Orbital Education Platform: Introducing Orbital Robotics to Secondary Education

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Abstract. In this paper, the development of an Orbital Robotics educational prototype platform is presented, consisting of a hardware-developed physical system and an accompanying set of curriculum-based lessons (IB Physics curriculum) that target upper secondary students (16-18 years old target group). The platform was the outcome of a joint project between the European Space Agency and the National Technical University of Athens. The students use the hardware interactively, consisting of a bespoke space-emulating table and small satellite mockups. The lessons are inquiry-based and are structured so that the students are actively engaged in the learning process, according to a learner-centric approach. During the lessons, this platform allows students to acquire knowledge of the dynamics of space systems, as well as of the environmental conditions and physical constraints that characterize on-orbit operations. Students are able to manipulate the space robot (satellite) mockups performing basic tasks such as docking and landing, or grasping space debris. Additionally, a smartphone application has been implemented to allow the interaction with the platform, via a dedicated User Interface (UI).

Keywords: educational robotics, orbital science, physics, Secondary Education, IB Curriculum, ESA Education

1 Introduction

The use of robotic applications in education is increasing rapidly, after the realization of the various benefits they can bring to the learning process. These include both the motivational and pedagogical value provided by a direct hands-on and interactive experience, that places the learner at the centre of an educational journey of discovery; during this journey the learner's critical and innovative thinking is stimulated, leading to a deeper understanding of physics and technological principles, [1]. A basic advantage is that it engages the students in synthesis and engineering, both of which are missing from many secondary education schools' curricula.

Currently, the approach to STEM (Science, Technology, Engineering and Mathematics) Education in Europe is still based extensively on passive learning (theoretical knowledge transmitted through lecturing); to a large extent, it still lacks the practical, inquiry-based and learner-centered dimension required for students to become an active part of the learning process. This would lead to an efficient integration of theoretical knowledge into an experimental process of learning.

Inadequate STEM teaching in school is considered by several recent European studies as one of the key factors responsible for the relative decrease of young people's interest in STEM-related studies and professions in western countries today, [2].

Under this scope, the Educational Project *OrbiLEP: Orbital Levitation Educational Platform*, aims to provide an active-learning tool for physics and technology, specifically in the fields of orbital mechanics and space robotics. The development is taking place at the facilities of the Automation and Robotics Laboratory (ARL) of ESTEC, ESA's European Space Research and Technology Centre in the Netherlands.

The project, aimed at the upper secondary school target group (16-18 years old), includes the development of an educational space environment emulator using air levitation (planar space emulator platform) and a set of space robot (satellites) mockups, which can float on its surface (for the rest of this work the term mockup will be used for the robots). A set of lessons, which for the prototyping phase are based on the International Baccalaureate's (IB) Physics guide, accompanies the emulator. An earlier implementation of this work can be found in [3].

2 Pedagogical Targets

The challenge of the lessons is to raise student interest and engagement in STEM subjects. This is achieved by guiding the students through the application of physical principles in the space environment - a context usually fascinating to students. For example, as the teacher demonstrates a physical phenomenon, such as rolling a ball on the table which stops at some point, s/he asks the students to describe what they saw and to explain what happened. In this way, the teacher can introduce Newton's Laws and friction. At the same time and in order to highlight the difference between space and Earth dynamics, the teacher shows a video of a satellite on orbit, of landing on an asteroid, and of docking between two objects in space.

During such a lesson, the students are called to describe both what they saw and to notice the differences that exist between the bodies' behaviour on Earth and on orbit. In this way, the students start to think about what they have just experienced. Meanwhile, the teacher keeps stimulating the active learning process by searching for the rationale behind a space mission. Essentially, the methodology developed seeks to trigger all the learning routes that students with different personality types choose to follow into perceiving, acting and decision-making.

2.1 Lessons' Content

The topics addressed through the lessons are based on the IB Physics Curriculum. The first lessons address basic physics principles and build up to discuss more advanced concepts. Alongside with the physics laws, in principle, the lessons' content will raise awareness on space in general and space missions: motivation for space missions, basic mission analysis, robot interaction in free-floating environments, docking, space debris and trajectory design (in a gamificated final lesson).

3 Pedagogical Approach

The pedagogical approach followed in this work consists of deploying a set of inquiry-based lessons that gradually build up the knowledge and the skills needed to complete the final lesson, which makes use of principles introduced in the previous ones. The learning process and the lessons, whose goal is teaching physics through the students' experience of a two-dimensional representation of space dynamics, implement cognitive neuroscience research and developmental psychology known as MBE (Mind, Brain and Education) Science, [4]. Through an interactive use of the physical platform, the learning process also introduces a hands-on experience. Methodologies are being implemented that are derived from the belief that the human brain constantly searches for meaning and seeks patterns and connections [5], while the main focus remains on reaching a deep understanding of the basic school physics concepts that lie in the fundamentals of space and orbital robotics.

The lesson plan is based on the 4MAT Theory [6], a use of the extensive research on brain-based teaching methods. The implementation of the 4MAT Cycle into teaching engages the students through all the steps of the learning experience. The movement around the 4MAT cycle represents the learning process itself; it is a progression from: (a) experiencing, to (b) reflecting, to (c) conceptualising, tinkering and problem solving, to (d) integrating new knowledge with the self.

The development of the lessons takes into account the different personality types (according to the Myers Bricks' type indicator [7]); all personality types are equally respected. The 16 distinctive personality types result from the interactions among the preferences: (a) *favorite world*: whether one chooses to focus on the outer world or in his/her inner world -Extraversion (E) or Introversion (I), (b) *information*: whether one prefers to focus on the basic information he/she takes or he/she prefers to interpret and add meaning -Sensing (S) or Intuition (N), (c) *decisions*: when in dealing with the outside world, whether one prefers to get things decided or he/she prefers to stay open to new information and options -Thinking (T) or Feeling (F), (d) *structure*: in dealing with the outside world, whether one prefers to get things decided or he/she prefers to stay open to new information and options -Judging (J) or Perceiving (P) [8].

In more detail, the *sensing types*, perceive what is happening around them making logical connections in their mind, opposite to the *intuitive types* who use their intuition. Some take decisions based on their logic and others on their emotions (*thinkers* and *feelers* respectively), while for some, the decision making process is more difficult than for others (*perceivers* and *judgers* respectively). Personality types also account for the different channels one uses to express oneself: for the *extraverts*, the source of energy is external, while for *introverts* it is internal.

Overall, the lessons suggest a pedagogical approach that follows a pattern that provides the students the opportunity to acquire the knowledge in the way that is the easiest and most preferable for them, and are meant to favour the development of their communication skills, since most of the work is carried out in teams. The students are led through interactive activities into the basics of physics principles and of their specific phenomenology in the space environment. Every lesson is structured around a themed assignment, or mission, that makes use of orbital robotics and which has to be accomplished as a team. At the end of the assignment, the students have to present the process they have run through, the results of their mission, and the outcome of their teamwork in which every member had specific tasks. Then, under the guidance of their tutor, they have to engage in an open discussion to share the trade-offs made, the challenges overcome, the lessons learnt both individually and as a team, etc. Through this process, we expect the students to gain a first-hand understanding and direct experience of the curricular subjects introduced, an experience of project management and teamwork, and the development of their communication skills, self-confidence and awareness in a learning environment that respects the wide variety of personality and learning types.

4 Platform Design Objectives

Assuming lab infrastructure is not present, a central objective of this work was to create a hardware platform that is affordable for schools and suitable for classroom environments. However, this introduces many challenges to the design process. The implementation should be of a low-cost, low-weight, low-energy, portable and easily mountable system, while allowing the students to reach the learning objectives of each lesson through active participation. In more detail, the physical platform design requirements includes:

- Emulation of the behaviour of space robots in a 2-Dimensional environment: resemblance to the effects of zero-g environment on bodies on orbit, in 2D;
- encouragement student interactivity;
- small-sized, low-cost, low-weight, low-noise and safe for use in a classroom environment;
- sustainability and reusability by different student 'generations'.

These requirements and constraints led the design decisions and trade-offs made during the prototype development. The final layout, the selection of materials, and the functionality of all components have been developed in accordance with the educational scope of the project. As the construction of a 3D emulator is out of the scope of this work, a planar space environment emulator allowing for an effective two-dimensional representation of satellite motion in space was chosen. The emulator was based on the concept of a frictionless air-hockey table, allowing the mockups to hover on top of it, in zero-gravity and with zero-friction.

The table had to provide working space for two mockups, such that a number of interesting operations could be performed on its surface. The mockups had to be lightweight and with a small footprint, and be capable of performing basic space tasks resembling to real satellites with a good degree of fidelity. A great effort has been put into reducing the minimum power and mass budget requirements of both the mockups and the table.

5 The Planar Space Emulator

5.1 Concept and High Level Requirements

From the early stages of the development, one of the main challenges was the design and construction of a system able to emulate zero-gravity environment conditions, while at the same time taking into account all project requirements and the physical limitations. The chosen design incorporates the benefits of planar simulators already developed in the USA (MIT, Stanford), Europe (U. of Padova, U. of Southampton, NTUA, etc.) and Japan (Tohoku University), scaled down to a low budget and to a simplified system that does not need compressed air. Planar emulators using air bearings are perhaps the most versatile and least expensive systems for emulating zero-g environment, and allow for repeated and thorough testing of control algorithms and verification of dynamics [9]. They require minimal preparation compared to other emulation methods and are easier to upgrade and adapt to alternative scenarios.

These systems usually use a thick and massive (e.g. granite) or fragile (e.g. glass) material as the surface on which the air bearing space emulators hover. However, these are not suitable for a classroom environment. Moreover, the direct use of air bearings would have introduced a considerable weight, cost and complexity to the mockups due to the required payload for gas or air supply. Therefore it was decided that the platform would follow the example of planar emulators using air bearings, although this time the method of hovering would be reversed: the air flow would come out from the table instead from the mockups. For this reason, the planar educational space emulator developed follows the air hockey principle consisting of an assembly made of additive manufacturing (AM) parts.

5.2 Implementation

The platform is designed as a modular structure consisting of small modules. The modules are glued together to provide a total working surface (top surface of the upper part of the assembly) with dimensions 380x300 mm2. The module's upper part is a modular box-shaped element -more parts can be glued together in order to increase the total surface, with custom-made nozzles and holes on top, which produce the air film. Each box-shaped part has provision for attaching a fan at the lower part or a cap (sidewall) in case of no fan. The lower part includes the mounting point for the fan or cap, the mounting element between upper and lower part and the support truss. This way the structure is provided with sufficient support and distance from the ground, while using the least possible amount of material.

In Figure 1, four modules are connected to form a larger orthogonal working surface; the modularity of the design allows for an increase of the working surface area with the addition of more modules.

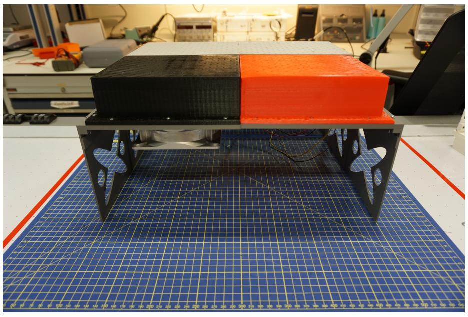

Fig. 1. A working surface (table) obtained by assembling four modules.

It is to be noted that the students are not aware of the fans-enclosed-in-nozzle mechanism used to simulate the thrusters function on space objects. This alternative in design was used in order to reduce the mass budget of the platform and its complexity. The use of small compressed gas containers (usually of Carbon Dioxide CO2) with tubes and valves, is another option that was taken under consideration, however overpasses the satellites mass limit set by the lifting capability of the air levitation platform.

5.3 The space robot 'satellite' mockups

The mockups represent either the bodies orbiting in space (space debris) or satellites. The observation of their movement and the interaction with other objects on the planar space emulator environment are meant to allow the students to study the dynamics of orbiting bodies.

The goal is to make the mockups as small and light as possible. This will enable them to be lifted by the film of air created by the platform, and at the same time decrease the minimum required dimensions of the upper surface due to additive manufacturing limitations. The fact that no pressurized air has beem used by the platform, created various challenges to overcome during design.

In principle, there should be no contact between the bottom surface of the mockups and the upper surface of the platform. However, a small mass misalignment on the mockup could cause an instantaneous impact during its movement. Moreover, aerodynamic friction forces develop within the air gap, resulting from the motion of the mockup over the platform.

Additionally, since resemblance with real satellites is required, translational and rotational motion of the mockup must be generated by thrusters. This would have introduced the problem of using compressed air and a pneumatic system on board, increasing the mass and power budget, not to mention the complexity. Instead, small nozzle-enclosed fans were selected, which look realistic both in appearance and function. To emulate thruster/rocket propulsion, the fans operate in a pulse-like mode, significantly reducing the inertial issues that occur. In addition, their mass is minimal, making the previous assumption reasonable. The first system implementation employs four fans, as shown in Figure 2; while more fans can be added to allow a full set of motions.

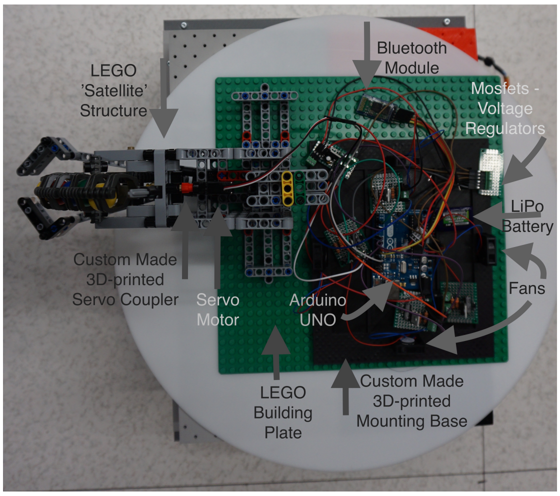

Fig. 2. The satellite mockup - top view

5.4 Remote Control

The fans are connected to an Arduino® system, which is an open-source physical computing platform based on a simple microcontroller board [10], controlled remotely via an android smartphone application and Bluetooth.

6 The Platform Exploitation

The platform (air levitation generator and the satellites mockups), which will be used by the students and for the needs of each lesson, can be upgraded with more LEGO® components (on the satellites mockups), during the execution of each exercise. Except from the First Lesson, which will be introductory, the platform is expected to be used in various ways. The Lesson Plan consists of 10 Lessons, which can be excecuted either individually or in a particular order. The concept is that each Lesson builds up on the theory delivered by the previous Lesson, as well as by the structure of the satellite mockups.

Firstly the satellites are used in their primary form, for demonstration purposes only (the friction and absence of friction effect on objects). Then the students are complying the 'thrusters' and observe the satellites' behaviour in a free floating environment. Later a LEGO® arm is mounted on the satellite LEGO® base, which the students are either manipulating with the use of the Android Application, in order to move it, or to shoot LEGO® balls, by assembling and attaching the LEGO® shooter on the arm. Following that, the students are called to build an identical LEGO® satellite mockup, and try to execute tasks between the two satellites, the final one being docking (a LEGO® mechanism with magnets is attached on the mockups for the needs of the docking exercise).

The two last lessons are of higher difficulty. On the 9th lesson the students attach any kind of rope to the balls of the LEGO® balls shooting mechanism, and shoot the ball inside a cavity to 'retrieve' it, thus demonstrating a way of debris removal. In the last lesson, the students manipulate the 'thrusters' through the application and have to go from point A to point B through a maze, while finding the optimal path. The team to reach the final point in the least time is the winning team.

7 Discussion and Future Work

Talking about space always fascinates young students. Through the active discussions and activities taking place in this course, students are led through an introduction to the space environment, orbits, applications of space technology and robotics, and their impact on modern society. They also learn how to work in teams while improving their communication and presentation skills. It is foreseen that a detailed manual will be produced on how the lessons can be replicated in a classroom environment.

8 Conclusion

This paper presents a proposal of an Educational Platform on Orbital Robotics. Using a set of mockups, able to float on a planar space emulator platform, the authors aim to reach OrbiLEP's educational objectives through a lesson plan which focuses on the active interaction of the students in the learning process. The students are led through a set of inquiry-based lessons, and are introduced to concepts of orbital mechanics and space dynamics. This is achieved through a 2-dimensional representation of the zero-g, zero-friction space environment, made possible through the manipulation of the mockups hovering on a space emulator. Additional fine-tuning of the design of the planar emulator platform and of the mockups is intended, as well as the study of the results of the implementation of OrbiLEP in Upper Secondary Education classrooms. Through this platform, the authors intent to increase the awareness of public in STEM.

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