three components of the local magnetic field which will be the sum of the geomagnetic field and the magnetic field created by components on the circuit board. The MAG3110 has a full scale range of ±1000 µT, features a fast mode standard I^2C serial interface up to 400 kHz in fast mode and is guaranteed to operate over the extended temperature range of -40 °C to +85 °C.

Components of magnetic field measured by the MAG3110 were compared to values obtained by a Vernier Magnetic Field Sensor giving percent differences of only 3 %.

4.6. Infrared temperature sensor (MLX90614)

The MLX90614 manufactured by Melexis is an infrared thermometer for non-contact temperature measurements. The device is factory calibrated in wide temperature ranges: -40 to 125 ˚C for the ambient temperature and -70 to 382.2 ˚C for the object temperature.

An optical filter (long-wave pass) that cuts off the visible and near infra-red radiant flux is integrated in the package to provide ambient and sunlight immunity. The wavelength pass band of this optical filter is from 5.5 till 14 µm.

A heat plate has been used to compare values obtained by the MLX90614 with those of an Agilent multimeter, resulting in percent differences of 6 %.

4.7. Geiger counter tube (SEN-11345)

Instead of the LND716 gamma detector from the original ArduSat sensor suite, the USB powered SparkFun Geiger counter SEN-11345 has been used to detect ionizing radiation. One of the main reasons to opt for the latter sensor is the fact that the SEN-11345 itself is equipped with an ATMega328 which can be programmed very easily.

Radiation from a cobalt-60 source measured by a Vernier Digital Radiation Monitor gave percentage differences of 6 % compared to values obtained by the SEN-11345 sensor.

5. UPLOADING TO SPACE

By the time students had to present their results at Hasselt University, a new satellite named Lemur-1 had been launched on June 19, 2014.

Lemur-1 is a triple-unit (3U) CubeSat built by Spire, the new name for company NanoSatisfi since July 2014. The satellite was deployed from the Italian UniSat 6, which in turn was launched aboard a Dnepr launch vehicle operated by Kosmotras. Lemur-1 is in a sun-synchronous low Earth polar orbit with a more elliptical shape compared to the formerly launched ArduSats.

The satellite's primary mission is a technology demonstration of several science payloads. In addition to technology demonstration, Lemur-1 carries two Earth-observation payloads, i.e. firstly an electro-optical imaging system operating in the visible band with a ground resolution of approximately 5 m and secondly a low-resolution IR imaging system with an approximate ground resolution of 1 km.

Although Lemur-1 has been successful sending data from temperature sensors and the magnetometer, no uploads from student experiments have been established.

In April 2015, Spire successfully tested the education payload on a high altitude balloon launch. The company will have several satellites launched by the end of 2015, eventually allowing students to run their experiments. These satellites will head for higher orbits, where it is estimated that the payload computers will be able to operate for 8-12 months before radiation damage becomes a factor.

6. CONCLUSIONS

This manuscript describes a project carried out by two undergraduate physics students during a time period of 15 days spread across 10 weeks. Like a previous project at Hasselt University [1], it shows that in this short amount of time it is possible to write and test valuable code ready for upload to a satellite in a low Earth orbit. The open-source platform Arduino was the base of this project and once again proved to be very student friendly [2].

Unfortunately, so far it has not been possible to upload the code to one of Spire's satellites. Depending on the level of sponsorship, contributors will have access to up to an entire week of time on the satellite to run applications. Nevertheless, experiments being carried out on a test satellite show that the results obtained from the different electronic devices are reliable and ready to be carried out in space.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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