Preparing a team to Field Robot Event – educational and technological aspects

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Abstract
Field Robot Event is an annual competition for small field robots intended for student teams. 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 been a joint team with students from different institutions 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 in separate groups 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. Dividing education in 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. This, in addition to considering the teachers as clients ordering a working end product, but on the other hand as hands-on teachers in individual problems, was proven successful as the team won the FRE 2008 competition.

Keywords: agricultural robots, teaching, project-based learning, robot technology

1 Introduction
The Field Robot Event is an annual competition for small field robots intended mainly for student teams. A student team from Finland has participated Field Robot Event four times during the years 2005-2008 (Honkanen et al. 2005, Telama et al. 2006, Maksimow et al. 2007 and Backman et al. 2008). Each year both the student group and the robot itself have been different. High interdisciplinary educational goals have been set every time and the student teams have consisted of students from different technological areas. So far 29 students from Finland have got experience in building a small agricultural field robot to the competition.

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 question may not be so constrained that the outcomes are 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 of the situation 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). We argue that a project such as Field Robot sets higher demands for teachers than for students.

This paper describes the evolution of our education methods related to the Finnish Field Robot project team. 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 Teaching

2.1 Agricultural technology education in Finland

A brief description of agricultural and technical education in Finland is needed to explain the interdisciplinary of the team. The University of Helsinki (UH) is the only institution giving master’s degree education in agriculture in Finland. Inside the faculty of Agriculture and Forestry stands a department of Agrotechnology which focuses on giving a broad view of technologies, measurements and research methods related to farm processes and environment research. While 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, the Helsinki University of Technology (TKK) 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 no courses on agricultural automation or agricultural machines at TKK.

It is quite clear from the agriculture viewpoint that in order to be successful in Field Robot event, a joint team is needed. One could say that “the UH agronomists are able to state what the robot should do, the TKK automation engineers how to make intelligence in it, and the TKK mechatronics engineers are able to design and actually make the robot moving”. Such 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.

2.2 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. One more challenge, unrelated to education, is the lack of maize field testing environment because of northern climate conditions.

During the first three times the team was composed of students of TKK automation technology and UH 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 which are 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 including the freestyle task 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 is 9 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 preceding ones have made this a bit easier.

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, *µCallum* (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 was intensively emphasized to the team in 2007-2008. 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 tests runs are carefully planned in order to get optimal settings for wings, suspensions and all the other tuneable parameters in Formula 1 car. 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. It is not possible to fix dozens of tuneable parameters without a carefully planned and organized procedure.

2.3 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. The information of the first FRE was carefully read and this information was combined to previous experiences in building mobile robots and agricultural machines.

During the first year in Field Robot Event the advisors of Finnish team did not participate in technical construction of the robot and gave only general guidelines. It was thought giving unambiguous technical instructions was against the spirit of the competition and almost all of the technical decisions were left to the students. However, the instructors carried out administrative duties to ensure project funding and to provide the students the possibility to start designing the robot right from the beginning of the course. Scheduling and planning of the project were left for the student team itself.

The result of the first competition was moderate but we recognized clearly that much improvement was needed in the team work practices. We concluded that better results required a more structured and outlined robot development process. At the same time the trade off between the ranking of the team and learning by trial and error was recognized. Handing out specific instructions 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 good learning experience nor competition success. As the Finnish team instructors have got more experienced, after the first time experience, certain specifications for a robot have been given out as a starting point. For example it has been specified by instructors that "robot should have four wheels, diameter of tyres 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. In addition, we found that the students' own ideas were not that innovative after all. Perhaps the awareness of their own duty to actually execute the robot suppressed the wildest ideas.

During the recent years we have taken a clearer role as teachers rather than advisers in individual problems. For the team 2007-2008 we decided beforehand to spend the autumn in teaching all required skills (machine vision, signal processing, software development, simulation, kinematics, navigation, robot control etc.) in a systematic manner. In the spring term the team had to apply the obtained knowledge and integrate everything together into a winning robot.

2.4 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. In our case we soon decided to assign project funding and budget keeping away from the team students; the first reason was that financing was governed through university accounts and secondly the developing and technical work was considered to support the most important learning goals.

2.5 Leading education towards a competitive robot

In 2007-2008 we tried a new way of educating algorithms at the TKK. In the first quarter of project in machine vision and in signal processing algorithms a clear specification of basic components was given to students. These algorithms were known to work satisfactorily but not necessarily optimally. For the student team it was given a task to program the specified algorithms and then also develop a competing algorithm that they had to invent by themselves (some clues were given). Finally students had to compare the performance and find out which one works best. 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.

On the university side we gave the agrotechnology students a new way to kick off the project. Instead of starting chassis design and test field planning, we bought a most simple four wheel drive radio controlled (RC) car and a PIC-based microcontroller development board. The students with zero experience in electronics or programming were lead step by step towards building an own robot, which would be able to navigate between to walls or “maize rows” with two ultrasound sensors. The intermediate steps were defined as one-week tasks, such as reading a distance value and turning a LED on and off accordingly, then turning the wheels according to one distance value and hence driving at a specific distance from a wall etc. Since the advancement speed could not be known beforehand, the next week task was always defined on the basis of the previous task success. Simultaneously, the idea of how far the students would get until Christmas was refined. The actual teaching events were clearly hands-on contact lessons and are a bit hard to describe as “problem based”. When the rehearsal robot was finished by Christmas the worst gap between the UH and TKK team parts was overcome and the UH students started to design a sowing machine (for the freestyle competition), which of course was too built on the now familiar PIC-board. Without the rehearsal robot the UH students would not have been able to independently work with microcontrollers nor understand the navigation and control problems of the actual competition robot. The goal of building the sowing machine was not only the participation on the Event and for freestyle task, but also to give an agronomical aspect on robotics.

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. It was found out students have 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 attraction. In the early prototyping phase the construction changes its shape in dramatic ways and it is inefficient to model fancy details to the models which are not developed further. 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 for the precision of virtual prototyping. In the first phase the 3D models are very simple shoving only sketches of the ideas. 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. When 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.

3 Robot technology

Several technologies have been tried out in mechanics, mechatronics, software and control implementation. Only the machine vision has been quite similar every time. Choosing suitable RC model car parts has been one educational aspect, but decreasingly since there have been backlashes with adequacy. Robot 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. In the first year only some controllers were tuned with Simulink, later a kinematic robot model and a 2D simulator were developed. 2008 all position estimation and navigation along with all calculations (excluding machine vision) were done in Simulink. Focusing on one good tool keeps the education concise. 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 developing logics etc., the simulation model of the robot together with control system runs in Simulink and after tuning it is easy to deploy online 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. The team 2008 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.

3.1 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. For the first robot all parts of the drive chain were taken from ClodBuster car and only the chassis was custom built to support a onboard laptop, camera and other sensors. 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 10kg 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. In robot 2008 only the axles and steering servos were taken from RC-car. This was possible because students doing their major in mechatronics participated the team.

3.2 Computing & software development

As robots need sophisticated algorithms and some algorithms require reasonable amount of computing power, our solution has been putting 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 are 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 first year quite heavy laptop was used (we had to use the one our sponsor supplied), the weight was more than 3kg – later on lighter laptops are used, 2008 a small 12" laptop less than 2kg was used. Later on so called mini-laptops, which weight about 1kg, have appeared to markets but they were not available yet at end of 2007.

3.3 Sensors

In the education viewpoint it would be necessary to use such sensors that are used in industry and guide selecting proper sensors. However, it is not possible to use industrial sensors in these projects as the price is out of reach for student robots. Therefore cheap hobbyist sensors are mainly used, such as ultrasonic rangers, infrared rangers etc. which are used by other teams also. These sensors give a good enough accuracy so they are valid for this purpose but on the other hand selection of sensors is given, not to be done by students.

3.4 Machine vision

It was considered from the first year that machine vision should be a part of this project work, even if this was not necessary for 2005 competition. Machine vision is educated in one course at TKK, and it is important also give practical hands-on experience. In the very beginning various softwares and software libraries were investigated and analyzed which of those are suitable for this project – so that the amount of work and on the other hand education are in good balance. Some tools, such as LabVIEW were considered "too ready" in order to make good education, as some other software libraries required almost everything to be programmed by hand and deep understanding of C/C++ was required. OpenCV (Open Source Computer Vision Library) was found to be the best software library for this purpose, and besides it was open source. OpenCV is a library where sophisticated algorithms are realized and it is quite optimized for real-time computing, but it is not possible to start using it without getting into algorithms and understand how they work. OpenCV has been used since the beginning and it is still considered a good choice even if other tools may have appeared.

4 Summary and Conclusions

We have described the evolution of our Field Robot team education methods. In addition to 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.

We discovered too much freedom leads to a less valuable learning experience and a decreased work motivation because of the inevitable disorientation. Detailed robot specifications have enabled the students to focus on the essential work. The best solution has been found to maintain a role as a client ordering a specific kind of an end product, but act as teachers concerning individual problems. 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, budget keeping and marketing to allow the students to focus on the primary tasks and achieve the set educational goals.

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