Mechanical Subsystem Description
for
REEL – E

Project
Experimental Gravity Research with LEGO-based Robotics on-board a Stratospheric Research Balloon (xgravler)

part of the
High Altitude Lego Extravaganza (HALE) 2008

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A. The Project

The REEL-E payload, the final implementation of the *xgravler* project, is measuring the g-forces under changing conditions in high altitude environments. This was realized by using the LEGO Mindstorms NXT processor in combination with a 3-axis accelerometer very similar to the one used in a Nintendo Wii Remote (WiiMote) and some additional electronic hardware (e.g. LEGO Mindstorms servos). The idea was crafted after being invited by LEGO to participate and present a proposal for the H.A.L.E. project.

H.A.L.E. (http://www.unr.edu/nevadasat/hale/) was an event "that carried nine LEGO Mindstorms-based payloads into the Earth's stratosphere. At that altitude HALE was above 99.9% of the atmosphere. Two balloons carried payloads from the USA, Taiwan, Luxembourg, Sweden, and Denmark to an altitude just over 99,500 feet. Brian Davis' payload set the world record for the longest NXT freefall at 80-seconds. HALE, to our knowledge, also set the record for the most NXTs flown at once (5 on one balloon and 4 on the other). The balloons were launched on July 29th 2008 form the Nevada desert, close to Reno, U.S.A."[1].

Micro-g is useful for a variety of scientific research areas ranging from crystal formation, biotechnology, medical/drugs research, and fluid physics research to the emerging field of nano-technology. The European Space Agency (ESA) has a database of all ESA funded or co-funded experiments done in micro-gravity during the last 30 years[2].

1. MISSION OBJECTIVE

The experiments done with REEL-E should have generated new data on micro-g generation in high-altitudes. The main purpose of the mission was to check the feasibility of our idea, check if it is doable with such a small budget and also find out how much the acceleration can be reduced by our experiment.

[1] taken from the HALE webpage referenced in the paragraph before

[2] Erasmus Experiment Archive database (http://eea.spaceflight.esa.int/)

2. MISSION OVERVIEW

REEL-E consisted of 2 payloads connected by a tether. The main payload (REEL) had the main microcontroller as well as the main reeling structure, whereas the secondary payload (E) had only a 3-axis accelerometer and some needed additional electronics.
E was dropped from REEL and would experience a short period of free fall, during which it would measure its acceleration with the accelerometer, and then send the data, via a Bluetooth wireless link, back to the main payload.
After a few seconds the secondary payload was reeled in again and the experiment was repeated to acquire a set of measurements that after the mission could be compared and analyzed.

In this document, the mechanical structure for the reeling-up and free fall part of the experiments, which was one of the main objectives, will be described.

B. Mechanical Subsystem

1. SYSTEM GENERAL DESCRIPTION

The main payload (REEL) consisted of the following parts:

- **3 Motors:** for handling the reeling of the tether, the locking mechanism and the triggering of the camera, *see more details later*
- **1 NXT Module:** main processing unit and data storage memory
- **1 Digital Photo Camera:** for taking pictures
- **LEGO structure:** including the reeling system, picture taking module, cradle for NXT, and structure for holding it all together and in place in the box
- **1 Counterweight**: used in the pre-release mechanism to prevent the tether from tangling.

The secondary payload (E) consisted of the following parts:

- 1 **Bluetooth** wireless communication module: for communication with the REEL module
- 1 PIC-based **microcontroller**: for ADC and UART communication
- 1 3-axis **accelerometer**: to measure gravitational forces

2. MECHANICAL STRUCTURE

The first tests showed that the motors are not fast enough at unwinding the tether to actually generate something like free fall in the E-payload. Therefore one of the main features integrated into the mechanical structure is the possibility to reach free fall. To add this functionality to the system, a 3-stage release mechanism was implemented:

1. **Release Stage:** releases (the lock of) the secondary payload, starting free-fall (while still attached to the tether).

2. **Reel up Stage:** reeling the secondary payload back to the main payload, by just pulling the entire tether straight into the main reel.
3. **Lock/Pre-release Stage:** a lock is activated before the tether is unwound which prevents the load from slow lowering; when almost all the tether is unwound the payload can switch to the release stage.

Free Fall & Lock Mechanism

Figure 1 the shows a test-run of the lock and release stage during operations. In (a) the secondary payload (here illustrated by an L shaped LEGO piece) is locked to the box, and the reel mechanism is releasing the tether, which is pulled out of the main payload through pre-release holes by the counterweight attached there. In (b), which depicts the next stage, the lock has been released and the secondary payload is going down, and in (c) the secondary payload has pulled the counterweight all the way to the box and the payload is in free-fall, it stops when the end of the tether is reached.

Figure 1: (a) (b) (c)

The stages during operation: (a) Lock/Pre-release mode, (b) releasing the load & (c) free fall.

Locking

The locking mechanism is based on friction to stop the payload from slowly being reeled down. By unlocking it enables the free fall of the E module. The idea is that the tether is using an inlet to go through a rotatable structure. This bar is rotated several times around its center; the tether will be wound around the bar and friction prevents the tether from moving back through the inlet.

Figure 2: (a) (b) (c)

Locking Mechanism, un-mounted (a), mounted unlocked (b) and mounted locked (c)

In Figure 2 the locking mechanism can be seen. Picture (a) shows the lock by itself (not connected to the structure). It shows the bar and the inlet attached to the side of a motor, which will rotate it around its center when activated. In (b) the lock is attached to the mechanical structure of the system but not locked, allowing the tether to run freely, where as in (c) it is locked and the tether is wrapped around the bar, therefore preventing it from moving.

Reel

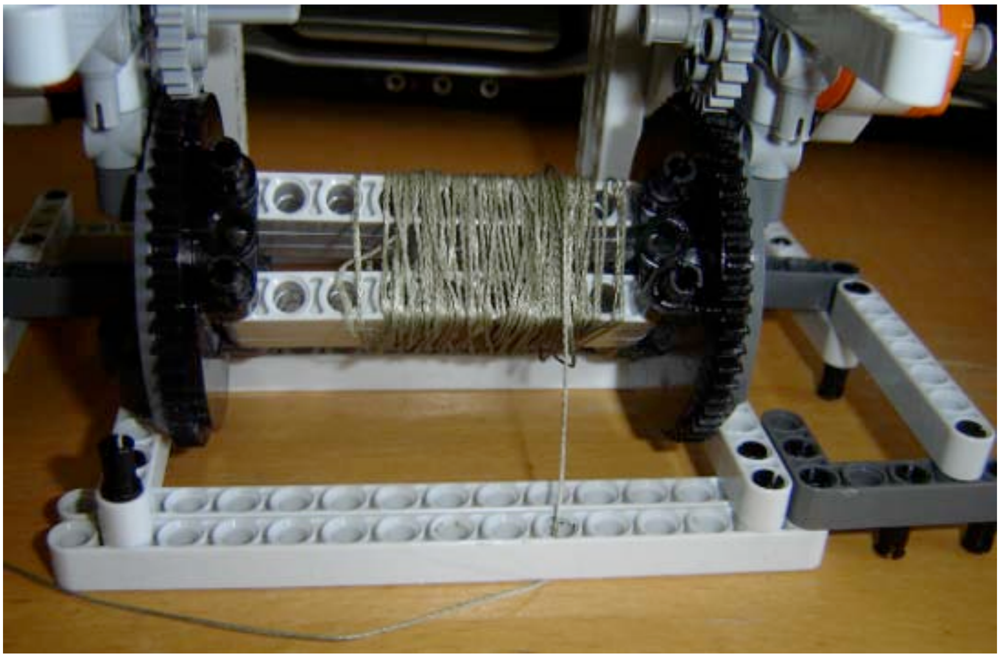

Figure 3: The reel of the reeling mechanism

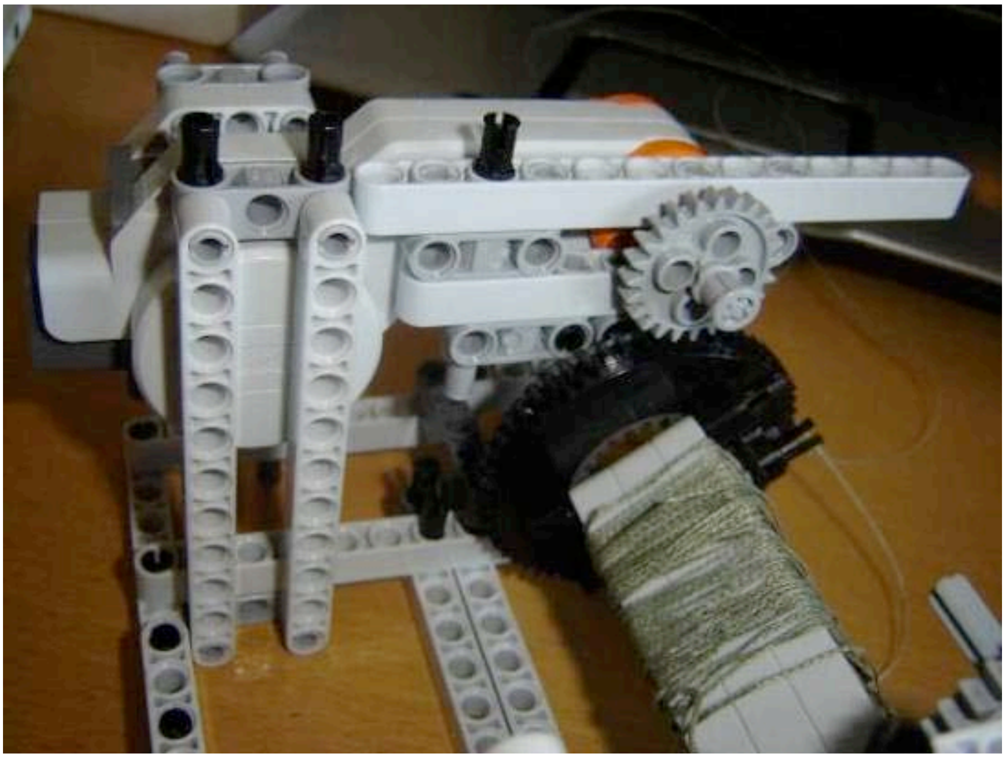

Figure 4: The mounting of the reel with the motors and the supporting structure

The reel is made of LEGO cogs resembling a fishing reel, Figure 3 shows the mechanism separately (not yet integrated with the rest of the system), it shows how the tether, is rolled around the bars connecting the cogs, which make up the main reel. By activating the motors the cogs will start turning and the reel will start rotating, therefore releasing or retrieving the tether.

The main reel is rotated by 2 motors, which directly move 2 gray cogs, shown in Figure 3 and Figure 4. They then turn the black cogs building the suspension of the main reel. The connection of the motors to the cogs and to the whole structure is shown in Figure 4.

Digital Camera

Near the end of the project, it was decided to add a digital camera to try and capture some pictures while the payload was going up. The camera needed a mechanical system to push the button and take a picture. In order to do this a photo shooting system was implemented using the same motor that was used for the locking system, as the Lego NXT cannot handle an extra (fourth) motor. A hole in the insulation was made in order for the camera to be able to take pictures properly.

Figure 5: Camera Hole in the REEL insulation

Figure 6: The camera cradle made out of insulation (left) and the shooting mechanism (both) using the locking-system motors

The picture taking system uses the rotating movement of the locking system to move some worm screws to push the “Power” and “Shutter” buttons of the camera. As shown in Figure 6 the rotating beam coming out of the motor makes the small gray cogs rotate, which in turn create a rotating motion which would move two beams forward to turn the ON and the trigger button.

Press–Before–Launch Button

In order to make things easier for the crew in charge of the launch, a press-before-launch button was implemented. It gives a signal to the software to start the reeling-sequence after a predefined delay. To prevent the button from triggering ahead of time, a LEGO piece was used on the outside of the box preventing it from being pushed by accident.

Figure 7: Press-Before-Launch Button (external and internal view)

Cradle

As the NXT module needed new batteries before launch the mechanical system needed to be able to remove the NXT easily. For this, a cradle was designed to make the module easy to remove and slide back into the system.

Figure 8: The cradle for the NXT

3. THE SECONDARY PAYLOAD – THE E-MODULE

The E-Module consists of a PIC microcontroller, a three-axis accelerometer, a Bluetooth module and a 9V DC battery as depicted in Figure 9. It should deliver the acceleration measurements of the drop tests to the NXT main CPU (in the REEL payload). The accelerometer used is generating an analogue output signal, which is converted via the ADC (Analogue to Digital Converter of the PIC) and sampled by the PIC. The samples are sent via the UART connection of the controller to the Bluetooth module, after a “transmit” command was received via the UART on (from the Bluetooth connection to the NXT).

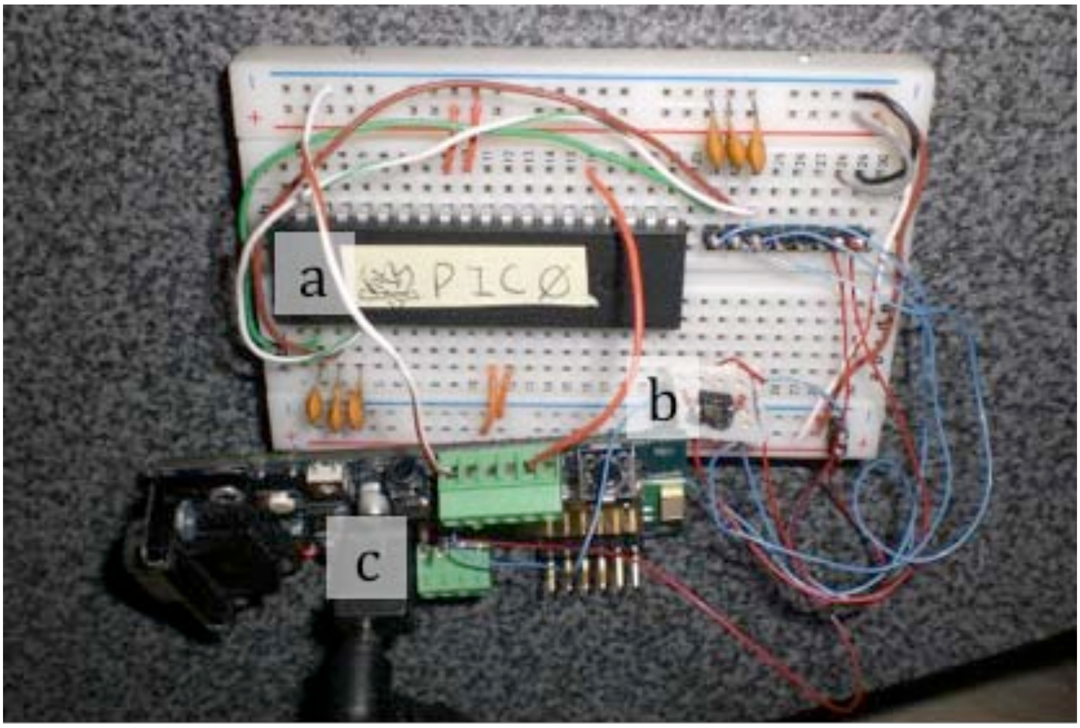

Figure 9: The E module (internals), (a) the PIC microcontroller, (b) the accelerometer, and (c) the Bluetooth/UART module

The Bluetooth module is the bridge between the NXT and the PIC. It bridges by connecting to the NXT via a compatible Bluetooth profile compatible (Serial-Port-Profile, SPP) and providing a connection with the PIC via an UART port; the Bluetooth communication is invisible to the PIC.