Project Results for the REEL-E launch *(part of H.A.L.E.[*])*

xgravler - Experimental Gravity Research with LEGO-based Robotics [SpaceMaster Robotics Team]

Jürgen Leitner[†]
juxi.leitner@gmail.com

David Leal Martínez
david.leal@gmail.com

Graduate Students, SpaceMaster Programme[‡]
Dept. of Automation and Systems Technology
Helsinki University of Technology

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ABSTRACT

This report presents the experiences and results from the **xgravler** project participating in the H.A.L.E. balloon flight campaign in Nevada in the summer of 2008.

1. INTRODUCTION

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 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 was an event that carried nine LEGO Mindstorms-based payloads into Earth's stratosphere. Two balloons carried 9 (5 on one, 4 on the other balloon) payloads from all over the world to an altitude just over `99,500ft`. At that altitude the HALE balloons were above 99.9% of the atmosphere. Brian Davis's payload set the world record for the longest NXT free-fall at 80-seconds. 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, fluid physics research to the emerging field of nano-technology. More information about micro-gravity research can be found at an European Space Agency (ESA) database of all ESA funded or co-funded experiments done in micro-gravity during the last 30 years[2].

1.1 Mission Objective and Overview

The experiments done on *REEL-E* were supposed to generate 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.

The **xgravler** project was implemented using 2 separate payloads, dubbed *REEL* and *E*, connected by a tether and a Bluetooth (wireless) communication-link. The second payload would experience a few moments of free-fall during which the acceleration due to gravitational forces is measured, if some free-fall can be achieved those forces will change to the situation in which it is just tangling along with the first payload. The *REEL* payload releases (drops) *E* and reels it back in. During the free-fall *E* measures its acceleration, and sends the data, via a Bluetooth wireless link, back to *REEL*. After *E* is reeled back up, the experiment is repeated to acquire more measurements, for post-flight analyzing.

The *REEL-E* payloads can be seen in Figure 1; to the left just before shipping and while being attached to the balloon on the right.

2. INTEGRATION

2.1 General System Description

The main payload *REEL*, handling the data processing and reeling, consisted of the following parts: *3 Motors, 1 NXT Module, 1 Digital Photo Camera, the main LEGO structure, and 1 counterweight.* The secondary payload *E*, which measures the acceleration and sends the data back

Figure 1: *REEL-E* after final integration & testing, and being attached to the balloon

[*]High Altitude LEGO Extravaganza, a balloon lauch organized by the University of Reno, Nevada and sponsored by the NASA Space Grant, Energizer, LEGO and National Instruments. `http://www.unr.edu/nevadasat/hale/`

[†]Work partly done while at the Intelligent Space Systems Laboratory, The University of Tokyo, Japan. *The work of Mr. Leitner is supported by the* Austrian Space Applications Program *through its "conceptual research initiative" framework. See more in section 6*

[‡]previously at Kiruna Space Campus, Sweden

[1]Information taken from the H.A.L.E. project webpage

[2]Erasmus Experiment Archive database, published online at `http://eea.spaceflight.esa.int/`

to the main payload, consisted of the following parts: *1 Bluetooth wireless communication module, 1 PIC (micro-controller), and 1 3-axis accelerometer.*

At final integration the system measured `23.5x23x25.5cm` (for the *REEL*) and `7x11x6cm` *(E)*, with the full system (both payloads together) weighting a bit more than 2kg[3]. The payload being heavier than planned was not a problem, since we were informed that there will be a second balloon, which allowed us to include the camera not included in the planning phase but included in the final weight.

2.2 Mechanical Subsystem

The mechanical subsystem consisted of the insulation of the payload, the internal structure as well as the reeling mechanism to release and reel-in *E*. The mechanical structure itself is very similar to other projects flying on balloons but it has one main feature which allows the payload to experience free-fall for a very short time. Another stage (named "Locking/PreRelease") was added to the "Reel-Up" and "Release" stages.

2.2.1 Locking/PreRelease Stage

The locking mechanism is based on friction to stop the secondary payload from slowly being reeled down thus enabling the free-fall. 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, due to the rotation, wound around the bar and friction prevents the tether from moving back through the inlet.

More details about the full mechanical structure can be found in the *Mechanical Subsystem Description*, which is published online at the project website[4].

2.3 Software Subsystem

The software subsystem consists of two main parts, related to the two separate payloads. The software for the *REEL* system was running on the LEGO NXT micro-controller and was using an object-oriented implementation. For this the leJOS firmware was put onto the NXT and the system was programmed in Java.

For *E* a simple C program with some assembler commands was written. This was done in 'quick hack' fashion since the available accelerometer was not providing digital output.

2.3.1 Software for E

The code for the *E* payload is quite simple. It reads the ADC values every given interval (50ms) and sends it to the UART out of the PIC controller. These ports are connected to the BlueRadios BT radio reiver/transmitter which was set to allow connections from the *REEL* module and was passing the data just as if the NXT would be connected to the PIC and communicating to it via a serial bus.

2.3.2 Software for REEL

As already mentioned above the *REEL* software system was developed using leJOS and Java code. The main reason to chose Java was the included Bluetooth library. This allowed wireless communication based on a given standard with the accelerometer. The choices were also limited since no lower-level code for using the Bluetooth module in the NXT were found.

leJOS is a Java-based firmware for the Lego Mindstorms NXJ micro-controller replacing the standard firmware. leJOS, pronounced like the Spanish word 'lejos' for 'far', is a tiny Java Virtual Machine, that includes all the classes in the NXJ API as well as the tools used to upload code to the NXT brick. It offers for example the following: Object-oriented programming, threads/tasks, synchronization and exceptions, all in a well-documented robotics API.

Object-Oriented Approach.
Due to the use of Java an object-oriented, class-using implementation was done. This together with internal leJOS functionality generated a robust system for controlling and observing the experiment. For example, leJOS provides a simple behviour-based approach for simple robot control but the manager classes were not working well for our problem, therefore we implemented a simple `ProjectManager` class by ourselves. It would iterate through the behaviours and hand over the controls to the activated behaviour with the highest priority (i.e. the first in the list). The behaviours represented the different phases the experiment would go through while flown. The behaviors are shown in Figure 3. leJOS provided also other functionalities, for example easy file access and motor control. Classes provided by the leJOS system are shown in orange in the class diagram.

Sequence Control of the Experiment.
The before-mentioned behaviours together with the managing class provided the framework to create and control the experiments sequence.

As can be seen in the sequence diagram (Figure 4) the planned routine is as follows, with a status variable set accordingly:

- After powering the *E* and the *REEL* on the software waits until it receives the input from the "PUSH BEFORE LAUNCH" button. Then the initial waiting phase is started, which lasts for `WAIT_AFTER_START = 3000` ticks.

[3]The final weight was 2050g, which was exceeding the planned weight by almost 35%.
[4]`http://smrt.name/xgravler/MechanicalSubsystem.pdf`

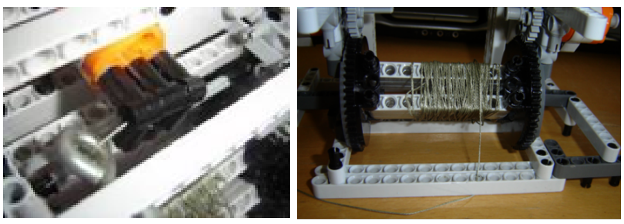

Figure 2: The lock and the reel used on ***REEL-E***.

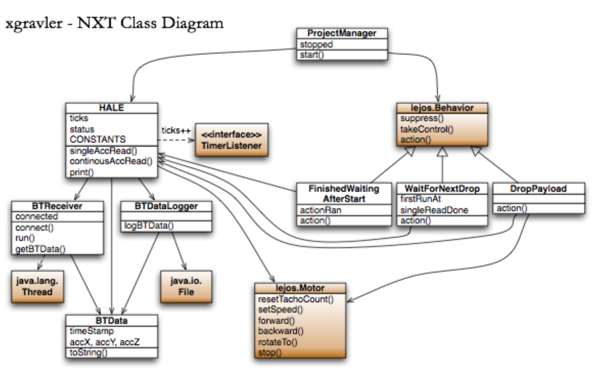

Figure 3: ***REEL*** software class diagram.

- Loop until the `MAXIMUM_RUNNING_TIME` is reached: *(or the payload is powered off)*
  - The payload is then dropped (for this the motors are first run for a few seconds forwards and then the line is unlocked) with continuous measurements of the accelerometer data. The software than waits for `WAIT_AT_BOTTOM = 8` ticks.
  - The motors are run backwards until the *E* payload is reeled back in. The locking mechanism is activated.
  - The system is in waiting mode and takes 5 measurements during the `WAIT_FORNEXTDROP = 300` ticks.

The code for the NXT program can be found on our webpage[5], the code for the PIC is not available since it was partly developed by Luis Guerrero.

3. FLIGHT

The HALE project launched two ballons on July 29, 2008. *REEL-E* was launched on balloon two (dubbed *Energizer*) at about 7:41 a.m. (local time, MET) (which was roughly 50 minutes after the first one) from a latitude of 41.080527° North, and a longitude of 118.706034° West. It reached an altitude of `99 566ft` (= `30347.72m`), touched down again a bit more than 120 minutes after launch and was recovered at around 11:45 a.m. by the ground team.

REEL-E logged `10 765 ticks` (time-stamps), which correspond to roughly 1000ms each and therefore nearly `3 hrs`, recognized `24 drops` of *E*, and it had 2540 readout tries of the accelerometer, which unfortunately all resulted in `NULL` readouts.

[5] `http://smrt.name/xgravler/NXTcode.zip`

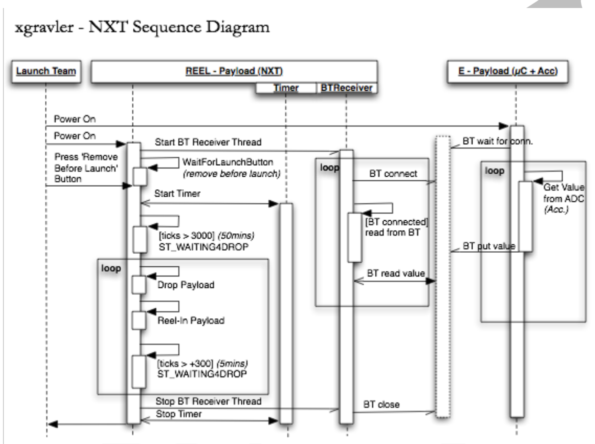

Figure 4: *REEL* software/experiment sequence.

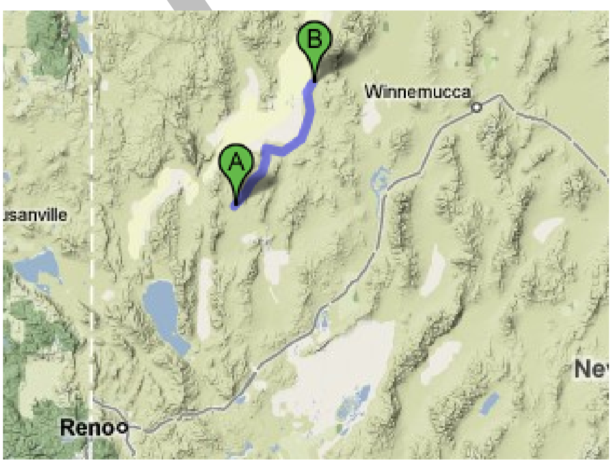

Figure 5: Launch and touchdown location of the *Energizer* balloon carrying the *REEL-E* payloads.

4. EXPERIMENTAL DATA

Unfortunately our payload did experience problems with the communication link between the accelerometers and the NXT chip. Due to the limited storage space and hence limited logging capabilities we could not clearly define where the communication error was rooted. From the data we got we can although say that the mechanical actions were taken and we can say, and verify through visual confirmation, that the mechanical parts worked without major problems[6]

The results we see, which is a null readout for all 3 values for the accelerometer, could have happened due to various technical difficulties. Due to the communication going through various different subsystem the error could have happened in any of the following (or even in multiple systems):

- Accelerometer: *The accelerometer could have not sent any data, due to problems introduced after final tests and integration (e.g. transport and handling)*
- *E*-electronics: *A lose wire or a short on the board could have lead to the readout recorded. These electronics in* E *were needed for the accelerometer and GPS module.*
- Power: *A power disruption or a flat battery, especially in* E *could have led to the readouts observed*
- Bluetooth: *The network layer itself is not prone to errors, a link failure or transmission errors could have occurred. Another possibility is that either one of the sides could have lost or terminated (due to e.g. timeouts) the connection.*
- Software: *The software running on the micro-controller or the one running on the NXT (Java), although extensively tested, could have introduced errors to the data before it was written*

[6] *Some minimal wear and usage was seen on various parts, but most of those were already seen during testing and they were only marginally extended during the actual operation.*

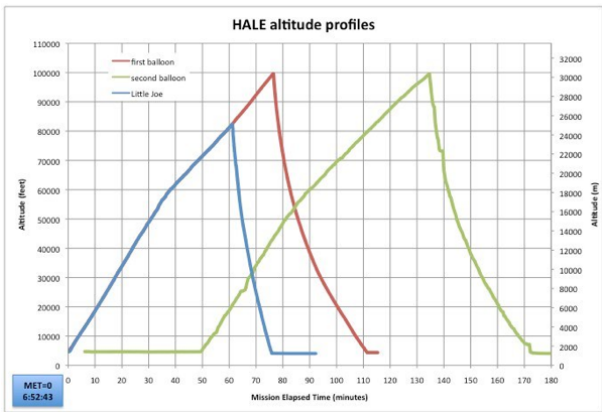

Figure 6: Altitude profiles of the balloons, *REEL-E* was flown on the second balloon (yellow-green).

5. CONCLUSIONS

Although we could not acquire useful data on micro-g generation on balloons, we did learn a lot about balloon projects and generally what it takes to build something that actually flies into (near) space. Our project was mainly done using hands-on approach and using materials available to almost everyone. We would like to further investigate this matter and applied for the 2009 BEXUS launch campaign. Currently 9 students are working with the *SpaceMaster Robotics Team* on the follow-up mission named *reel.SMRT*[7] to finish the latest design review slated to take place in June.

The main focus was on the feasibility and the mechanical structure. The REEL-E boxes survived the full campaign, which also means that the LEGO structure was strong enough to survive more than 20 drops of the *E* module.

The use of logging during operations became very clear to us and this is the only time we reached the limitation of the NXT controller. The storage capabilities are just too little for having a decent log file, which would also allow us to have done a better bug-tracking beforehand and an easier approach to finding the fault in post-launch data evaluation.

The project itself takes quite an effort and a lot of different (unexpected) things need to be dealt with but the feeling on launch day and the emotions involved are something very hard to describe and we can only recommend to do and experience it by yourself! All in all we are very happy that we were part of H.A.L.E. and were able to send our payload into near-space.

6. ACKNOWLEDGMENTS

We want to thank everybody who was involved and helped with the HALE project. We want to especially thank *Prof. Eric Wang* from the University of Reno, NV and his team for organizing the whole project and *Steven Canvin* from LEGO for inviting us to participate. We wanna thank the following people for the help they gave us: *Barbara Leal* (insulation and construction), *Luis Guerrero* (PIC programming), *Hector Gonzalez* (help with debugging and troubleshooting and providing the accelerometer) and SEMEX (for providing the Bluetooth modules). Their help and input was greatly appreciated. We also want to thank all sponsors of the HALE project.

6.1 Austrian Space Applications Program

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APPENDIX

A. ADDITIONAL INFORMATION ABOUT THE *SPACEMASTER ROBOTICS TEAM*

The *SpaceMaster Robotics Team (SMRT*[8]*)* consists of graduate students enrolled in the *Joint European Master in Space Science & Technology (SpaceMaster)*[9] programme. They are currently studying in their second year and finishing their master thesis at the Helsinki University of Technology (TKK), Finland, where they work on robotics and automation for space systems. These studies were preceded by a semester at the Julius-Maximilians-University Würzburg (JMUW), Germany and one semester in Kiruna, Sweden, at the Space Campus of the LuleåTekniska Universitet (LTU), which is co-located with the Swedish Institute of Space Science (IRF).

They developed a robot for a student design competition at the 2008 Human-Robot-Interaction conference held in Amsterdam, The Netherlands, participated in a Field and Service Robotics Competition (part of the curriculum at TKK), participate in the 2009 BEXUS launch campaign and are currently planning their participation in the 2009 IJCAI conference in a multi-robot teaming challenge.

[7] `http://smrt.name/bexus/`

[8] `http://smrt.name/`

[9] `http://www.spacemaster.eu/`