

Robot Competition as a Teaching and Learning Platform

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Abstract: Field Robot Event is an annual student competition for small field robots. A Field Robot project has been seen as a motivating challenge for project-based learning as it results to a working prototype. In Finland the team has consisted of students from different major subjects (mechatronics, automation and agricultural engineering) and interdisciplinary educational goals have been set: 1) to let students apply theoretical knowledge in practice; 2) to teach team working skills; and 3) to get acquainted with robot design. This requires well-planned student guiding and teaching. Dividing the team into separate groups makes schedule keeping hard, decreases working motivation and hinders learning from each other. Dividing education into consequent work tasks enables schedule follow-up and learning evaluation. Too much freedom leads to less learning and a decreased work motivation. Detailed robot specifications have enabled the students to focus on the essential work. Robot building project has been found to be a good platform for learning technology and practising theoretical skills studied in other courses.

Keywords: education, robots, project-based learning, automation

1. INTRODUCTION

The Field Robot Event is an annual competition for small field robots, mainly intended for student teams. A student team from Finland has participated the Field Robot Event six times during the years 2005-2010 (Honkanen et al. 2005, Telama et al. 2006, Maksimow et al. 2007, Backman et al. 2008, Kemppainen et al. 2009, Pentikäinen et al. 2010). Every year a new student group is formed and the group starts to build the robot more or less from scratch. The technological approach has not been to miniaturize an existing agriculture implement, but rather to suggest completely new field operations that could only be carried out by small robots. High interdisciplinary educational goals have been set every time and the student teams have consisted of students from different technological areas. So far 44 students from Finland have got experience in building a small agricultural field robot to the competition. Instructors have remained more or less the same over years.

Researchers argue that learners generate knowledge by solving complex problems in situations in which they use cognitive tools, multiple sources of information, and other individuals as resources (Resnick, 1987). Project-based learning can be described as teaching by engaging students in investigation. The project requires a problem that serves to organize and drive activities and these activities result in a final product that addresses the driving question. The problem may not be so constrained that the outcome becomes

predetermined, leaving students with little room to develop their own approaches (Blumenfeld et al. 1991). Previous "hands-on" and discovery learning attempts in the 1960s were not very widespread, one reason being insufficient attention to the nature and extent of teacher knowledge and commitment (Blumenfeld et al. 1991).

Students often are resistant to tasks that involve high-level cognitive processing and try to simplify the demands through negotiation (Doyle, 1983). Consequently, project-based education is not likely to work unless projects are designed in such a way that, with teacher support, they generate and sustain student motivation. Teachers need to a) create opportunities for learning by providing access to information; b) support learning by providing instructions and guiding students to make tasks more manageable; and c) assess progress, diagnose problems, provide feedback, and evaluate overall results (Blumenfeld et al. 1991). Based on experience in education Field Robot teams, it can be said that the project sets even higher demands for teachers than for students.

This paper describes the evolution of our education methods related to the Finnish Field Robot project teams. The main goals have remained the same: 1) give students the opportunity to apply theoretical knowledge in practice; 2) teach team working skills in a technologically heterogeneous group; and 3) to build a robot from scratch and to get acquainted with mobile robot subsystems. After university level theoretical studies it is interesting for students to build

something that must actually work and finally put the result into test in the competition.

2. FIELD ROBOT EVENT AS A COMPETITION

Field Robot Event is an annual outdoor robot competition, intended mainly for student teams all over the world. The Field Robot Event has been organized since 2003 in the Netherlands (Wageningen University) and Germany (hosted by various universities). The challenge is to build a small autonomous robot that is able to navigate and do various tasks in maize (corn) field.

The environment (maize field) naturally limits size of the robot; the maize plants are seeded in regular rows with 75 cm spacing. The event consists of various tasks. Usually the basic task evaluates navigation capabilities in between crop rows where the rows may be curved. In the second task robots must perform advanced navigation at the headland of the field, such as “choose the fifth row to the right and go back”. Other tasks involve detecting weeds and destroying them, finding holes, or even co-operating with other autonomous robots. Finally, there is a freestyle task where each team may demonstrate a special beneficial task their robot can do, and the jury evaluates the demonstrations.

The tasks and rules vary every year. Number of participating teams has varied during the years 2005-2010 in the range of 10-20 teams.

3. TEACHING

3.1 Agricultural technology education in Finland

A brief description of agricultural and technical education in Finland is needed to explain the interdisciplinarity of the team. The University of Helsinki (UH) is the only institution giving master's degree education in agriculture in Finland. In the department of Agricultural Sciences, the major subject Agrotechnology focuses on giving a broad view of technologies, measurements and research methods related to farm processes and environment research. As the agrotechnologist is meant to act as an interpreter between agronomists and engineers, the education does not include deep insight in any specific engineering branch. On other hand, Aalto University (former Helsinki University of Technology) is arranged into faculties and departments focusing on engineering fields such as automation or

mechatronics but not in conjunction to any specific field of application. In some specific application areas courses are organized but there are no courses on agricultural automation or agricultural machines at Aalto University.

In order to form a successful Finnish team for Field Robot Event a joint team is needed. The team usually consists of students of Agrotechnology (at UH), students of Mechatronics (at Aalto) and students of automation and control (at Aalto). This approach gives an obvious opportunity to interdisciplinary learning from the team partners but it is not likely to happen without close and well planned student guiding and teaching.

3.2 Challenges for teachers

Three aggravating issues must be emphasized: 1) the students have very varying background knowledge and skills; 2) the two campuses lie 20 km apart from each other; and 3) the project group must be kept in schedule.

During the first three editions, the team was composed of students of automation technology and agrotechnology. The background knowledge differed a lot. The education of automation and systems technology contains high level mathematics, physics and computer programming courses as well as applied mathematics like signal processing and dynamic systems, but no courses on how to design complicated systems. On the other hand the education of agrotechnology contains no courses on computer programming and only a few superficial courses on machine design.

As the students came from two universities, both located in Helsinki area, but 20 km apart from each other, the interoperation was resolved by dividing the team so that students of agrotechnology concentrated on building the chassis and mechanics and students of automation technology concentrated on machine vision, navigation, sensors, electronics and computer software. This approach did not produce as much interdisciplinary learning as desired and the team remained bipartite.

As said, one of the major challenges for the teachers has been managing the scheduling. Every time the project has started on September or October, preceding the year of the Event. The students are keen on thinking that “no hurry, there are 9



Figure 1. Robots built by a student groups, from left: SmartWheels (2005), Demeter (2006), 4M (2008), EasyWheels (2009), Turtle Beetle (2010)

months to finish this” and explaining beforehand just how much effort all subparts will require has been difficult. Strong worded letters from the previous team members to the successive ones have made this a bit easier; a message from a student to another student is taken more seriously.

It is clear a field robot that performs adequately in the competition can be built in a very simple way, as we have seen over years. This makes level setting of education challenging. For example FRE 2005 winning robot, μ Callum (Joosten et al., 2005), was quite simple and straightforward compared to the robot the Finnish team had built (Honkanen et al., 2005). Generally “simple is better”, but we have not seen the simplest algorithms, sensors and computing to meet the educational requirements for students of automation technology. Thus we have always set the level of complexity much higher than perhaps would serve the competition, and hence developed a quite sophisticated AI. In the first years this was problematic as sophisticated algorithms resulted in lots of parameters and usually there was not enough time to test all the algorithms and tune the parameters carefully.

The importance of tuning was recognized as the major problem restricting the success in the competition time after time. Therefore a very detailed tuning procedure has been intensively emphasized to the latest three teams. A figurative reference to Formula 1 race weekend was introduced for the student group: the teams have prepared very carefully the plan for the whole weekend, for Friday testing, for Saturday qualifying and for Sunday race – and there are pre planned roles and tasks for each team member and the test runs are carefully planned. In our case, we demanded that the tuning procedure of each parameter had to be specified and documented simultaneously with the algorithm development and programming. This way all the work targeted to the competition site, where all the testing had to be carried out in just one day, was planned in detail beforehand. Tuning and testing are crucial parts in product development, and here advanced algorithms require emphasis.

3.3 Guiding vs. teaching

The academic advisors’ role amongst the Finnish team was not very clear during the first years. The uncertainty related to dividing duties was partly caused by the fact that the Field Robot event was only one-year-old and the rules did not give clear guidelines for advisors. On the other hand, taking a student team to this type of a competition was a new experience to the advisors, too.

After the first edition (Honkanen et al. 2005), it was clearly recognized that much improvement was needed in the team work practices. It was concluded that better results require a more structured and outlined robot development process. At the same time the trade-off between the performance of the robot in the competition and learning by trial-and-error was recognized. Handing out specific instructions and/or giving out the old robot may result in improved success in the competition but there is a risk of spoiling the students’ chance for innovative solutions.

The innovative aspect in robot building was previously considered important but experience showed that too much

freedom lead to neither a good learning experience nor success in competition. As the Finnish team instructors have got more experienced after the first time, certain specifications for a robot have been given out as a starting point. For instance, it has been specified by instructors that “the robot should have four wheels, diameter of tires over 15 cm, camera on top and maximum driving speed should be 2 m/s”. By defining some technological functions known to be important for a successful robot, the student team can in fact be guided to find their own way to solve the given problems.

During the recent years we have split the role of teachers in half. The autumn semester is used to teach basic skills by using prepared exercises or tutorials and the teacher will meet students once a week; the role is clearly a teacher. During the spring semester teachers act partly as project supervisors, partly as technical assistants to help solving the hardest technical problems (like mystical communication problems) which prevents working towards the project goals. Based on feedback from the students, this has been found to be a good solution.

The skills to be taught during the autumn semester are chosen to cover subjects that the students have not met in their prior studies and which are important in robot building. One branch of prepared exercises is microcontrollers and how to use them with sensors. A set of six exercises form a “microcontroller school”, Figure 2. These exercises have resulted in great results and good feedback; nowadays these exercises are given even for students in other project work courses and there is demand to extend these exercises to many more specific courses.



Figure 2. Students doing prepared microcontroller exercises.

3.4 Project management tasks

A project such as Field Robot includes lots of learning in building a functioning robot with all subsystems and participating in a competition. This brings many different duties and there is plenty of work for every team member. The common challenges involve team integrity, roles inside the team and scheduling work among the members. As the competition is international, also project funding, budget, marketing, PR and other non-technical duties must be carried out.

3.5 Towards a competitive robot

The most optimal way of education seems to depend on the student’s personal character. During the period 2007-2008 the students were rather competitive. That year the exercises

on autumn were designed so that the teacher gave clear instructions to build a simple version of each algorithm type (machine vision, signal processing, and navigation). The basic versions were known to work satisfactory but not necessarily optimally. The student team was given the task to first program the specified algorithm, but then also develop a competing algorithm which they had to invent by themselves (in some cases some clues were given). Finally students had to compare the performance and find out which one worked better. This was found to be a powerful way in education: students could immediately get involved into a problem but it also gave the opportunity to apply creativity. Finally, in the 2008 competition there were two competing algorithms for almost all functions and the final decision of which one was the best was done at competition field just one day before the event. However, this kind of approach requires enough resources (students and time) in order to function – in our case it worked as this was done in autumn semester.

During the concept creation process the students of mechanical engineering have used 3D CAD modeling to create virtual prototypes. The feasibility of the mechanical solutions could be evaluated without building a real robot and time and money was saved. On the other hand students need guidance in the virtual prototyping phase. We have found that students have the tendency to model some details with great precision but more important mechanical properties related directly to the functionality of the robot seemed to gain less attention. In the early prototyping phase the structure shape changes dramatically and it is inefficient to model fancy details which may be excluded from the final solution. This fact was recognized by the instructors after the first years and the efficiency of the prototyping phase has been increased by defining different levels of precision of the virtual prototyping.

At first the 3D models must be very simple and sketch the ideas only. It is fast to create models based on different ideas and the 3D models can be used to visualize the ideas to other team members. Once the basic functional principle is chosen the mechanical feasibility of the structure can be evaluated with a more detailed model. In this model the functionality of the mechanism can be validated and calculations for e.g. mechanisms can be made. In the final phase the components satisfying the mechanical constraints are chosen and the essential features are modeled. By having a dimensionally precise model of each component, computer aided manufacturing and CNC machines can be used in the manufacturing process.

4. ROBOT TECHNOLOGY

Building a robot requires several technologies; incorporating mechanics, mechatronics, software, control, signal processing, machine vision and other computational algorithms. Robot's price is one competition factor and it is hard to find parts with both high quality and low price. Therefore e.g. sensors have been very similar throughout the competition history, which has strongly directed education. On the other hand, low level electronics is one essential part of building a mobile robot and therefore it is necessary to include also those parts in education.

Signal processing, navigation and position/state estimation has been increasingly done with Matlab/Simulink. During last three editions, all position estimation and navigation along with all calculations (excluding machine vision) are done with Simulink. Focusing on one good tool keeps the education concise and most of the students know the tool from the other courses. In product development more advanced tools with rapid prototyping capabilities are more and more important in the future.

C++ code generated from the Simulink model is used for real time computing. For tuning and component testing purposes, the simulation model of the robot together with control system runs in Simulink. After tuning it is easy to deploy code just by pressing a button and connecting signals to real signals in the runtime computer. As this phase is more fluent in the development process compared to traditional software development, there is more time to concentrate developing algorithms and tuning the parameters. Some teams have developed also a visual simulator that was connected to Simulink kinematic environmental model and in that way it was also possible to simulate the camera image. Simulating robot behavior enabled evaluation of chosen technologies before building the hardware in the short project timeline.

4.1 Mechatronics

As students did not have design and construction skills of miniature mechanics and mechatronics in the first year, it was decided to use parts of radio controlled (RC) cars. Good properties in RC cars are that they are cheap and replacements are easily available, but on the other hand the quality and durability are not so good. Existence of backlash, hysteresis and elasticity in steering is not making development and tuning of navigation algorithms easy. Also as the RC car parts are designed to support weight of 1-2 kg, and if a weight of 10-15 kg is put there, this causes tire implosion, which causes plenty of friction to make steering on place, which leads using more powerful steering servos, which results using more powerful batteries and so on more troubles are caused. Over years, less and less RC parts are used to make a robot. Later on more and more mechanical parts of a robot are manufactured by team, differentials are from high-end model cars and steering servos are connected to steering blocks with custom parts. In the last two editions the locomotion is based on axle modules, see Figure 3.



Figure 3. Students are solving a communication problem, axle modules on the right.

4.2 Computing environment

As robots need sophisticated algorithms and some algorithms require reasonable amount of computing power, during the first four editions the solution was to put a laptop computer onboard. Advantages in this approach are good processors, integrated energy system (batteries), easy-to-access debugging environment (keyboard, display), integrated communication system (WLAN) and possibility to use advanced development tools. However, there are also disadvantages: unnecessary components, such as display, cause weight, cooling may be problematic, battery charging has to be made with computer and desktop operating system may not be stable enough. In the last two robots embedded computers are used, with Windows Embedded CE (WinCE) operating system. The benefits of WinCE operating system are real-time capabilities, simplicity for robot usage and quick boot times. As the tool chain to develop robot software for WinCE is available and not differing much from the desktop version, the project gives an opportunity to get familiar with embedded operating systems.

5. CONCLUSIONS

In this paper we described the evolution of our Field Robot team education methods. In addition to instructing how to build a competitive robot, we have sought interdisciplinary learning opportunities as the team consists of students with varying background. Building a robot involves a lot of issues, both technological and educational. The better the education is planned, the more the project work gives to students.

Dividing the team in separate groups working with divided tasks makes schedule keeping hard, decreases working motivation and hinders learning from each other. A better division has been found to spend the autumn term for catching up knowledge gaps in separate groups and then integrating the team in the spring term.

To motivate schedule keeping we have found hind sighted letters from the previous team members to the preceding ones useful. Dividing the autumn term in many consequent work

tasks has enabled both schedule follow-up and close learning evaluation.

It has been discovered that too much freedom leads to a less valuable learning experience and a decreased work motivation because of the inevitable disorientation. More detailed robot specifications (than the rules say) have enabled the students to focus on the essential work. In conjunction to this approach, it is natural to let the students freely organize their roles inside the team but to occupy all the roles strictly defined by the teachers. We have also found it worthwhile that teachers manage all non-technical tasks, such as funding and budget keeping, allowing the students to focus on the primary tasks and achieve the set educational goals. It has been important that teachers have not changed too much over years; that has guaranteed yearly made progress in the teaching and learning platform.

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