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Robotic Competition Based Education in Engineering (RoC-BEE)

Manvendra Singh Raghav, Shailesh Jain and Subir Kumar Saha

Dept. of Mechanical Engineering
IIT Delhi, Hauz Khas, New Delhi 110 016
Email: saha@mech.iitd.ac.in

Abstract

In this paper, methodology, experiments and experiences of the authors over a period of last six years with engineering students of the Indian Institute of Technology (IIT) Delhi involved in robotics projects, mainly, Robotic Contest (RoboCon) organized by the ABU Asia-Pacific Broadcasting Union are presented. The effect of the project on the engineering education is emphasized under the concept of Robotic Competition Based Education in Engineering (RoC-BEE).In the said competition, each team represents a participating country and is selected through a comprehensive national competition in all participating countries. The students of IIT Delhi have been participating in the annual national-competition since 2003 and became champion in 2007 to represent India at the international-competition. In this journey of six years, the authors have realized the significance, impact and consequence of such competitions on the engineering education. During the preparations for the competition the students have to plan, synthesize (mechanical/ electrical/ electronics/ programming aspects), design, fabricate, assemble, test and debug the robots. The project embeds in them not only all aspects of engineering product development, but also teaches them management techniques essential for proper coordination of the team of 15-20 students.

Keywords: Project-based education, Robocon, Kinematic analysis

1. Introduction

A rapid evolving society with swift development in the field of information technology and globalization requires a graduated students to possess tools and skills which enable him or her to function successfully in ever-changing environments, take decisions, handle responsibilities and work in teams. Thus, students need to acquire not only a sound base of knowledge specific to their domain of expertise, but also a number of managerial, administrative and executional skills. They must be capable of applying the theoretical knowledge gained through classroom studies in practical applications. Alternative learning methods and environments like project-based learning are playing an increasingly important role in shaping the students for their future professional life. Project-based education is a learning environment congruent with the principles of student- and competence-centered vision. It can be seen as a pedagogical innovation which integrates theory and practice by means of problem solving of working life issues[1]. A number of experimental and theoretical investigations have been done on the application, development, and benefits of project-based learning in education. Integrated group-work leads to improvement in the attitude towards working with others and academic-performance of students[2]. The role of the student changes from that of a consumer in a traditional classroom based setup to a more involved role of

an actor in project-based learning[3]. Excellent results in teaching basic electrical measurement at the fourth year of university studies have been achieved by Èugene due to increased maturity of students at this stage[3].

According to current literature, traditional assessment methods are considered to be less appropriate to measure the level of understanding and skills students acquire by project-based learning[1]. An assessment format that relies on many different evaluation aspects and fits the characteristics of the particular learning environment is required[1]. Here, a project-based education through open-competition is highlighted. In project-based education through open-competition, say, RoboCon, the goal is defined and final outcome is judged by people from all walks of life instead of a group of examiners. This emulates real life engineering and product development. Each year, the students at IIT Delhi develop robots over a period of seven months for the Annual National RoboCon. The robots developed by them are appraised through peer review, expert reviews and through the competition between the participating colleges. After the competition, further development of robots and assessment of the students is done through a Mini-project. In the Mini-project the students are encouraged to theoretically study and optimize the robots. They are motivated to extend the work they have done while preparing for the RoboCon and modify the robots for industrial and other practical applications. The students are then evaluated by a group of examiners (professors) on the basis of how the students could correlate these projects with their lectures; understand the importance of design, production drawings, circuit diagram etc.

The paper is organized as follows: Section 2 presents an overview of various robotic competitions and RoboCon. Section 3 presents the preparation and performance of IITD students at RoboCon 2007 when the team won the national competition and represented India in Hanoi, Vietnam, while Section 4 correlates the RoboCon competition with academic project through Mini-project. Finally, conclusions are given in Section 5.

2. Robotic Competitions

Robotics is a field born out of the desire to automate. Making things happen by themselves is easier said than done. Development of robots involves repeated planning, trial manufacture, experimentation, analysis, and improvements. In order to emphasize and import these amongst the engineering students, several robotic competitions are held around the world, at institute level, national level and international level. Few of them are briefly described below:

Fig. 1: Robocup 2006 Game Field

1.*RoboCup*[4]: It is an international initiative to foster research in the field of robotics and artificial intelligence, using robotic soccer. The International RoboCup Competition entails the construction of fully autonomous, fast moving robots, which work together as a team to compete against similar teams of robots in a robotic soccer match. Figure 1 shows the game field for RoboCup 2006.

2.*RoboCon*[5,6]: This competition involves the building a team of robots, and the software to control them, in order to achieve a particular task within a given time against another team. The

theme of the game changes every year based on the country hosting the competition. For example, Fig. 2 shows the game field for the competition held in Vietnam on August 26, 2007.

3.*RoboFesta*[7]: RoboFesta typically includes several robot competitions, as well artistic performances.

4.*FIRST*[8]: This Robotics Competition is an exciting, multinational competition that brings together professionals and young people to solve an engineering design problem in an intense and competitive way.

5.*National Robotics Challenge*[9]: It consists of different robotics contests in USA with several levels of difficulty that are sure to challenge any student who wants to participate and demonstrate their engineering ingenuity and creativity encouraging them to pursue rewarding engineering careers.

6.*Eurobot*[10]**:** Eurobot is one of the most innovative robotic competitions in the world. In this competition two fully autonomous robots must compete one against each other, following specific rules. The rule set defines each detail of the match, but at the same time leaves enough space to team fantasy.

2.1 Robotics Contest (RoboCon)

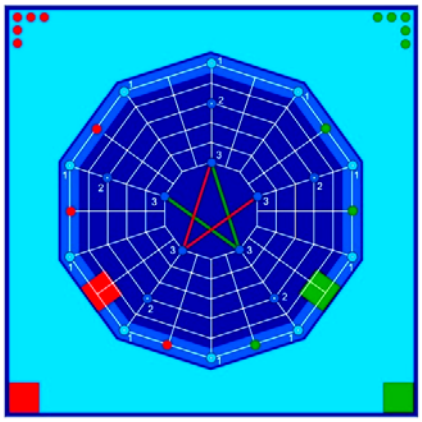


Fig. 2: Game-field for RoboCon 2007

RoboCon, an acronym for Robotics-Contest is an annual robotics competition organized by Asia-Pacific Broadcasting Union (ABU) for university, college and polytechnic students in the Asia-Pacific region. The competition entails the participants to compete with their peers in other countries from Asia-Pacific region to create a set of robots using their creative and technological abilities in an open competition, under a common set of rules. It involves not only building a team of robots but the associated software to control them. The Robots are categorized as Autonomous and Manual, to distinguish the former that is pre-programmed from the latter that is controlled by a human operator through a panel control and/or joystick. Each year, a new problem statement is designed by the hosting country and all the participating colleges have to make a robotic team of their own to solve it. Each year, a new problem statement is designed and all the participating colleges have to make a robotic team of their own to solve it. Today, it has become the stage where robots from the best engineering colleges of Asia-Pacific region compete. It has emerged as the most sought after award among robotics students in many countries. For example in Thailand 125 teams out of about 150 engineering colleges in the country took part in their National-RoboCon competition 2007[6], whereas Vietnam saw about 400 colleges taking part in their national-competition.

2.2 RoboCon 2007

A brief introduction to ABU RoboCon 2007 held in Vietnam is given in this sub-section as an illustration to the complexity level of RoboCon competitions. As the competition was hosted by Vietnam the rules were based on the legend of Ha Long bay in Vietnam. Robots (symbolizing dragons) have to carry the blocks having the shape of cylinder (pearls) to build islands symbolizing 'Ha Long' and 'Bai Tu Long'[5]. Teams have to operate a manual machine

(symbolizing the Mother dragons) and automatic machines (symbolizing child dragons) to put the 'Pearls' on the 'Islands'. The first team to complete the building of 'Victory Island' (in the shape of letter 'V' in the centre of the game field) as indicated in Fig. 2 will be the winner. Duration of the game is three minutes. In case no team forms Victory Island, the winner is declared based on points scored by placing Pearls at different locations of the field.

3. IIT Delhi Students for RoboCon

The students of IIT Delhi have been competing in national RoboCon for the last six years, since 2003. The team generally consists of 2nd and 3rd year undergraduate (UG) students (competition is open to only UG students) from Mechanical, Electrical, Computer Science, Mathematics, Engineering Physics and other disciplines. Sometimes students from Chemical Engineering and Civil Engineering also join but they loose interest when they cannot correlate the competition activities with their lectures. This is an interesting and may be quite obvious outcome of our experiments. But it reinforces the fact that as a student if he or she cannot connect the robotics project with the classroom teachings, no effective lesson can be imparted in them. Next, the 1st and 4th year UG students generally avoid taking part in RoboCon competitions. While 1st year students feel they are not ready for the task, the 4th year students, even though they may have taken part in previous years, remain busy in their on-campus job interviews. In order to rectify the situation, the 1st year students are encouraged to have hands-on-experience by bolting, hammering, screwing, soldering, etc., so that they can get priority in the next year's core team. Besides this, they are encouraged to study the previous year's robots, their design and also to recreate the CAD drawings of the robots or the controller circuits during the summer vacation of about 80 days. The summer activity prepares them to take a very active role in the next year's competition. The 4th year students on the other hand are requested to play more of analyst's and consultant's role where they can take up one or two of the robot building or design as their final year project of one year duration. Through such projects they would be able to provide in-depth analysis that will certainly help their juniors to build more robust and reliable robots. The team of 2007 has won the national championship to represent India in Hanoi for the ABU RoboCon held on Aug 26, 2007. Even though IIT Delhi lost the matches in Hanoi, as a team its best performance in the national level was achieved after 5 years of continuous participation. Hence, the activities of 2007 are highlighted in this paper to enforce the success of Robotic Competition Based Education in Engineering (RoC-BEE).

3.1 Team Selection, Structure and Job Assignment

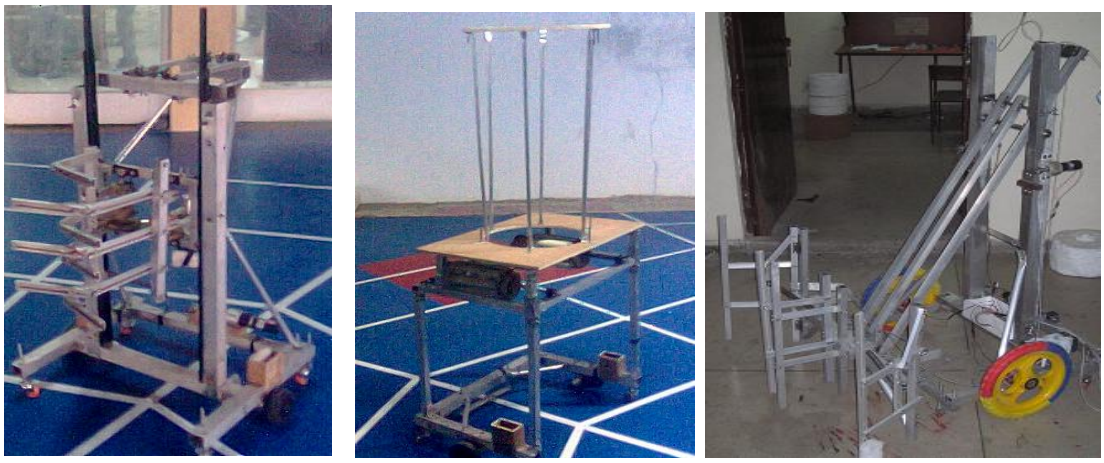
For RoboCon 2007, an introductory session was organized in the college in August, 2006. All students interested to work for RoboCon 2007, were invited for a design competition on the theme of the actual competition. On the basis of the past record, ability and enthusiasm as judged through the design competition, the interested students were shortlisted for Core Team and Extended Team. The Core-Team included Team Leader, Mechanical Coordinator, Electrical Coordinator and 7 other members, and was responsible for the overall project success. Extended Team consisted of 20 students mainly newcomers and was responsible to support the Core Team in market-survey, room-maintenance and other non-technical activities. A separate post of Treasurer was made to deal with the accounts and financial matters.

The team was then divided into four sub-teams, three of these teams were responsible for the development of the three separate robots viz. Automatic 1, Automatic 2 and Manual Robot. While the fourth team was responsible for developing strategies for the robots under different game conditions. Mainly three streams are preferred at the time of Team selection; those are Mechanical Engineering, Electrical Engineering and Computer Science. As Computer students are lesser in number, they are solely kept busy in Technical jobs. On the other hand, Mechanical or Electrical students being on majority, deal with the non-technical jobs as explained in 'Job-Assignment' section. Students from other branches are kept with any one of the above teams based on their interest relevant to robot design and fabrication.

3.2 Performances of IIT Delhi students

Even though RoboCon started in 2002, IIT Delhi started participating since 2003. Its performances over the years are as follows:

2003: Reached semi-finals amongst 7 participating teams.
2004: Reached semi-finals amongst 14 teams beating champion of 2003.
2005: Reached quarter-final amongst 17 teams; Second highest scorer.
2006: Reached semi-finals amongst 23 teams; Award for best manual robot and operator (a special award announced on-spot for IIT Delhi)
2007: Winner of national RoboCon 2007 amongst 25 teams. The winning robots are shown in Fig. 3.
2008: Reached semi-finals amongst 38 teams; Award for best manual robot and operator.



(a) Automatic 1 (b) Automatic 2 (c) Manual

Fig. 3: Winning robots for national RoboCon 2007

Table 1: Estimated work-done by an average-student for national RoboCon 2007

S. No	Work Done	Month	Hours/ day	Days/w eek	Wee ks	Total Hours
1.	Formalization/Planning, Rules, Team Formation	Aug.'06	3	3	4	36
2.	Market Survey/Initial Design	Sep.'06	3	5	3	45
3.	Final designing and force analysis	Oct.'06	4	5	4	80
4.	Drawings and design approval	Nov.'06	4	4	2	32
5.	Manufacturing	Dec.'06	8	7	3	168
6.	Assembly and debugging	Jan.'07	4	6	4	96
7.	Testing	Feb.'07	4	7	4	112
					Total Hours	**569**
					Hours/Week	**23.7**

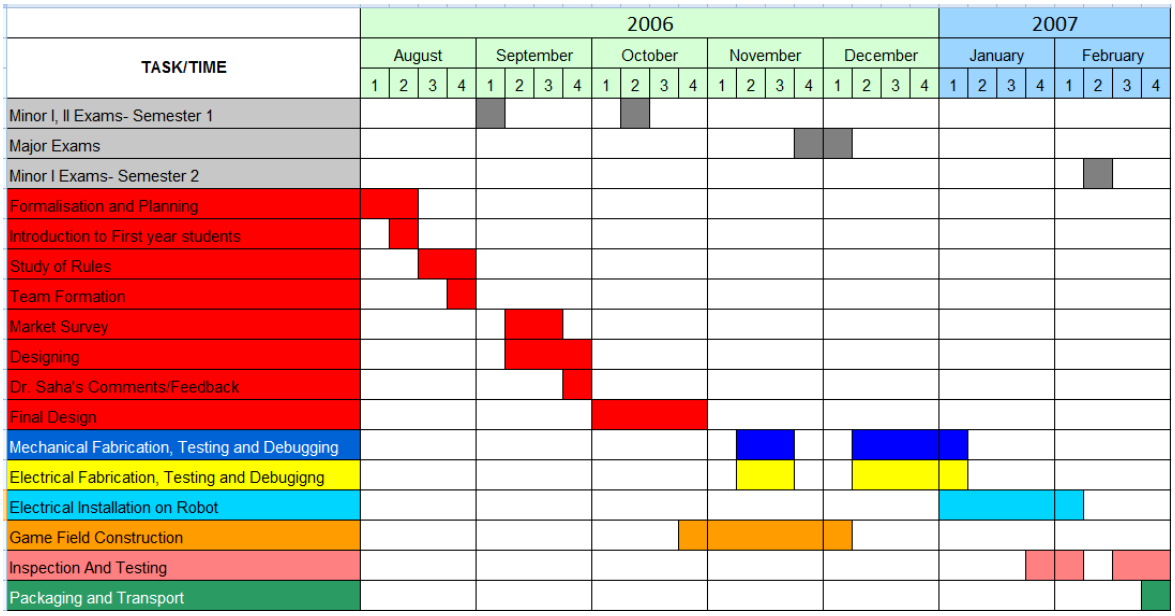


Fig. 4: Gantt-chart for national RoboCon 2007

Table 2: Average CGPA

Participating Students	CGPA Before RoboCon,2007	CGPA After RoboCon,2007	Rise in CGPA
Nine 2nd Year	7.55	7.71	0.16
Nine 3rd Year	7.23	7.38	0.15

In order to successfully synthesize, design, build and integrate the mechanical, electrical hardware with the appropriate software the time schedule shown in Fig. 4 was followed. As indicated in Table 1, an estimated total of about 569 hrs were devoted by a student for the RoboCon 2007, i.e., an average of about 23.7 hrs per week which is more than a 4 credit course at IIT Delhi. Due to such intense involvement the authors suspected some adverse effect on the students' academic performances. Hence, the Cumulative Grade Point Average (CGPA) of 18 actively engaged students were checked. As shown in Table 2, the average CGPA has increased rather than dropped. This may be attributed to the facts that while working on such projects the

students were able to see the practical applications of what they study in the class. This helps them to understand the theoretical subject better. This not only gives them a pleasure but makes them enthusiastic about learning the related subjects even more keenly. As a result, there was an increase in CGPA. Even though the statistics for RoboCon 2007 is given, the outcome is similar in other years as well. Note however that the personal interaction with those few whose CGPAs have decreased after RoboCon revealed that they do not want to leave this activity to concentrate only on lecture-based studies. In fact, in some cases with appropriate counseling on how to manage time, the CGPAs have also improved later.

4. RoboCon as Academic Projects

During the last six years in which IIT Delhi had participated no credit was earned for their degree requirement. This has deterred many other students who otherwise have been interested. So attempts were made to include these activities in the curriculum through academic Mini or Major projects that can earn credits. This helped to attract students not only for the competition but also how they can encash their hard work to convert it to credits. Typically, the preparation for RoboCon competition at IIT Delhi starts in the month of August every year, as indicated in Fig. 3, after the game plan for the next year has been announced. It continues till the beginning of March of the following year when the national competition is held. After the competition, further development of robots was done by some students as their Mini-projects (MiniP). For 2009 RoboCon, some final year students have registered for their Major projects in July 2008. In such projects, the students are encouraged to scientifically analyze/study the robots, refine/modify to suit industrial/practical applications and undertake complete documentation of the robots. As an illustration, MiniP work on a RoboCon 2007 robot is presented.

4.1 Mini-project (MiniP)

The main objective for RoboCon 2007 competition was to develop robots to pick circular blocks kept on the ground or at some height and places them on an elevated platform. After the national competition, the team realized certain shortcomings in the robots which need to be rectified for the International competition. Hence, one of the objectives of the MiniP was to undertake kinematic and dynamic analyses of one of the robots namely, Automatic 1 as shown in Fig. 3(a). Here, only the kinematic analysis and some associated optimization of the gripper mechanism of the robot are presented.

4.1.1 Automatic 1

The design of the automatic robot 1, as shown in Fig. 3(a), was developed in Pro-E solid model. This is shown in Fig. 3. It has three separate parts, namely:

1. *Gripper,*
2. *Lifting Mechanism, and*
3. *Base*

As the gripper has to move up and down, it is mounted on two vertical telescopic channels as shown in Fig. 4. The upward motion is provided with the help of a motor, which being the heaviest part in the assembly, is placed at the lowest point in the

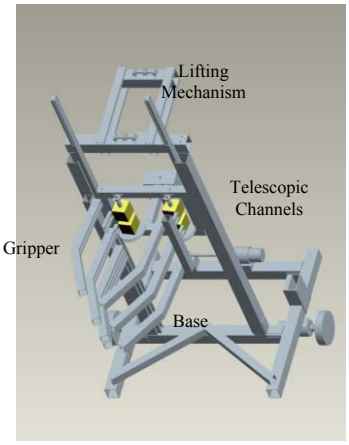


Fig. 3: Solid-model of the robot

robot at the back to keep the centre of gravity as low as possible and increase its stability. For smooth transfer of motion from the motor to the gripper assembly a three-pulley-arrangement is used as shown in Fig. 5. The gripper assembly is planned to have the following specifications:

a. Vertical Motion : *900mm*
b. Maxon motor: *15 W*; gear ratio *226:1*
c. Time required by the gripper to lift up to its upper limit: *9 sec*
d. Time required by the gripper to move down from its upper limit: *7 sec*

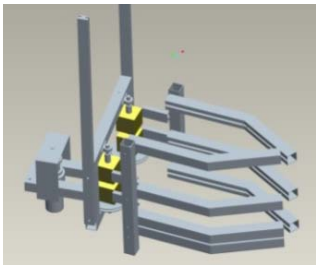


Fig. 4: Solid Model of the gripper

The two gripper arms are controlled by a single motor so that both of them open and close symmetrically, with the same angular displacement and velocity. This is important as the block must be aligned with the axis of the pole. Note that the fingers of the two gripper arms are placed in different planes so that they can crossover each other to save space. The gripper has been designed in such a way that the centre of mass lies approximately in the same plane in which it is being lifted. Moreover, the base is provided with two Maxon motors. To give linear to and fro motion both the wheels are given rotations in the same direction with almost same RPM. The turning is a rotation about a vertical axis passing through the axis joining the motors. The optimum linear speed obtained is 1.5 m/s while a turning speed of 190 degree per second can be achieved.

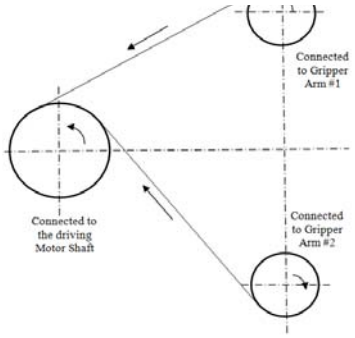


Fig. 5: Three-Pulley arrangement

4.1.2 Kinematic analysis of gripper mechanism

A complete kinematic analysis of the robot was undertaken. Here the general methodology followed and the results obtained from the analysis of the gripper mechanism are presented.

a. The entire robot is divided into three separate parts, i.e., the gripper mechanism, the lifting mechanism and the base.
b. Simplified modeling of each part was done. All dimensions were kept variable to obtain an optimized value of the system variables. For example the variables for the gripper mechanism are indicated in Fig. 8.
c. Input-Output table are obtained for each geometry. Table 1 lists down all the symbols for inputs and output.
d. Generalized output equations were developed as a function of the input data1[11]. For example, the equation below relates the angle when the gripper is fully open (α_3) to the various input parameters.

$$\alpha_3 = -\tan^{-1}\left(\frac{q\sin\theta}{q\cos\theta - p}\right) + \sin^{-1}\left(\frac{k - \frac{D}{2}}{\sqrt{p^2 + b^2 - 2bp\cos\theta}}\right)$$

e. Based on the above equation, Matlab code was written to display the mechanism and the outputs for suitable inputs. This provided a user friendly interface for studying the kinematics of the mechanism. Sample screenshot and the input parameters corresponding to it for the gripper is shown in Fig. 9. It shows three states of the gripper viz. closed, gripped and open. The maximum area enclosed by the gripper is also displayed by a rectangle.

f. Optimization of the gripper mechanism is done next. Motion of the gripper is optimized from the plot between the variable inputs and outputs. For the gripper, outputs are plotted as a function of Θ for a range of 30°< Θ <150° keeping the other input as fixed. Fig. 10 shows a graph between the area occupied by the gripper and angle between the two links.

g. The optimized values of Θ for achieving different objectives are given in Table 2. Depending upon the requirement of the designer the required value can then be selected. For example, the gripper opens up in the minimum time if the included angle between the gripper-arm (θ) is kept at 105°.

Table 1: Input-Output table for the gripper

Input	Symbol	Output	Symbol
The distance of hinge point from the centreline	k	Angle when the gripper is closed	α_1
Length of AB	p	Angle when gripping the block	α_2
Length of BC	q	Angle when fully open	α_3
Angle between the two links, AB and BC	Θ	Point at which the block touches the link AB	a
angular velocity	ω	Point at which the block touches the link BC	b
angular acceleration	dω/dt	Position of the center of block	X_c, Y_c
Diameter of the block	D	Angles at which it touches the block	Γ_1, Γ_2
		Maximum space required by the gripper	AXB
		Time from closed to fully open	t_1
		Time from fully open to gripped position	t_2

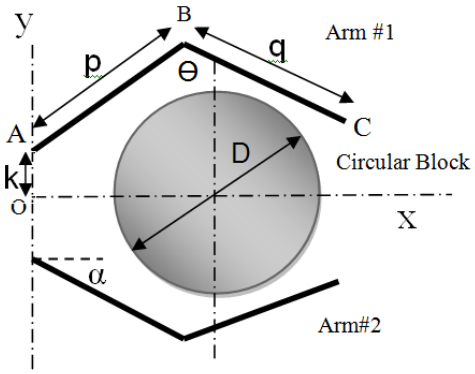


Fig.8: Simplified schematic of the gripper mechanism

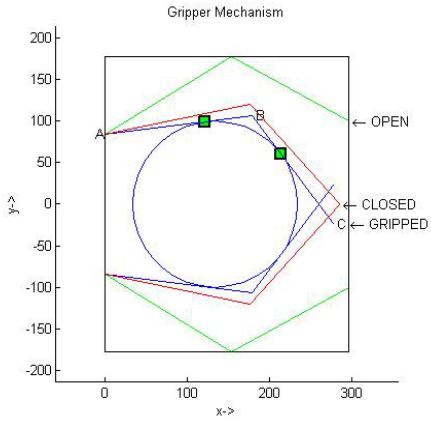


Fig. 9: Screenshot of Matlab screen showing gripper; p=180;q=162;k=84; Θ= 120°

Table 2: Optimized value of Θ

S. No.	Objective	Optimized Θ
1	Minimum Volume Requirement	62°
2	Minimum Centre Distance	59°
3	Minimum Opening Time	105°
4	Minimum Closing Time	140°
5	Maximum Included Angle	60°

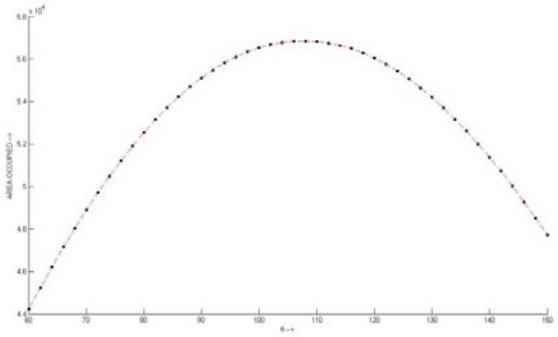


Fig. 10: Graph between the area occupied by the gripper (y axis $X10^{-4}$ m^2) and angle between the two links (x axis deg.)

4.2 Evaluation

The evaluation of the MiniP is done in two stages. The first evaluation is done typically in the middle of 14 weeks semester, i.e. around the fourth week of February. The students have to submit a report explaining the aim, literature review, work-plan, and any initial work done by them on the study. The students are also required to give a presentation of 5mins to a jury of 3-4 professors followed by 5 mins of question and answer round. During this gathering the professors evaluate the feasibility of the work-plan and the aim of the study. The final evaluation of the MiniP is done in the month of May at the end of the semester. The students formulate the research goals, design the research methodology, collect and analyze the data and finally report the research results. In order to manage this, the students need to combine and apply subject-matter gathered in the various subject-courses learned in the previous years. The research report of each group is submitted to an evaluator (professor). The students are also required to present their research results to the jury. During this gathering, the instructors also share their experiences with and opinions about the quality and dedication of each group. Based on the discussions and the comparison between the different researches, the jury gives a score to each research. The final score is composed of the jury's grade for the evaluation of the presentation, the evaluator grade for the evaluation of the research report and the instructor's evaluation. The MiniP under discussion scored A- grade which is equivalent to a score of 9 out of 10.

5. Conclusions

This paper presents how a Robotic Competition Based Education in Engineering (RoC-BEE) concept can be effective in a UG curriculum. Illustration of RoC-BEE is made through Robotics Contest (RoboCon) organized by the member of the Asia-Pacific Broadcasting Union (ABU) in India, i.e., Doordarshan. Note that the interconnection between the hardware and the theoretical development is generally missing during the development of robots for the competitions. Many times the students take intuitive decisions for the choice of certain parameters, e.g., the included angle between the fingers, and perform trial and error to get a satisfactory value. This, obviously take a lot of time. Through MiniP, the students became aware of the mathematical tools and software available to do the analysis. The students under discussion used Matlab to quickly and

efficiently evaluate the included angle between the fingers of the gripper of automatic robot 1. It also prepares the students for future research work to be undertaken by these students.

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