ET Robocon: A Software Design Robot Contest for Educating Embedded Systems Engineers

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***Abstract*— The ET Robocon (ET software design robot contest) was established in 2005, with the aim of educating embedded-software engineers. While most contests of this type tend to focus on hardware development, ET Robocon is centered on the software. Participants compete with one another to model and implement technologies used in robot control.**

The robots are constructed using the LEGO® Mindstorms® kit, and run autonomously. Software design, maneuverability and running performance are evaluated. To further encourage the creative spirits of embedded systems engineers, we added a new category, "Architect", in 2013. The contest was opened to the public, and streamed live via the Internet. In this paper, the contest details and examination methodology are described, followed by a discussion of the survey-results. We confirmed improvements in each participant's modeling technology, clearly indicating the usefulness of project-based learning (PBL).

***Keywords*— Software Design Contest, Engineering Education, Embedded Software, Unified Modeling Language (UML), Model-Based Development (MBD), Project Based Learning (PBL)**

I. Introduction

Embedded software development technology is essential to strengthen the industrial competitiveness of Japan. With any increase in functions implemented in embedded software, the complexity of the embedded software increases, and maintenance of the quality and improvement of the development efficiency have come to the limit. To solve the problems, the model-based approach has come to be adopted in the development of embedded software [1].

However, conventional ways of software development are still used in many companies. Therefore, we carried out a contest of embedded software design based on the model-based method for the education of young software engineers and novices, called "ET Robocon" [2], Embedded-Technology conference's Robot software design contest. This paper overviews the ET Robocon and discusses the educational results of the contest.

The ET Robocon is aimed at skill improvement of model-based design methodology for embedded software engineers (MBD). The contest is open to teams from schools, universities and companies. It is held in support of industry, academia and government.

In the contest, participating teams each develop a program for driving identical autonomous running products, and race them two-at-a-time. They must design the program by the model-based method using some programming language, such as a Unified Modeling Language (UML) [3] to run it on a predetermined course. The ranking of the teams is determined by both the time for running the course and the program model used for development of design.

The contest "UML Robocon" began in 2002 among members of the Society of Embedded Software Skill Acquisition for Managers and Engineers (SESSAME) [4]. In 2005, Japan Embedded Systems Technology Association (JASA) became the organizer of the contest [5] and its name was changed to "ET Robocon". The contest is not limited to modeling in UML, but is open to various new programming techniques, such as SysML. At present, local contests are held in 11 districts in Japan from Hokkaido to Okinawa, with the winners of each coming to together at the national convention, are held every year, in Yokohama.

Over the years, ET Robocon's governing body has made numerous changes, not only in the way evaluations are carried out, but also, how contest-results are fed back to participants. Also highlighted are any significant new trends among participating teams.

Fig.1 shows the number of participating teams and their organizations. Initially, most of the teams came from companies, but teams from educational institutions have been gradually increasing their presence to the point where they now make up nearly half of all entries. The number of the

teams had been increasing until 2008, but stabilized from 2009 after the Lehman Shock. The ET Robocon is funded by registration fees from participating teams and independent sponsors, and operated by an organizing committee of more than 290 volunteers.

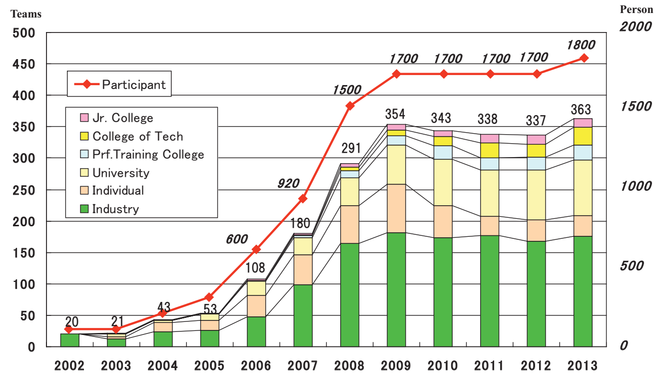


Fig. 1 Changes among the participating teams at ET Robocon

II. Contest-Rules

ET Robocon is not a simple competition of racing time, but a competition of both program model design and racing time as a result of implementation of the model. The participating teams must submit a document (5 A3-size pages) showing the program model, including a concept sheet. The submitted documents of the program model are evaluated by judges of each local contest. During the race, a pair of robots runs a predetermined course, controlled only by their program code.

Registration is open from March to April, and technical seminars are held during May and June. Trial-runs are held on the course, in July and August, with local contests taking place during September and October. The championship contest is held in November.

A. Championships

The winning teams in the local district contests compete in the championship, which is held during an exhibition of Embedded Technology (ET) sponsored by JASA.

40 teams from the local districts are allowed to participate in the championships held in parallel with the ET exhibition. This is a major motivation for teams. Furthermore, schools and companies enhance their image by participating in the championship. Fig.2 shows the Championships held in 2013.

During the first day of the championships, a reception is held after the competition. The second day begins with a panel session, then, a model tour, mini workshops and consultation are held. During the panel session, the latest trends in software modeling are discussed. Judges then analyze the software during "model tour" of the event. The mini workshops are held by judges focusing on specific technical topics. The teams visit "consulting room" to receive advice and comments from the judges. All events conducted by the panel of judges can be enjoyed live, via Ustream and Twitter feeds.

The championship venue

Workshop

Robot navigating the course

Fig. 2 Championship in2013

B. Competition

Robots use IR sensors to track black lines laid out on the course, measuring 546 cm x 364 cm (Fig.3). Because the contest focuses exclusively on software design, teams are required to use robots constructed according to the blueprint provided by the organizers.

Devices are carefully inspected prior to the start of competition. Those that pass inspection are supplied with a fresh set of alkaline batteries from the sponsors. Once installed, the devices are sealed to prevent the replacement of batteries.

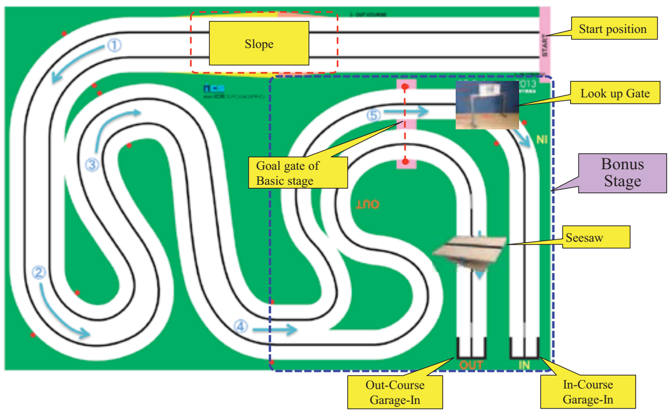


Fig.3 ET Robocon course-configuration in 2013

The race-course consists of a pair of in/out tracks that allow two robots to run simultaneously. Times for single runs of each of the two tracks are recorded, and the total accumulated time is used to determine the winner.

There are "Basic" and the "Bonus" stages; the Basic one, to judge speed. The Bonus stage involves a number of "choke points" along the course that are difficult to navigate, using simple line tracing techniques. Robots that successfully pass these are awarded a number of bonus points, depending on the level of difficulty. The layout of the courses and the choke points are changed, every year.

One of these gates, called “Look up!” is lower than the actual height of the robot. Therefore, robots cannot pass through this gate, standing upright, but should pass through by tilting the body with a tail wheel. At that time, robot needs to find accurate position of a gate by using an ultrasonic sensor.

The robots have only two minutes to reach the goal, including the time required to pass choke points along the route. If they take longer, they face elimination.

The race is judged on the actual running time, but accrues bonus points, according to the speed the robots run and the number of choke points passed. If the robots are quick, and succeed at all choke points, times can be even faster. Fig.4 shows the course-configuration used in 2013, with bonus choke points.

kind of the bonus		Bonus time	Comments
Remote start (Bluetooth start)		5sec	
Intermediate gate pass	1st gate	5sec	
	2nd gate	5sec	
	3rd gate	5sec	
	4th gate	5sec	
Goal gate pass		10sec	
Seesaw pass	Single	5sec	It's applied for only Out-course. Either "Single" or "Double"
	Double	10sec	
Look up gate pass	Single	5sec	It's applied for only In-course. Either "Single" or "Double"
	Double	10sec	
Garage in (Out-course)		5sec	
Garage in (In-course)		5sec	

Fig.4 Choke points and Bonus time

C. Robot used during the competition in 2013

The design of devices used during ET Robocon2013 follow rules explained in Fig.5. Every team must use identical devices. The current version being based on “the Lego Mindstorms (NXT)” [6], originally designed for educational purpose, which is a two-wheel inverted pendulum with a 32-bit computer. It is equipped with an IR sensor, an ultrasonic sensor, a gyro sensor and Bluetooth, to enable sophisticated control.

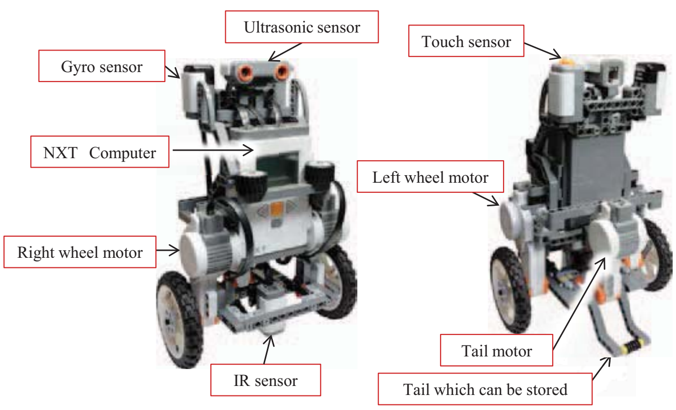


Fig.5 Standard robot of ET Robocon

D. Evaluation of Software Model

A software model is another evaluation item of the contest. The models are evaluated by judges who are professional in software modeling. The submitted models are evaluated and "Good" and "To be worried" comments from technical and performance points are feed backed to the teams. The evaluation of software models is a unique feature of this contest, requiring significant input from the judges.

Since evaluation of results of the software models is a difficult process, we decided to have the judges make their determinations, based on a 10-level scale:

A, A-: "Excellent" levels
B+, B, B-: "Good" levels
C+, C, C-: "Insufficient" levels
D+, D : "Should be reconsidered" levels

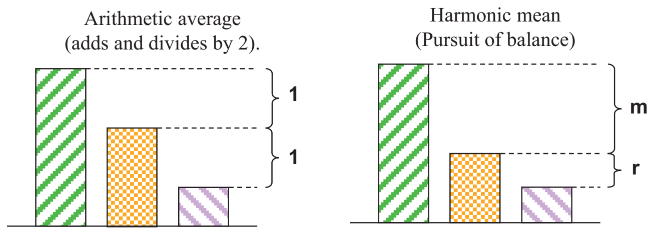
The final scores for the software models are determined by the total number of points awarded: "Excellent", "Gold" and "Silver" awards are given for first, runner-up and third prizes, respectively.

In the initial rounds of the competition, ranks were determined on the arithmetical average of the software score and lapsed times. Therefore, the average became "50", if one scored "100" and the other, "0". It therefore became possible for a team to lose a race, even if their modeling software was of a high standard, or another team to win a race with low-grade modeling software, thereby achieving similar rankings, at the end of competition. This would seem to contradict the theme of ET Robocon; that: "Good software modeling is the Key to Success".

After carefully analyzing the results of the initial rounds, it was agreed that one of the reasons for the above issue, was insufficient implementation of the excellent model of the software. To resolve this, a "Performance Evaluation Team" has been selected from among the members of the ET Robocon committee. These have, in-turn, joined the judges who evaluate software model from the standpoint of performance; in other words, whether it can be implemented practically or not, and whether it can be coded on current hardware.

Within the committee, there are many alumni from winning teams of the past, who have become judges or technical members, after retirement. They teach important lessons to the new faces and pass along technical know-how learned from earlier “Robocons”, providing invaluable positive feedback for organizing the Robocon.

From the Robocon 2008, which is the first year of organizing the “Performance Evaluation Team”, the ranking is decided by the harmonic mean of regularized scores of the model evaluation and the speed race (Fig.6).

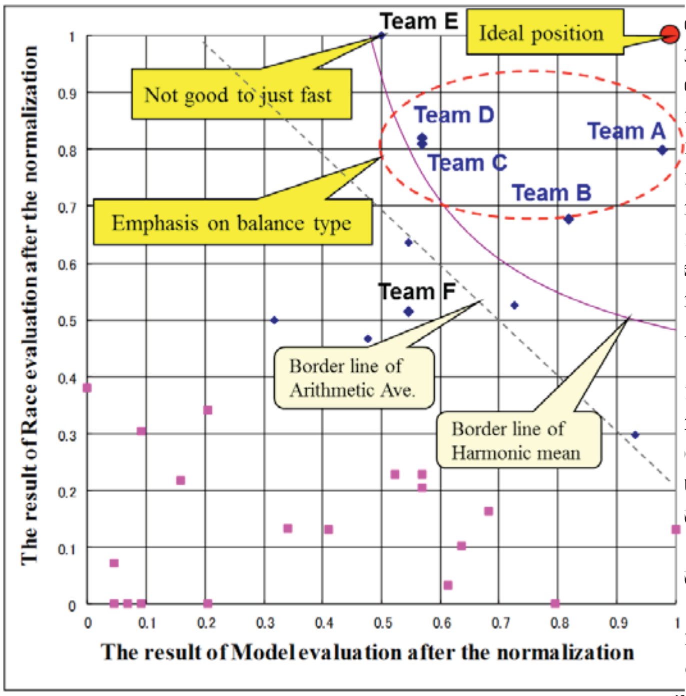


Result of model evaluation: Normalization, Min. 0 - Max. 1.
Result of race time: Normalization. Slowest time=0 – Fastest time=1.
Normalized to [0-1] result of model evaluation & race time is obtained by the following calculation.

$$\text{Synthesis result} \quad \frac{2 \times \text{Model} \times \text{Race}}{\text{Model} + \text{Race}}$$

Fig.6 Calculation of Harmonic mean

As shown in Figs.7 and 8, Team E in this example recorded the fastest time, but the overall evaluation suffers, falling to 5th place, due to its poor showing in the model evaluation. Team A, on the other hand, which ranked a lowly 4th place in the race and 2nd in the modeling segment, wins the competition.



Fig,7 The result of Harmonic mean

Based on the above consideration and changing game rules, the team with the better model is getting the better score in the contest, which means "Good model is the key for winning", in local and championship contests of the ET Robocon in 2011.

CS	Team Name	Time	Race order	Model order	Overall ranking
x	Team A	-5.1	4	2	1
x	Team B	32.7	6	4	2
x	Team C	-11.4	2	11	3
x	Team D	-8.1	3	11	4
-	Team E	-66.6	1	18	5
-	Team F	78.7	9	7	6

x = Participated the Championship

Fig.8 Overall ranking, as determined by the harmonic mean

III. Educational Seminars and Their Contents

The principal aim of ET Robocon is the improvement of software modeling skills among the current and future generations of software engineers. In practice, it helps level-1(primary class) engineers reach level-2(middle class). Programming techniques are not the main focus, as it assumes participants have experience in one or more languages, such as C, C++, Java.

ET Robocon offers participants a 2-day series of technical eminars focused on software models, with the first day ooking at modeling techniques. The second day of the eminar is actually held, after a break of a few weeks' time, nd is devoted to the educational aspects of the software nvironment; -practical details regarding robot control API nd development tool chain, as well as some knowledge of nechanical systems. The second day's work is carried out fter a two- to three-week time delay, so that participants can eview and apply what they learned, before moving on to nore practical details. Some districts offer additional seminars, epending on local demand.

The participating teams start development immediately fter their education is complete, and spend two to three nonths perfecting their models. Contestants in all districts repare for their trial runs, the day before the final call for ubmissions, so that their models will be ready to face real-vorld challenges.

On the day of the contest, detailed charts are hung on the valls, allowing teams to compare notes.

The following day, modeling workshops allow participants nd judges to come together for a free exchange of ideas, and dvice from the judges. As a historical fact, each issue raised during workshops held one year, are reflected in the designs that teams display, the following year.

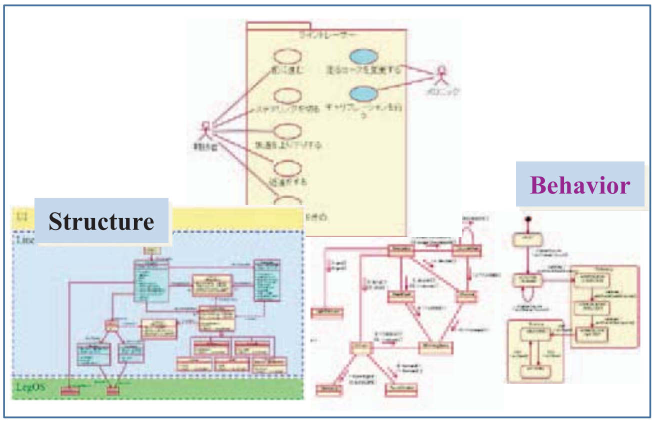
Every workshop is followed by a party where people discuss and exchange opinions with committee members and participating teams, increasing the educational benefits.

IV. Educational Effect of the ET Robocon

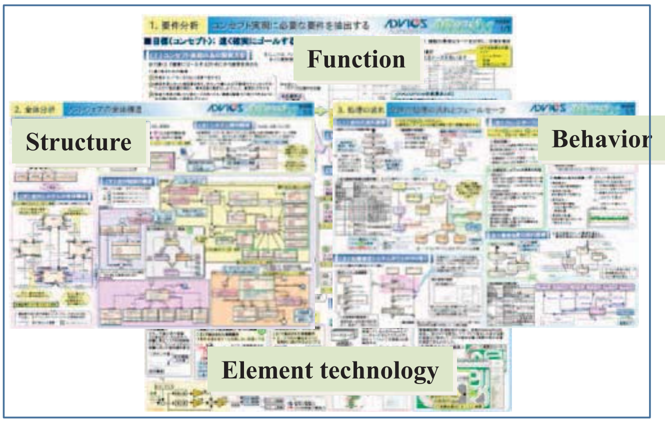
In the ET Robocon, a model requires such a complete robot control by software that physical robot action control and method of these controls are included by nature. The participating team consists of people who already know UML

as software language and control software programmers who know UML little. Therefore development of the robot action control software is a new and exciting experience for the members who have been working with pure UML software model. On the other hand, constructing a pure software model is a really new experience for the robot control specialists.

Fig.9 shows championship-winning models from 2004 and 2011. Though the descriptive text is too small to read, the models' configurations are substantially matured, from those displayed seven years ago.



The champion model in year 2004



The champion model in year 2011

Fig.9 Comparison of the champion model of 2011 and 2004

The number of student teams has increased, since 2008. They come mostly from area universities, but, in 2013, a high school team from the northern region of Kanto joined, and took top honors, for both modeling and competition.

They studied based on the judge member's comments and the previous champion models. No handicap was given to those high school students and they are equally evaluated. They have done the modeling, programming, and completed the project as a team. People believe students who accomplished such a good mark are ready to go as professional in the real industry.

Such young generation team's achievement is good stimulus for professional engineers. This means ET Robocon is not merely offering modeling technique education but also offering really effective PBL (Project Based Learning). Participants learn practical method to accomplish their project by themselves naturally.

An effect for an education method will be recognized several years after the education has been provided in general cases. It is also hard to see the input/output correlation. On the contrary, the ET Robocon provides significant educational effect to both modeling and race in relatively short period. Some participants from industry archive winning the championship contest at second or third challenge year.

A questionnaire survey is conducted each year for getting the feedback from the participants. The participants who submit the answer for the survey will receive the complete model documents from all districts. The ratio of fully filed answer was 81% in the year 2010 and 58% in the year 2011. This might happen because the loss of interest for the participants who already have previous year models. The survey has a lot of questions with free description, and forces a great deal of effort for answer them to the participants. Therefore, some participants did not find the benefit of getting model documents and they were not motivated to answer the survey.

There are 48 questions and many of them require description in text form. In year 2011, 4017 comments are collected. This fact proves that participants recognize the aim of ET Robocon and they are serious. Here are some of questions and collected answers. Notice some questions are different between company teams and student teams.

A. Reason of challenge

Fig.10 shows why participants decided to participate in the ET Robocon. The question allows multiple choices. Two third of participants aimed at an educational aspect. Some company teams intend to train new employees with the ET Robocon. Other than new employee education, the reason is diverse, such as modeling technique learning or personal skill up. This pattern is stable through years of ET Robocon history.

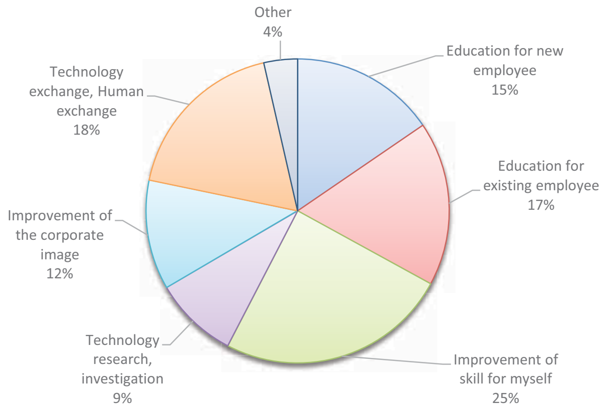


Fig.10 The participation purpose of the corporate team in 2011
(multiple choice)

B. Years of challenge

Fig.11 shows the number of years of participation. One third of teams are joined for the first time. This ratio is same for both company and student teams. On the other hand, most student teams join for second year but for third year. It is supposed that students join ET Robocon as part of PBL curriculum in their school. In addition, since 46% student teams are third and fourth year in university, they participate in the ET Robocon as a practical entry gate for a professional job opportunity.

Controversially, company teams keep challenging for more than four years. They seem challenging until getting championship title.

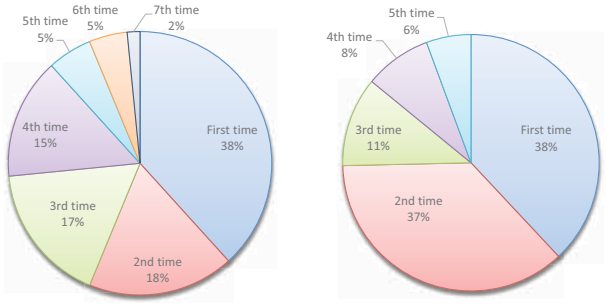


Fig.11 The number of participant times

C. Educational Effect and Satisfaction

Fig.12 summarizes the ratio of parts which the participants feel learning effect. The modeling occupies 1/3, development process is 20%, and management is 17%. 80% of participating teams are answering satisfied. The rest of 20% declared as not satisfied because of race retirement.

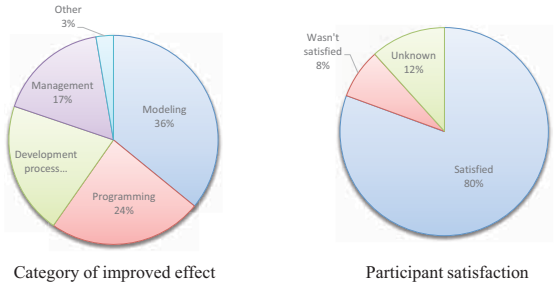


Fig.12 Category of improved effect & Satisfaction

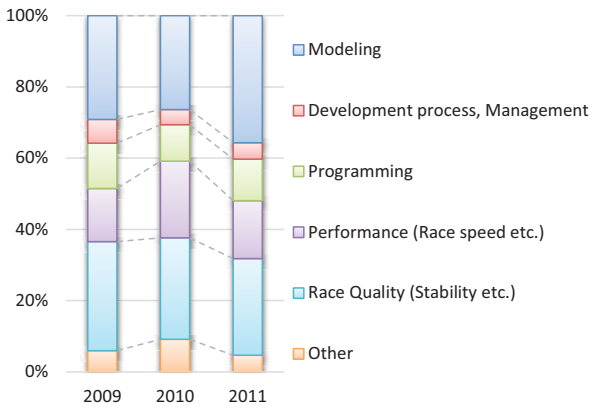
D. The Focused Area During Development

Fig.13 is trend graph showing which part participants focused as their development activity. Differences between company teams and student teams are interesting. Company teams' answer (Fig.13(a)) shows higher focus on modeling and little on programing. The company teams are supposed to already have programing skill. Conversely 1/4 of student teams (Fig.13(b)) focus on programing and quality of race i.e. how robot run the course and behave to the hazard as programed.

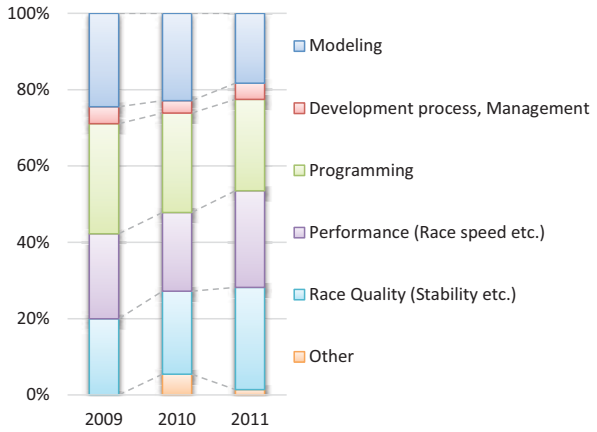
E. What was the Best Thing in This Contest?

This questionnaire is descriptive and free format to write answer. Related to the technical skill up for participants themselves was something expected answer and management issues are also answered. For example, the very specific keywords written are "Difficulty of project management" / "Toughness of make all members work together" / "Team management" / "Project management" / "Development difficulty by many persons".

Those answers suggest that ET Robocon is a PBL which offers the learning opportunity of overall process for software development. Some other answers emphasized the rare opportunity for discussion and communication with other companies, professionals, teachers, and students. ET Robocon has multiple aspects for education value as well as technical learning.



(a) Corporate team



(b) Student team

Fig,13 Most focused activity of development

V. Additional Category and Classes

A. An Additional Category from 2013

From 2013, the ET Robocon has been expanded from a single category competition into two categories, the "Developer" and the "Architect", for its purpose of software engineering education. The Developer is operated basically according to rules from the past, in which teams compete for speed and accuracy on a given course. Each team analyzes the course, designs a software model, writes a program code on the model, and run the code on a robot.

The software education based on software modeling is getting better results year by year. A code based on a better model is getting the better record in racing. It means the contest has become good training for model designing skill, but it does not mean it gives a good opportunity to enhance originality in model design. The committee of the ET Robocon believes that it is hard to win the global competition of software design only applying routine problem solving techniques. Creating some original technology is a must item to win the game.

As result, the Architect category has been started from 2013. As it focused planning and presentation skills, the Architect category is not position like a high rank of the Developer category. The purpose of the Architect category is human resource development for increasing the planning capabilities and presentation skills.

When the Developer category is compared to speed skating, it may be understood easily that the Architect category is compared to the figure skating of the free performance.

As for the Architect category, a participating team performs original performance on the white performance stage which is placed at latter half of the racing course. At that time, there are no restrictions for the performance except for the danger act. The participant itself plans the theme and the subject that is made to say "Excellent" from audiences. And while performance is performed, participant itself makes a presentation and description of performance.

It is admitted to place the devices and fixtures (called a gadget), other than standard robot on the performance stage. So participant can show performance with various idea and technic. Also, participant must submit a proposal paper instead of a model. And proposal is evaluated by judges as well as the models.

Regarding judgment method, 25% is the examining of contents of proposal and 25% is the examining of the result of performance whether it corresponds to the proposal. And remaining 50% is examined the result of performance by special and general audiences.

The first contest of the Architect category in 2013, in all 363 teams, 294 teams entered to the Developer category, and 69 teams entered to the Architect category. As a result, 13 teams were selected from the Architect category in the championships, and the company team and the technical junior college team won the same score.

The concept of the two teams is very different. Concept of company team was cleaning robot, and it look for objects in the room and put away. On the other hand, concept of technical junior college team was entertainment, robot is coalesced into the big one and rescued a princess. It is interesting that both teams of the different concept got the same number of votes from the special and general audiences.

B. New classes from 2014

The Architect category that began in 2013, raised the great achievements than we had imagined. However, as mentioned before, the difference of the level was expanded between the team which participated with a beginner and many times in the Developer category. So, the Developer category was divided into two classes, "Primary Class" and "Advanced Class", from 2014.

Contents of the Primary Class follow the Developer category of generally conventional one. It continues to hold as "a place of learning for beginners" which requires easy-to-understand model description and accurate acquisition of elemental technologies.

On the other hand, the Advanced Class provides a place to compete skills and study advanced technology. For the class, the authors have developed a new robot called "NXTrike" shown in Fig.14.

Fig.14 The "NXTrike" which will be used in from 2014

It would be possible to capture the choke point high degree of difficulty and advanced control strategies than traditional robot. This robot is a trike type, so the torque dividing of the left-and-right drive wheels is usually performed using the differential gear. However it needs to carry out a traction control by controlling the motor which achieved left-and-right independence like the in-wheel motor used with newest electric vehicles.

Moreover, the trailing wheel is attached to the body back upper part, and a run in the handstand state is possible with carrying out the wheelie of the robot. If using this, for instance, even if there is a tight curves which cannot be turned by minimum turning radius in three-wheel driving, if robot does not decelerate, it can change to a handstand state quickly and

can also take the strategy of turning at that place and quickly escaping from a corner.

It is almost impossible to create such bodies in actual vehicles size, and to use it by 400 teams. However, in the ET Robocon using a unified teaching material, LEGO Mindstorms series, it is possible to prepare a robot having a new mechanism every year.

Thus, by dividing class, a function as newcomer education which is the purpose from the beginning for ET Robocon is maintained by the Primary Class. The additional class, the Advanced Class, will create an environment that can be updated without hesitation and suited to the latest technology trends. This addresses continuous development of human resources which can play an active part in the embedded system development field.

VI. Summary and Perspectives

The present paper introduces our activity of a software design robot contest for educating embedded systems engineers, the ET Robocon, and reports its educational effects.

The ET Robocon is centered on the software, where participants compete with one another to model and implement technologies used in robot control. Software design, maneuver control and running performance are evaluated.

The contests were held annually and continued for 12 years. Through the feedback from participants, the authors assure that this robot contest provides very good opportunity for educating embedded software development skills for both students and professional engineers.

To broaden the spectrum of embedded software engineering skills, the developer category will be divided into the Primary Class and Advanced Class. With the introduction of the category of the two, it makes "human image" nurturing through the ET Robocon clear. A target of “human image” is a little different in the Developer category and the Architect category. Therefore, the contents of requirement of two categories are also different. Of course, elements of both are important, so it is better that participants will be able to have the skills of both in the future.

The Developer category.
It aims at rising of the ability to solve a given problem with quick, accurate and high quality.

The Primary class (for bingers)
- It is intended for beginners and carried out as usual engineering education.
- It provides an opportunity to learn the basics challenge of technology.

The Advanced class (for expert)
- The class which the person who graduated from the Primary class challenges.
- It provides an opportunity to hone the skills that can be applied technology.

The Architect category.
It aims at education of the engineer who can play an active part in 5 or 10 years. It provides an opportunity to hone the skills to plan and develop products.

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