5.2 Robotics-based educational tool for an airplane servo-loop model

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The proposed educational tool is an example of robotics-enhanced learning project for students, which originated from the TERECoP project. As some other examples approaching "Project Based Learning with Robotics", this project was developed for the training needs of the pilot training course in the University of Pitesti, Romania, which took place during the three years of the project implementation.

5.2.1 Teacher guide

Title of the activity: Learning on airplane servo-loop control by building a robotic demonstrator.

Introduction: This example addresses a complex topic and is appropriate for several educational purposes on general curricula, as well as for vocational disciplines. The key teaching issue addressed by this learning activity is focused on model and the students build themselves the learning tools.

Goals: The goals of an airplane servo-loop model as educational tool are divided into three classes: cognitive objectives, skills and attitudes as follows:

- *Cognitive objectives* include basic knowledge obtained in the area of airplane engineering focused on specific issues from mechanics and mechanisms. The understanding of the aircraft control problem involves, also, knowledge acquisition on related issues in the field of flow dynamics and aerodynamics. Basic knowledge on sensory (ultrasound transducers) and telemetry (ultrasound-based impulse range finder) are expected to be acquired with the proposed robotic model. The key cognitive goal of this example is the systemic understanding on the control issue for a body with six degree-of-freedom (particularly for an airplane). The strategy of control involves knowledge on cybernetics (error-based automatics, feedback concept, multi-loop control). Finally, this example helps the trainees to perceive the effect of fins and, also, helps the trainer explain the effect of combined rudders' deflection.

- *The skills* expected to be acquired with the robotic demonstrator for airplane servo-loop system involve both, creativity and ability to implement servo-loop controllers. The proposed application will urge the imagination to build specific mechanisms for aircraft serving with the elements from Lego kit.

- *The attitudes* expected to be developed with this project are also very relevant for trainees. They have to reason in terms of technical correctness, realism and feasibility of the proposed technical solutions. Comparative and critical thinking, as well as optimal reasoning, are the typical mental skills related to the attitudes to be developed with this example. Building a flying machine, either a real one or a model, is a question of responsibility, accuracy and reliability of technical solutions. Finally, this example creates a positive attitude for collaborative work and co-creation.

The example “NXT/Robotics-based educational tool for an airplane servo-loop model“ was created for a large age group of trainees, typically from 15, including adults, too.

Technical details: The activities in this example are organized modularly. Each module is provided in the face to face session of 2 hours. It is recommended to plan the entire course (all modules) during one or two weeks. The prerequisites are depending on the group of trainees-the age and their level of familiarity with Lego Mindstorms educational kit. For groups that are not familiar with the educational toolkit, an optional introductory session on Lego Mindstorms/NXT kit including software development tools is provided. In the following table the basic guidelines of the teaching process are presented.

Name of module (duration of session)	Activities carried out during the session
1. Introduction (2 hours)	1.1. Identifying the *learning needs* and *goals*, *expectations* and possible learning difficulties. 1.2. *Challenging and motivating* the trainees. 1.3. *Harmonizing the heterogeneous group* of trainees in terms of their background and experience. 1.4. Providing a generic course on *robotics as educational tool*- constructivism, constructionism and project-based learning.
2. Engagement (2 hours)	2.1. Identification and presentation of the scientific problem. 2.2. Trainer defines the problem of *airplane servo-loop control*. (Exposes the principles and gives the explanations referring to real life examples).
3. Getting started with robotics(*) (2 hours)	3.1. Dividing the group of trainees into *smaller work teams*. 3.2. Providing the *introductory course* (*) about Lego Mindstorms/NXT robotic toolkit. 3.3. Trainers challenge the trainees to imagine differ-

	ent constructions and the associated programs that could play the role of demonstrator and *help them in learning* different emerging disciplines.
4. Designing the project with robotic toolkit (2 hours)	4.1. Trainer and trainees identify the technical requirements for specific mechanisms. 4.2. Trainer assigns each specific mechanism to be developed by a group. 4.3. Trainer supervises the running of tasks paying a special attention to the following issues: - How the trainees are dealing with the particularities of the toolkit, encouraging an enthusiastic, uncritical attitude among trainees. No criticism of ideas! - The ideas developed and contributed by every one of the trainees, during the session, taking notes of any such ideas. - Relevant ideas that come out of the session.
5. Demonstration (2 hours)	5.1. The outcomes from the previous module are integrated by the students in a robotic demonstrator tool for the *airplane servo-loop controlling*. 5.2. Trainer performs different scenarios with the demonstrator in order to exemplify how the aircraft guiding systems work. 5.3. Trainer helps the trainees to adjust or to refine the software application on NXT controller in order to realize the effects.
6. Course evaluation (2 hours)	- Trainer makes a synthesis by summarizing trainees' ideas, as they emerged. - Trainer makes a comparative analysis of the ideas that were noted during the session. - *Structured questionnaires* should be applied immediately after the end of the course, simultaneously to all participants. <u>Note</u>. *Regarding participants that worked individually, the answers provided express their personal opinions and views.*

	- Conclusions.
(*)Introductory course on Lego Mindstorms/NXT (2 hours-optionally/ if needed)	Trainer presents the guide lines of the work with the use of slides on the following issues: - Robotic Lego Mindstorms demo (use of Lego Digital Design, pictures of already constructed robots). - Software development tools. a) Trainees work effectively in small groups proceeding *step by step to get familiarized* with the robotic Lego kit and software development tools. b) Trainees explore the *mechanical parts* focused on their function and practical lab exercises on assembly work, (lab activity, groups, 30 minutes). c) Trainees browse the NXT *brick menus*, (lab activity, groups, 30 minutes). d) Trainees explore the Lego Mindstorms software development tools and robot *programming*, (lab activity, groups, 30 minutes). Note. *Each trainee receives a copy of Lego Mindstorms software programming tool to study independently the help section of the functional blocks.*

Rationale of the teaching approach: The overall approach in this example is interdisciplinary, but the activities involved here can be implemented in many disciplines: Computer Science, Technology, Mathematics, Science and Engineering. The specific fields from Engineering are specially addressed in Control engineering, Flight mechanics and Aeronautics. The airplane servo-loop demonstrator is fully developed and is ready for teaching purposes. The aircraft control problem has a significant degree of complexity that requires knowledge from different disciplines.

Working in small groups, the trainees build different robots, making their own programs in order to demonstrate several rules, principles and techniques from physics, mathematics and informatics as follows:

- The Newtonian principles applied to a body with six degree-of-freedom;
- The rule of *forces composition* and the couples of forces working;
- Geometry of triangle and elementary trigonometry;

- Acoustic waves reflection and propagation;
- The principle of *closed-loop control* and feedback;
- Basics of *programming*, for instance: relational operators, conditional instruction, loop control, etc.

Other topics are also highlighted, for instance: *levers law*, *kinematics*, *reduction gear*, and so on.

The issue of airplane guiding by automatic control of its rudders can be understood in the context of preliminary knowledge on aerodynamics. Some possible students' difficulties can be avoided by using the robotics based educational tool for the airplane servo-loop demonstrator. We propose an innovative teaching approach with the use of the robotic construction to emulate an aircraft. Building a mechanical structure with feasible mechanisms to actuate the airplane's rudders challenges the students to find innovative solutions, other than those usually used when they build wheel-driven mobile robots.

The proposed scenario takes into consideration the key teaching issue addressed here: *learning by demonstration through building the demonstrator*. So, the experimental environment is defined by the idea of learning precisely by building the learning tools. Building the learning tools, in this case by using robotics, is performed by the following tasks in an experimental environment, as depicted in Fig. 5.2.1.

According to the constructivist and constructionist approach, the activities with students are organized in the following methodological: Engagement stage, Exploration, Investigation, Creation and Evaluation. As a matter of fact, to organize a project in robotics, the content of the individual stages are highlighted as follows:

- In the *engagement stage* students are provided with the open-ended problem and get involved in defining the project. This stage requires the identification and presentation of the scientific problem. Students work as a class putting their ideas into a question format as follows:
    - If I am piloting a plane, which command or commands should I actuate in order to: lift, dive or turn the aircraft?
    - Which are the elements that command effectively the airplane?
    - How do the forces that move effectively the aircraft work?

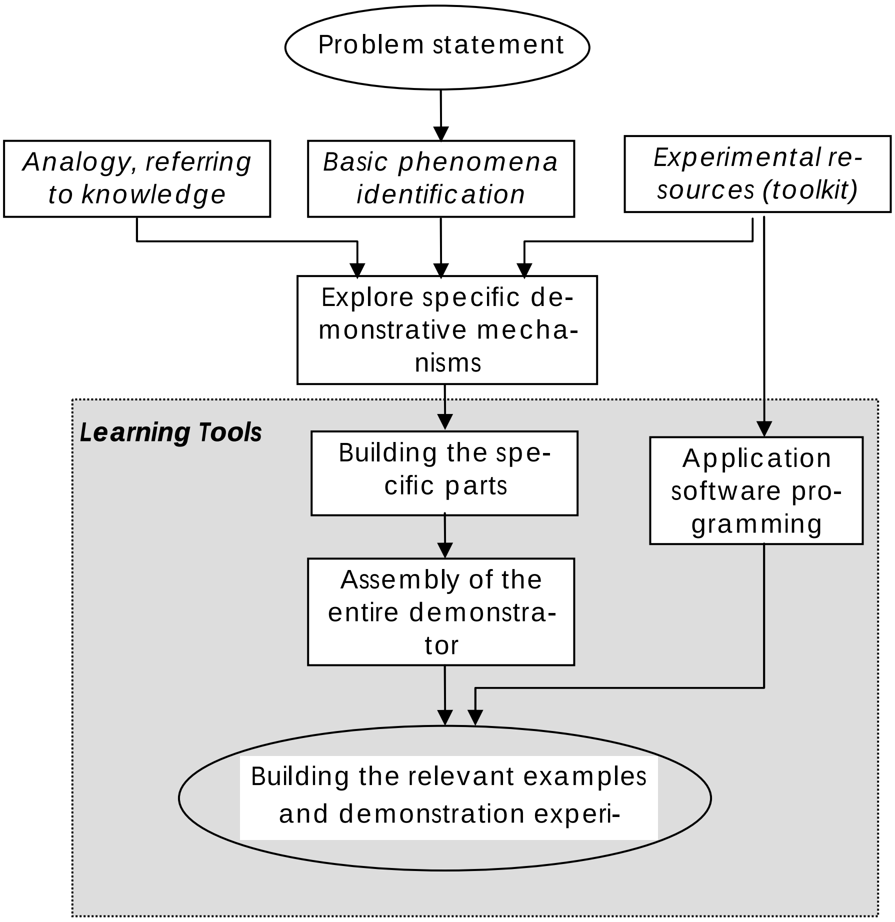


Fig. 5.2.1-*The learning environment*

- In the *exploration stage,* students get familiar with educational Lego Mindstorms kit, controlling devices and software, make hypotheses and test their validity in real conditions, provide initial ideas and preliminary solutions. This stage is performed in a flexible manner, depending on the level of students' familiarity with the educational toolkit. If the students are well introduced in the technology of Lego Mindstorms robotic toolkit, this stage will be adjusted adequately. On the contrary, if the students see for the first time the Lego Mindstorms kit, a special introductory session will be provided. In this case, the trainees should work effectively in small groups proceeding step by step to get familiarized with the robotic Lego kit and software development tools.

- In the *investigation stage*, students search for resources and investigate alternative solutions. Students reconsider the problem and the different issues arisen during the engagement stage, based on their experience gained through the exploration stage. In addition, the students involve their preliminary knowledge, their beliefs and own experiences via analogous reasoning and intuition to imagine specific demonstrative mechanisms. At this stage, students, in collaboration with the teacher, formulate the driving questions which link with the learning goals of the project, as they were defined: cognitive goals, skills and attitudes.
- In the *creation stage*, students share and combine their artifacts, synthesize 'solutions' to the project, reflect on their initial ideas. Students present their work in class and then work on the synthesis of a final product, including the artifact and the software, and reach a common proposal for the project. The result is the assembly of the final demonstrator. This work may lead to similar solutions, but, also, to innovative proposals. In this stage, the relevant part of the learning tools is achieved. Moreover, the demonstrator for airplane servo-loop control becomes itself a learning tool supporting related experiments and future developments.
- In the *evaluation stage*, the trainer and the students make together a synthesis by summarizing trainees' ideas, as they emerged from the preceding stages. Now, students share their ideas, products at class level, argue about their final proposals and evaluate them. Alternative solutions are also presented at class level and evaluated based on the driving questions raised in previous stages of the project (stages of engagement, investigation). All the solutions noted during the course are subjected to a comparative analysis on strengths and weaknesses. At this stage, students should critically judge their work, express their opinions and compare their works. The evaluation stage is considered a conclusive lesson rather than an assignment. In order to obtain a measure of the learning efficiency, with this example, some *structured questionnaires* could be applied immediately after the end of the course, distributed simultaneously to all participants.

5.2.2 Fully developed example

The fully developed example, based on an educational tool for an airplane servo-loop demonstrator, is presented here in terms of technical and methodological principles.

The educational tool is briefly described with main emphasis on the function of the proposed robotic construction and the teaching contribution: the questions, the problems, the experimentations and the investigations that students can perform with the suggested demonstrator. The entire educational purpose is defined by questions such as: "How is an airplane piloted?", and "How the aircraft can be automatically controlled?"

The problem statement starts with the presentation of the basic notions on the airplane's movement according to three-degrees of free rotations, which are the subject of control, as depicted in Fig. 5.2.2.

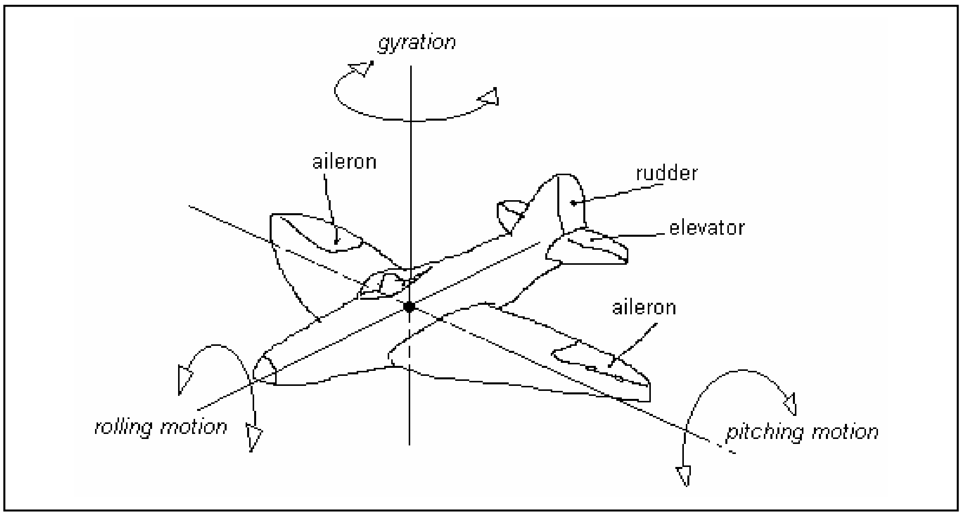


Fig. 5.2.2 *The airplane and basic controlled movements*

The next step refers to the connection between rotations and the three-dimensional displacement of the aircraft. The dependency between the three controlled rotations around the aircraft's center of gravity and the translations along the three axes are explained in terms of aerodynamic effect on the fin-rudders, as depicted in Fig.5.2.3.

Under these circumstances, the trainees should have clearly in their minds the cause-effect relationships that govern the evolutions of the airplane. The main relationship is between the *propeller thrust* and the *longitudinal driving* that defines the airplane's lifting and all the related aerodynamic effects. The propeller thrust is controlled by the pilot via the gas-throttle.

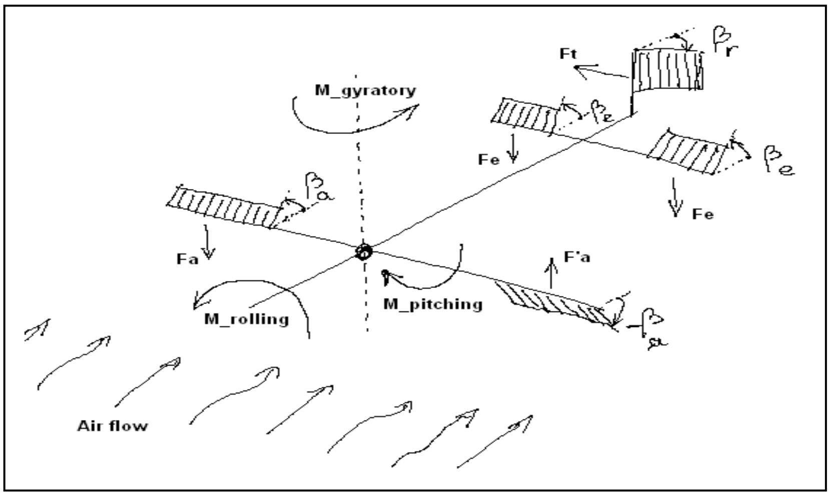


Fig. 5.2.3 *An intuitive draft on rudders' effects*

Table 5.2.1. *Synthesis of the cause-effect relationships governing the airplanes evolution*

Cause		Effect			
Pilot's command	Rudders' state	Translation	Rotation	Aircraft's evolution	
Handle (stick) right	Aileron right: up-deflection, Aileron left: down-deflection	Lateral	Rolling	Lean over on the right side	Banking to right
Rudder bar (pedal) right	Tail right deflection	Lateral	Gyration	Turning to right	
Handle (stick) left	Aileron right: down-deflection, Aileron left: up-deflection	Lateral	Rolling	Lean over on the left side	Banking to left
Rudder bar (pedal) left	Tail left deflection	Lateral	Gyration	Turning to left	
Handle (stick) forward	Elevator down deflection	Vertical	Pitching	Diving	
Handle (stick) backward	Elevator up deflection	Vertical	Pitching	Climbing	

Based on the rationale described above, in the next step, the airplane servo-loop control is introduced, which, in fact, is a basis of an automatic pilot. The task of the autopilot is to maintain a prescribed flight altitude and, possibly, to avoid air collisions of the aircraft. In this example, the servo-loop control system includes sensors, servo actuators, feeds, comparators and signal references. There are two separate main control channels in this case, as depicted in Fig. 5.2.4.

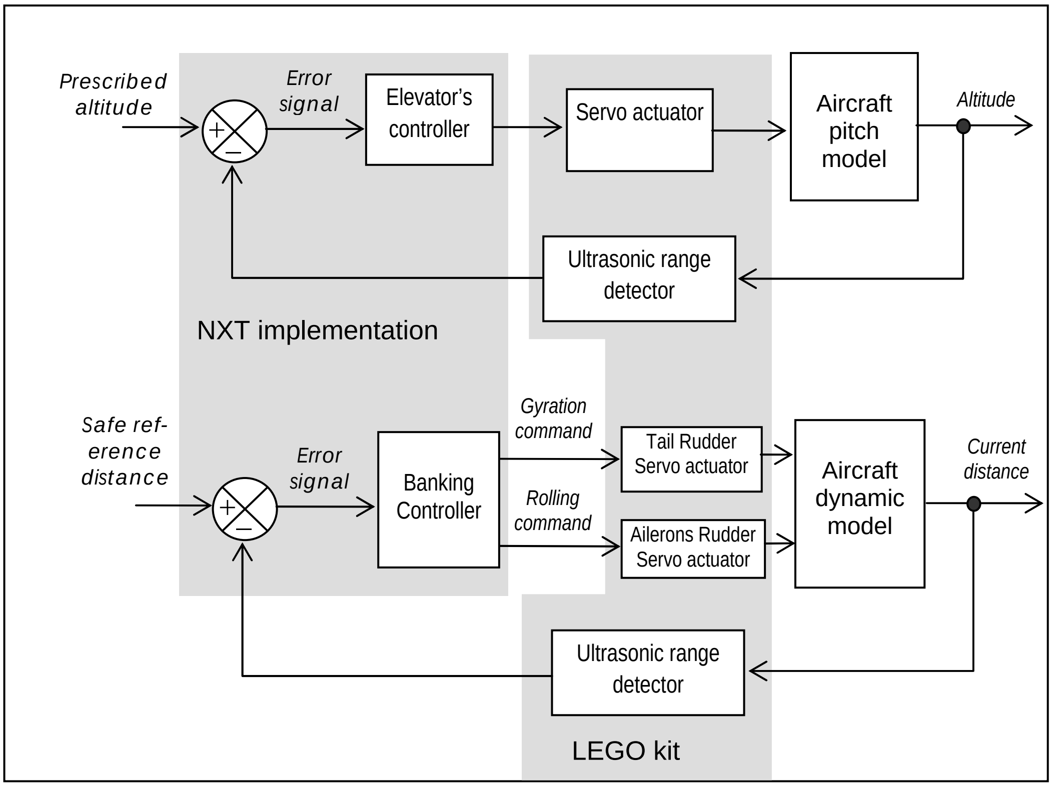
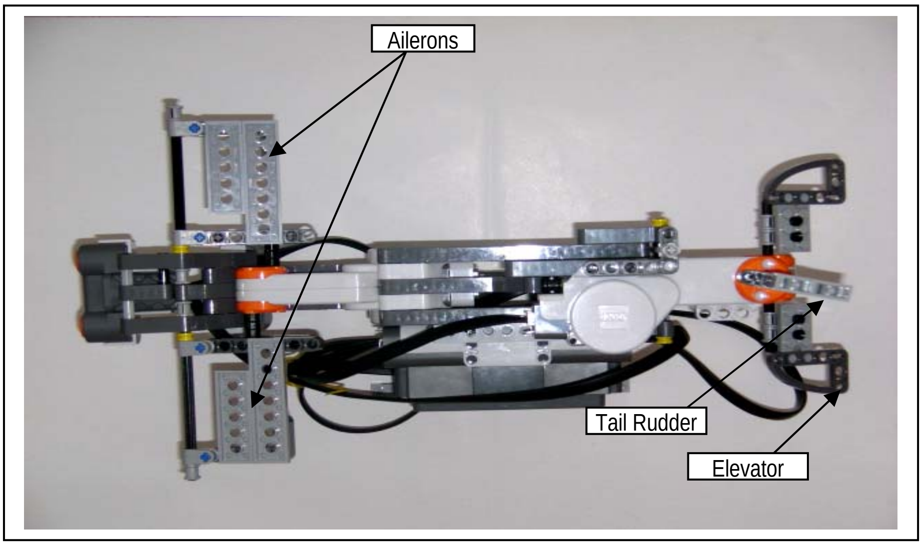


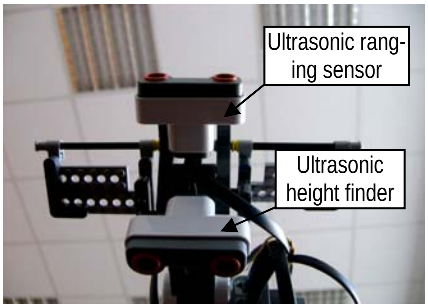
Fig. 5.2.4 *Block diagram of the control and the parts that can be implemented with Lego Mindstorms toolkit*

The following paragraphs are dedicated to the constructive details of the NXT Lego kit, based on the educational tool named demonstrator. Figures 5.2.5 (a) to (d) provide some annotated pictures of the demonstrator's mechanical structure, including sensors and the NXT brick.

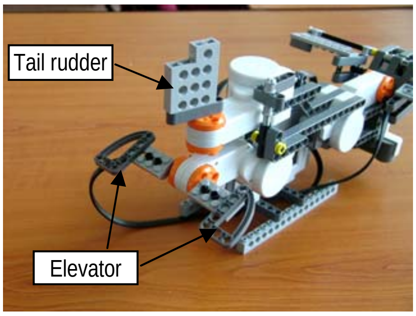
The demonstrator is programmed to emulate the control of an airplane by highlighting the cause-effect relationships during the following scenario: keeping a safe altitude and avoiding any obstacle that is heaved in sight, in a certain prescribed range. The NXT brick was programmed according to the above mentioned tasks. The control algorithm reflects the principle of closed-loop adjustment



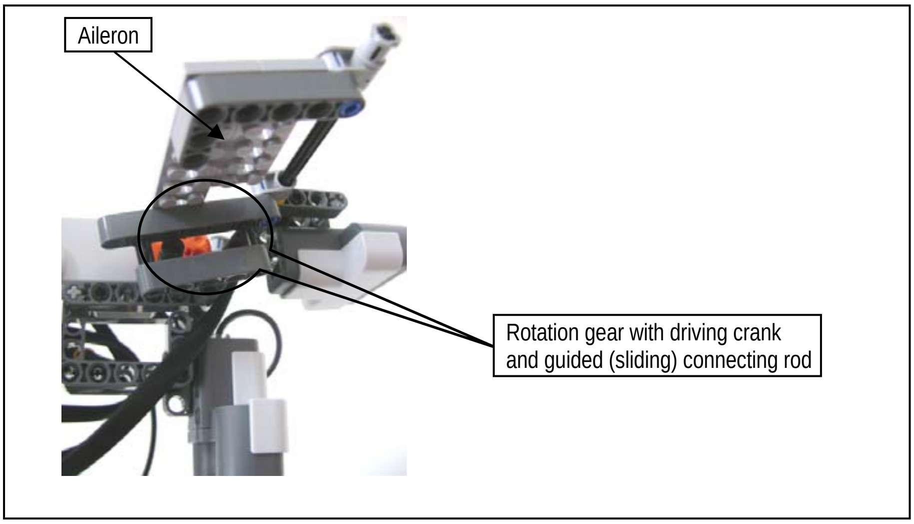
(a)The Aircraft's LEGO robotic replica



(b) A front side bottom-up view of the demonstrator



(c) The back side view of the dem-onstrator



(d) The details of the aileron driving mechanism

Fig. 5.2.5 (a, b, c, d) *The demonstrator*

An effective software implementation of the demonstrator is presented in Figure 5.2.6. The two main control channels introduced in Fig. 5.2.4 are implemented using LEGO Mindstorms education NXT software involving the common palette of programming blocks. The result is the introduction of three distinct controllers into a single program. The altitude controller is designed as an independent one, but the banking controller consists in two coupled controllers for both: the gyration and the rolling. This is because, as well known, the correct banking evolution imposes the correlation of the aircraft's gyration with its rolling.

An important part of the automatic servo-loop control system is the ultrasonic sensors that play the role of range detectors (for the danger altitude and the frontal collision). For practical reasons, the ultrasonic sensors are set up for ranges less than 0.8 meters. The motors of the servo-actuators are programmed to execute rotations up to 30 degrees in both senses.

Let us note that the demonstrator presented here is not a mobile robot. It was designated as an educational tool to be maneuvered by the trainer during the demonstrative scenario according to the learning purposes. Figure 5.2.7 presents an instance demonstrating the reaction of the model in case where safe limits for both distance and truth altitude are violated.

A typical scenario for demonstration can be described as follows: The trainer puts the demonstrator on a table in such a position that the ultrasonic height finder sensor is beyond the table's edge catching a signal reflection from the floor.

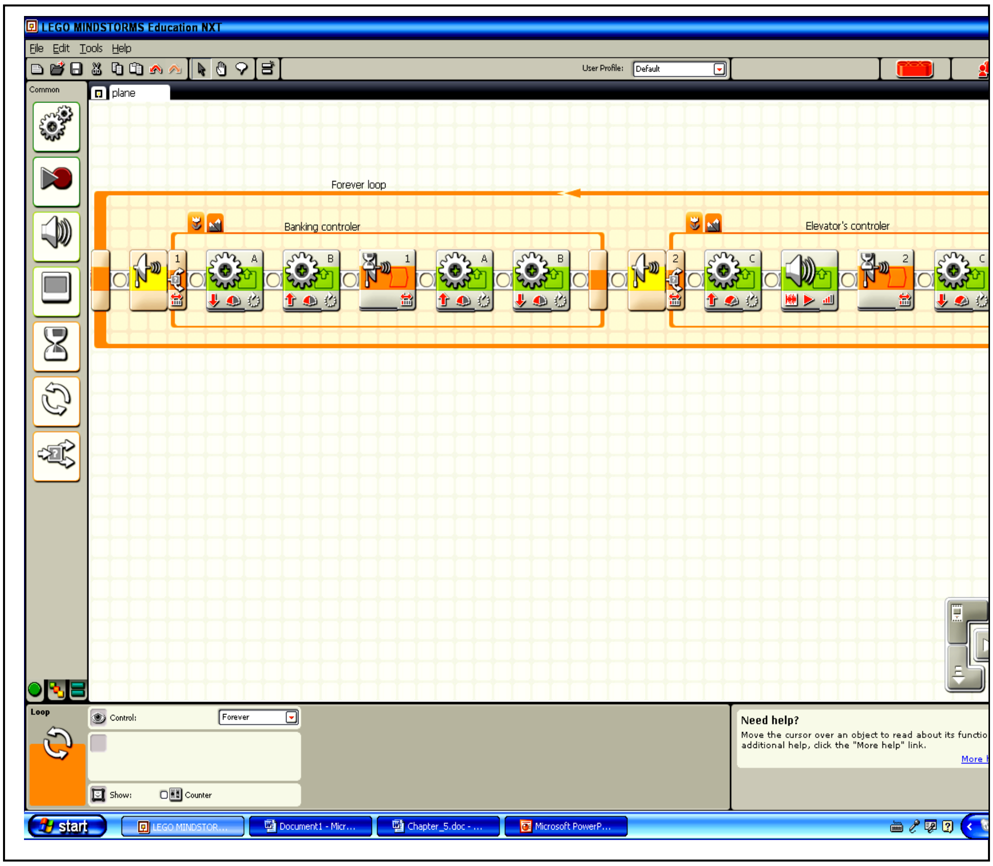


Fig. 5.2.6 *An example of control implementation*

In this position, the NXT program is started and the servo systems should not react. If any sensor detects an obstacle (for example, hand presence) in front of it, the demonstrator exhibits the appropriate reactions by deflecting its own rudders. The same effects can be highlighted if the trainer takes the demonstrator in his hand simulating a flight-path and approaching different obstacles in the class (walls, floor, etc.).

5.2.3 Final comments

The demonstrator proved its usefulness as: a *learning object* and a *learning tool*. From the constructivist approach, building the demonstrator was a challenge. The result is an advisable learning tool in the area of aircraft. Some constructive limits have been discovered in terms of learning object regarding the certain possibilities to joint the LEGO parts.

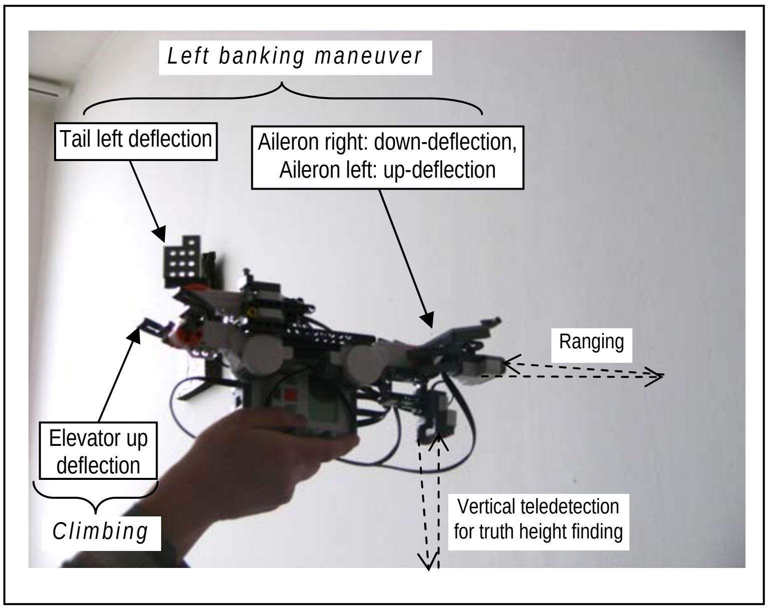


Fig. 5.2.7 *An instance of demonstration with annotated effects*

Other limits concern conceptual issues, such as processing capabilities of the NXT unit. In a real aircraft's system of control, the different tasks are concurrently executed, whereas our demonstrator is able to run three control-loops just sequentially on a single processor. An improved version of the demonstrator can be developed using, for instance, three NXT units.