ENHANCING UNDERGRADUATE RESEARCH AND LEARNING METHODS ON REAL-TIME PROCESSES BY COOPERATING WITH MARITIME INDUSTRIES

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ABSTRACT

Building embedded real-time systems of guaranteed quality, in a cost-effective manner, raises challenging scientific and technological problems. For several years at Aalesund University College (AAUC), there has been ongoing activity in the development of embedded real time systems in close cooperation with private technology developers from the local industry. Much of this work is related to the design and development of systems for process control and camera surveillance of industrial processes, with an emphasis placed on operations on board ships. The main purpose is to maintain and improve safety and efficiency in industrial and ship operations. A very effective way to meet this goal consists of developing distributed embedded real time systems that independently monitor different dedicated tasks and are integrated in a common ubiquitous network. In this context, bachelor students at AAUC are involved in several research projects that give them the possibility of working in an industrial prospective scenario and under the supervision of both their professors and company-employed engineers. Most often, these activities are also part of an innovative educational and research loop, in which the projects evaluated as having the greatest innovative potential are followed up with new prototypes and research activities. By adopting a pedagogical prospective, this paper introduces an overview of the most promising student projects and methods for including bachelor students in real-time process control research activities is presented. The pedagogical and technological bases of this work are first discussed, and afterwards an analysis is done regarding the importance of COTS (Commercial Off-The-Shelf) products and system integration. Software and communication protocols are discussed from a system integration point of view. Finally, the results and conclusions of this approach are presented.

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INTRODUCTION

Aalesund University College (AAUC) is located in the region of Møre og Romsdal, Norway. A particular challenge for this region, which is interested in facilitating the growth of technology-based industries and business start-ups, is the conceptualisation and promotion of the linkages between the regional science base, reflected most heavily in the region's universities but also in its non-academic research laboratories, and its industry base. AAUC has been working with remote autonomous embedded systems for process control and camera inspection purposes on board ships (Rekdalsbakken and Osen, 2012) over the past several years. Some of these projects have played a critical part in inspiring new concepts for more efficient and secure work operations on board ships and as such have been implemented in broader research programs in cooperation with the industry. Many of these projects have been realised as embedded systems on different hardware platforms. In this activity, modern sensors together with vision technology and wireless communication systems are combined into self-contained systems independently performing important tasks in ship operations. Most of these systems originated in student projects from the "Real-Time Programming" course or from other courses in the Automation Engineering Program (Sanfilippo et al. in press) and in the students' bachelor theses. A systematic evaluation and selection was done on these projects to pick out the most promising ideas and products with potential for further study. Follow-up work has been done on some concepts in the form of further development, done in steps of gradual improvement over time until their results could either be continued as industry projects or academic research programs. Therefore, some of these activities have initiated the development of industrial products or the publication of scientific papers.

PEDAGOGICAL BASIS

It is important to build enthusiasm from the start when working in this kind of educational environment. The objectives are to foster motivation and feelings of selfreliance, to build team spirit, and to help the students develop the skills to seek and retrieve the relevant information. The team learning approach, with students working in groups, constitutes the basis in the process of defining, adapting and selecting appropriate projects. The process involves both the university staff and external partners. The students are encouraged to present their own ideas and proposals in order to include the newest technologies and program tools in their projects. In this way the students are allowed to work with realistic problem set-ups by using the most recent advances in technology and methods. The students are involved from start to finish in this immersive approach. The idea originally comes from Piaget and focuses on operational learning. It is outlined in the book *Piaget in school* (Hundeide, 1985). The basis of this view lies in the concept of *implicit learning*, which represents a concept of knowledge based on experience. In this view, emphasis is placed on the significance of practical experience and close contact with real-life and applied research. In such a view, the student laboratory, as a working place, will have a central and challenging position. Piaget's theories about learning emphasises that the knowledge must be made personal through acting. By active processing of real situations the knowledge acquires meaning. Piaget calls the result of this process *operational knowledge* in contrast to figurative knowledge, which is the representation by the senses of the external situation (Kleive et al., 1994). This strategy can also be viewed as a kind of *Action Science* or *multimodal teaching and learning* (Kress et al., 2001) or as a process of building new knowledge through acting and the reflection about acting. This method is extremely demanding for the teacher, who must act more as a stimulator than as an authority and has to arrange for optimal conditions of active learning. According to our experience at AAUC on project based learning, the role of the teacher should be more that of a catalyst and a counsellor. In such a situation it is important that the students be confident that the teachers have the necessary professional skills to define the correct problem settings and to give appropriate advice and corrections concerning the students' work.

TECHNOLOGICAL BASIS

In this setting, it is important that the university staff work in a suitable context for selecting the most promising project ideas for the students. To be of benefit for the students, the projects must be relevant to the field of study of the students, have a realistic scope and be possible to complete in the given time. There are several steps during the development and study process, including: orientation, research framework and expectations discussion, weekly and monthly meetings, mid-term presentations and assessments. Furthermore, the technology and methods to be used must be among the most recent in the market. The fields of consumer electronics and game technology are the most relevant fields in this context, and they also represent the most rapidly changing current technologies. This is a demanding situation, but it also has the potential to come up with new ideas and to develop new and flexible products. This means that the student projects usually include an extended use of novel and advanced components, regarding electronics, micro-controllers, sensors, cameras and data acquisition equipment. Since problem settings are chosen from an application point of view, most projects are also related to the local maritime industry. Speaking from a theoretical point of view, it is possible to generalise by saying that the projects belong to one of three categories. The first is *stabilisation and control of motion platforms*, the second is *object recognition and surveillance* by use of cameras, and the third is *remote and autonomous control strategies* for all sorts of robotic vehicles. These three categories are analysed in the following sections.

Motion platforms

Motion stabilisation represents a challenging problem in all sorts of ship activity. Given that the ship is always in motion when at sea, care must be taken in all kinds of operations to avoid dangerous situations and damage of materials. This is relevant for all kinds of lifting and handling operations, especially when cargo is to be taken through the sea surface. Equipment such as cameras, search lights and precision instruments must also be screened from the ship movements. It is possible to compensate for this unwanted motion by mounting the equipment on a stabilised basis or platform, which counterbalances these movements. The construction of suitable stabilised platforms represents the best method for improving and avoiding these problems. To this end, the theory of kinematics and inverse kinematics is employed. The most common platforms are physical systems of three or six independent axes or degrees of freedom (DOFs). At AAUC, the work on motion platforms mostly concerns the development of a full-scale physical high-speed craft simulator, and stabilisation of equipment on board ships, such as cameras and search lights (Nogva et al., 2008), (Rekdalsbakken, 2005, 2006, 2007). A laboratory model of a 6-DOFs motion platform is shown in Figure 1. Based on a Cartesian coordinate system, the deck can be translated along three independent axes, in addition to being independently rotated about each of these axes. For example, the transformation of a coordinate basis in 3-DOFs from a given position to an arbitrary new position, is given by the transformation matrix below:

$$\mathbf{P}_{pr} =$$

$$\begin{bmatrix} \frac{L}{2}\cos\theta - \frac{\sqrt{3}L}{6}\sin\phi\sin\theta & -\frac{L}{2}\cos\theta - \frac{\sqrt{3}L}{6}\sin\phi\sin\theta & -\frac{\sqrt{3}L}{6}\sin\phi\sin\theta \\ \frac{\sqrt{3}L}{6}\cos\phi & \frac{\sqrt{3}L}{6}\cos\phi & -\frac{\sqrt{3}L}{3}\cos\phi \\ \frac{L}{2}\sin\theta + \frac{\sqrt{3}L}{6}\sin\phi\cos\theta & -\frac{L}{2}\sin\theta + \frac{\sqrt{3}L}{6}\sin\phi\cos\theta & -\frac{\sqrt{3}L}{3}\sin\phi\cos\theta \end{bmatrix}$$

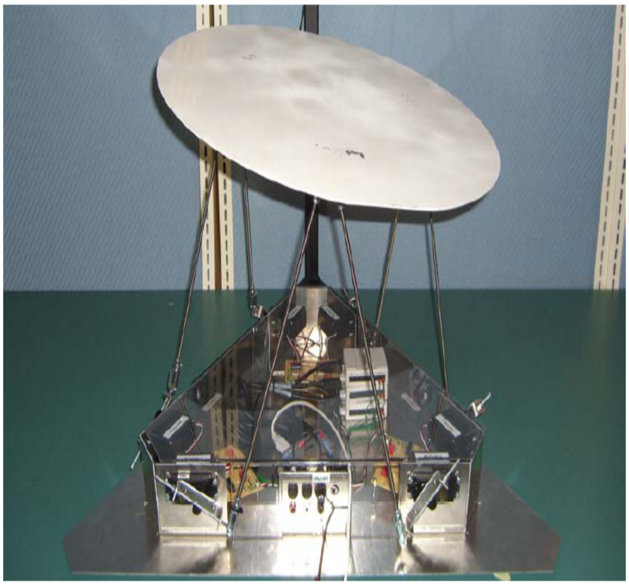

Figure 1: A laboratory Model of a 6-DOFs Motion Platform

Such matrix transformations naturally lead to the search for a general description of the relocation of object coordinates in a coordinate basis for any dimension. This is achieved by describing the objects and their transformations as tensors. The tensor algebra defines general linear transformations in a way that is valid in all kinds of coordinate systems. This is because a tensor includes the transformations of both the object coordinates and the coordinate basis itself. This kind of mathematics is also very useful in the description of the kinematics of 3D graphical objects. To display a 3D object from all directions one will need an extra dimension, i.e. a 4-dimensional coordinate system. The most general approach to obtain this is to define a number system in the equivalent number of dimensions. The obvious benefit is that each point of an object is now defined by a number, and the numbers follow the arithmetic rules of the number system. A 4-dimensional number system was defined by the Irish mathematician and physicist William Rowan Hamilton in 1843 (Graves, 1882). It consists of one real and three imaginary axes. He called it “Quaternions”. Today this number system is widely used by scientists and engineers to describe the general motion of 3D objects.

Surveillance systems

In many situations of potentially dangerous or advanced operations there is a need for close and continuous inspection of the working environment. In many situations, modern camera technologies can be used to extend the natural sight of an operator so that a better survey of a difficult or hardly accessible area can be obtained, for instance in rescue operations. With the aim of making such devices available at affordable prices in a competitive situation, the search for standard open source software and cheap hardware components is crucial to the future realisation of the products. The experience is also that the frontier of this technological area is driven by developers of open source public domain software and the multitude of producers of small scale hardware systems. The challenge is actually to foresee the technology market and to integrate components and software into useful systems. The intention is to build general camera surveillance systems. Such systems usually consist of two independent parts that communicate over a network as a socket connection with a client-server protocol. The communication may be based on a wireless or a wired LAN connection. The server side of the system is built upon an embedded hardware platform of which the central equipment is a camera that can be controlled to acquire images from any direction in its sight of view (yaw ±180°, pitch ±90°). The system is equipped with the necessary devices for fast image analysis in real time and driver software for the network communication. The client system is usually a computer with a network connection and software powerful enough for the communication and presentation of real-time image streams. On this topic, a number of experiments have been performed at AAUC, with different kinds of software and components. Some of these systems are for real applications in offshore operations (Xu, 2011) or dynamical positioning of ships (DP) (Brandal et al., 2011). Other applications are for inspection on land, e.g. the search by mobile robots for pollution, dangerous materials and mines (Fjørtoft and Lund, 2010), (Håheim et al., 2010) or automatic product control (Gao et al., 2009). As these systems become more autonomous and self-sufficient there will be a growing need to combine them into more comprehensive networks in order to compare and group vital information from many sources. This will give a much better overview of complex situations.

Vehicle control

The third main area of interest at AAUC is the development of remotely controlled and autonomous vehicles. Such mobile robots are used for numerous purposes and have a broad and increasingly important position in many kinds of operations. Very often such vehicles combine several advanced technologies into an integrated system. For instance, a robot intended for object search and recognition must have a sophisticated image acquisition and analysis system, inertial sensors for the registration of angles and accelerations and a wireless radio or WiFi system. In addition, a robust control system is needed. In recent literature, the most famous of such vehicles is the Mars rover, but the majority of the other related robots have much less sophisticated duties to attend, e.g. the search for mines in post-war locations. At AAUC, several control systems for such vehicles have been designed using different strategies. To speed up the prototyping process and save time on the mechanical design, model assembly kits with steering and speed control already implemented have been purchased from the consumer market. These kits have been used as bases to build up new control systems for the robots. The communication usually takes place over a radio communication link or a Wi-Fi network, typically controlled by a cell phone or a game controller. The most widely use of such vehicles is in search and surveillance operations. An example of one of these student projects is an iPhone controlled RC vehicle by use of the Apple remote control program OSCremote (Giske et al., 2009). Moreover, in the last few years, our research group at AAUC, together with our international partners, has also put some effort on proposing new prototypes of mobile robots. For instance, the mobility of several newly designed modular robots has been investigated. In particular, the configuration of a five-limbed modular robot was studied (Liu et al., 2012). A specialised locomotion gait was designed to allow for omnidirectional mobility as shown in Figure 2. Due to the large diversity resulting from various gait sequences, a criterion for selecting the best gaits based on their stability characteristics was proposed. In particular, considering the static stability of the pentapedal configuration different states s can be identified and a set of n gaits can be considered. When the walking direction x is given, a 120×10 matrix $M(x)_{n,s}$ can be derived, where $M(x)_{n,s}$ indicates the stability margin of the s^{th} state of the robot within the No. n considered gait. Moreover, two indices can be used as references for the gait stability. The first is the minimum stability margin $M(x)_{n_{min}}$, which evaluates the most vulnerable situation to disturbances during the whole period. The second one is the summed stability margin $M(x)_{n_{total}}$, which is used to investigate the overall stability gait. A series of simulations was performed to test and evaluate the various gaits in different walking directions. In this way the pentapedal robot was trained to walk in a stable manner. In Figure 3 the simulations results for all the stable gaits in the 90° walking direction are shown.

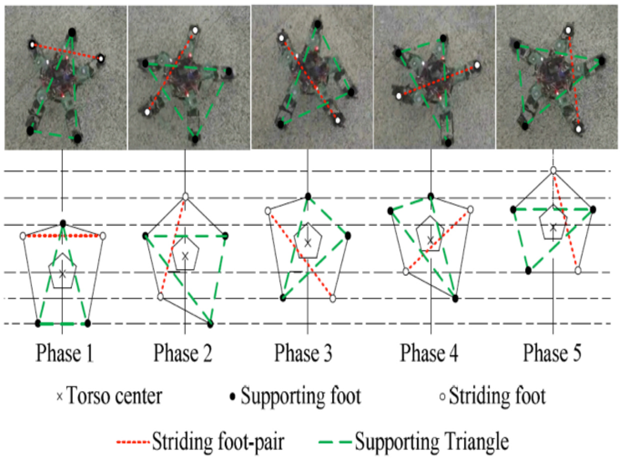

Figure 2: Stable Gait of the Pentapedal Robot

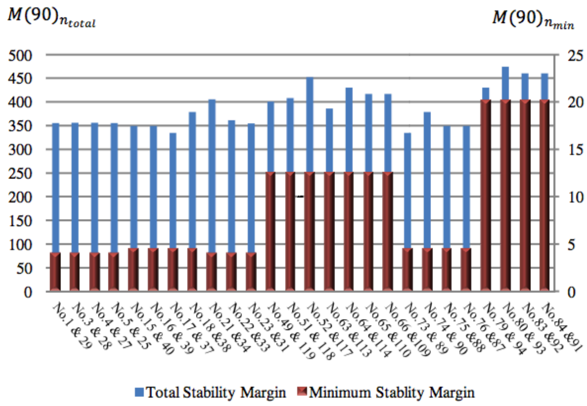

Figure 3: Total and Minimum Stability Margin of all the stable gaits in the 90° walking direction

THE IMPORTANCE OF COTS AND SYSTEM INTEGRATION

One of the most important advantages of this academia-industry cooperation is that these projects represent a way of testing the possible future realisation of new concepts and prototypes, both with regard to technology and economy. Having many groups of students working with similar problem settings on different hardware and software platforms provides an insight into solutions that may be worth taking further in a research project. For the implementation into a real industrial system, e.g. on a ship, among all of its necessary and useful devices, there has to be a motivated demand for that product. Secondly, there must be documentation to prove that the technology is reliable and necessary components will be easily available in the future. Furthermore, software solutions must be openly available and easy to improve and maintain. These kinds of systems must easily fit into the existing solutions for the operation of the ship. To manage the realisation of such systems it is highly important to have a broad knowledge of the electronic COTS market, especially in consumer and game products. Because of the large market and multitude of products the frontier of new electronic systems lies here and this market segment represents a vital dynamic. Wireless communication, camera systems and modern sensor technology have had and still have an enormous development through the mobile phone market and game industry. In particular, gyro and accelerometer components of high quality and small size, and cameras of extreme image quality and usability, have been developed in the last few years and can be bought at very low costs. Together with freely available software tools and driver libraries, this situation opens up a new world of exciting challenges to the engineer for developing complex embedded systems for all kinds of innovative applications.

Equipment and Assembly

In all our experiments, the involved computer hardware and all necessary equipment are available at ordinary customer retailers and net shops. A typical example is a student project set-up for building a search vehicle. The search operation is realised by building a small scale autonomous model vehicle equipped with a web camera which is placed on top of a stabilised motion platform, typically 3-DOFs. The motion platform and the steering system are usually controlled by using an Arduino Uno micro-controller board, featuring an ATmega328 micro-controller from Atmel. Because of the substantial computational load, the image capturing process is implemented by using a Hardkernel Odroid U2 open development platform that sends the image stream over a Wi-Fi connection to a stationary PC. The PC receives the stream and performs the image analysis. When the position of the object is found, its location relative to the vehicle is calculated, i.e. the distance and angle of direction. In particular, the target object is located by utilising two still images or frames taken from different points of view by the robot in such a way that a stereoscopic image of the target can be obtained. The location of the object is sent to the micro-controller on the vehicle and used to calculate the reference signals to control the vehicle and the camera. The internal vehicle application tasks are designed to do all local control and data acquisition, such as stabilising and positioning of the camera, controlling the vehicle motion, and capturing and transmitting the camera images. Everything is built and developed by use of low cost and openly available hardware and software. The system architecture implementation and class diagrams are shown in Figure 4 and Figure 5.

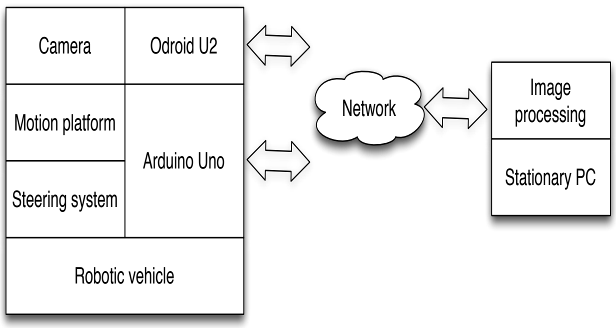

Figure 4: System Architecture

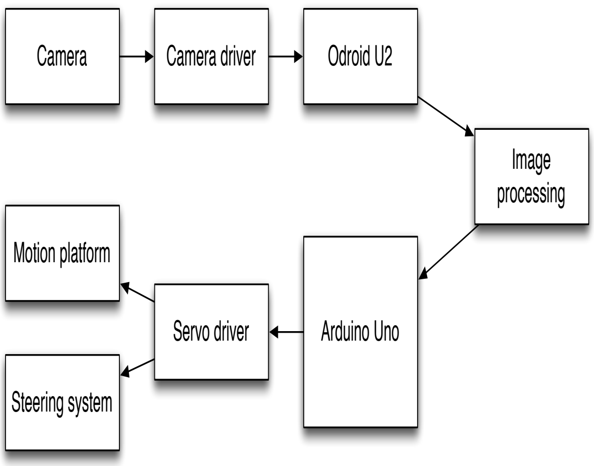

Figure 5: Vehicle Connection Diagram

SOFTWARE AND COMMUNICATION

The software implementation of these kinds of systems is quite extensive and represents the most intensive work and expensive part of the project. Thus it is important to choose a software base and development tools that are easy to work with, easy to update and low-cost. These are good arguments to look for public domain software. In general, Java is the programming language chosen for the software development of these projects, and NetBeans is the preferred development environment. Standard Java is an open source system, free for anyone to download and use. However, for each micro-controller and a chosen operating system, an application programming interface (API) is usually provided. This includes a runtime system and a software development kit. These products often implement a reduced version of standard Java and with some additional libraries for special purposes. In addition to standard Java, some custom tailored program tools and auxiliary program libraries must be used. Most important in hard real-time applications is that the Java runtime engine connects closely to the underlying hardware, which usually is the case with dedicated controllers.

Concurrent Java

Java is the preferred software development system mainly because of its platform independence and extensive and easily implemented real time qualities. It provides an integrated thread mechanism and a broad range of thread management methods. It also has an extended set of timer functions and an effective software interrupt system, implemented as a set of event listeners. The event listeners capture events sent to them from hardware devices via the Java runtime engine.

Linux OS and driver software

It is important to choose a lightweight and flexible operating system. Linux OS exists in many variations from independent developers, and all of them are openly available and free to use. When designing embedded systems, finding suitable driver software for needed equipment is crucial. Developing driver software is a time-consuming task. Linux has great potential in terms of driver software, and the desired software can usually be found on the Internet in public repositories.

Software Libraries

In spite of the extensive application programming interface of Java there will always be a need for special software methods. When working with systems comprising special and extensive equipment, specialised software is needed. Examples of such software applications are acquisition and analysis of images from cameras, and handling of communication protocols for the networks. Software for controlling different kind of motors and actuators will also be necessary. Software methods governing such dedicated areas are often collected into complete software libraries. Many of these libraries can be found for free on the Internet. A broad insight into the existence of such facilities is very useful and can save many hours of work. Considering the numerous software packages available on the free software market, the ability to choose and adapt the most useful system programs is vital.

RESULTS

In order to assess the effectiveness of the proposed pedagogical and research approach, the students were periodically surveyed and questioned. The students were asked to evaluate the effectiveness of the course structure, project and course elements. The students also had the opportunity to comment on aspects of the course that they valued and aspects of the course that they felt should be revised. A common response from the students at the end of a course is that the project was very important to them and that they wanted more time devoted to it. The results of this pedagogical and research system with continuous selection and improvement of student projects over a period from 2003 to present are in accordance with the goals of the plan, both with regard to students and teachers, as well as for local industry partners. Several project ideas have been tested in cooperation with local industry partners, and relations with local companies have been strengthened. A total of approximately 150 projects have been involved during the past ten years. About 15 scientific publications have been presented on international conferences and some of these have also been published in highly reputable journals. Most projects have been carried out in cooperation with local industry, for the bachelor thesis this amounts to about 80%.

DISCUSSION

This paper presents a systematic way to include bachelor students in engineering programs into research activities. The students belong to the study program in Cybernetics, and the focus is on the course Real-time programming and on the students' bachelor thesis. The primary issue of this work is to investigate new trends in sensor and vision systems for possible integration of such technologies in new products and operations, especially on board future ships. As the tasks required of modern products become increasingly more complex and demanding, there is a growing need for system integration from many fields and insight into the consumer and COTS marked. Here, the focus was to explore the rich market of consumer electronics driven mainly by the cell phone and game industry, using these components in the development of advanced and low-cost customer specified products. Experiments with selected equipment of this type were performed mainly by building small scale physical models. However, the aim is to integrate these new technologies into new products for the future. The models only represent an easy approach for testing equipment and methods in an adequate way for real operations. The tests will reveal and document which of these devices have a potential for further development in an industrial context. By this scheme, the activities best suited to pursue for further projects may be selected. This is like an interactive trial and error process where components and methods are systematically selected for further refinement and development. Through this process all students have a way to gain an insight into product development and scientific methods.

CONCLUSION

The underlying aim of this work is to investigate some new products in the consumer technology market for possible future employment of such technologies in the development of new products, mainly for operations on board ships. This activity of practical testing of vision and sensor systems on small scale models has shown to represent an effective way to reveal the potential for adapting such technologies in modern ship operations. The surplus of new devices within wireless communications, vision systems and MEMS (Micro-Electro-Mechanical-Sensors) components available in the consumer market, driven by the cell phone and game industry, represents fantastic new possibilities in the integration and adaptation of advanced technology in more traditional fields, both in the production process and in the products. The experiments performed in this work have revealed that it is of great benefit for young engineers and applied scientists to have a thorough insight into this market. The results of the experiments also encourage further work towards implementation and use of such technologies in product development. The way of conducting these projects, with careful selection of new ideas, and systematic follow-up of selected projects in close cooperation with industry companies, has also shown to be very fruitful. The industry partners acquire a tool to select and test new product ideas; the students have a chance to make good contacts with local industry companies and training in scientific thinking. Finally, the teachers are able to keep themselves technologically updated and have access to a system for applied research activities.

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