LEARNING CONTROL SYSTEM DESIGN USING NANO DRONE IN A PBL FOCUSED ONLINE ROBOTICS COMPETITION

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Teaching advanced conceptual knowledge and practical skills in a hands-on-manner to a large number of students is a challenge. The e-Yantra project hosted in IIT-Bombay, through it's e-Yantra Robotics Competition (eYRC) for college students, teaches these skills scalably. Participation is free and hardware is shipped to participants who are mentored constantly throughout the competition. The 7th edition of the competition, eYRC-2018, had a theme (a gamified problem statement), called "Hungry Bird," that taught Marker-Based Localization, Path planning using OMPL, and Waypoint Navigation using PID on a nano-drone using open source platforms such as ROS and V-REP. This paper outlines how we optimally designed and deployed these concepts as a series of tasks which eventually helped us to quantify the learning outcomes among students. 832 students were assigned this theme, and to achieve scale most of the tasks were automatically evaluated. Finally we illustrated how we have achieved the effectiveness of the theme with task results and participant's feedback. This study and its outcomes are beneficial for academicians seeking to teach advanced engineering skills at a large scale.

INTRODUCTION

e-Yantra, a project at IIT Bombay funded by the Ministry of Human Resource Development (MHRD), exists to develop and deploy transformative digital pedagogies to train both college faculty and students the concepts of robotics and embedded systems. One way e-Yantra implements this for students is through the e-Yantra Robotics Competition (eYRC) (Krithivasan et al., 2014a) that has been growing exponentially since it's launch in 2013 having had 28000 registrations (as teams of four students) in the 2018 (eYRC-2018) edition. The eYRC competition has effectively shown that students learn while competing and compete while learning (Krithivasan et al., 2014b) and delivers hands-on learning to a large number of students across the country at the undergraduate level. The training follows a project-based learning approach that teaches participants core skills in robotics and embedded systems by having them solve problem statements that are gamified instances of real world problems termed "themes." A theme contains a series of tasks culminating in a final implementation of a theme with continuous mentoring and progress evaluation. Using the model, students were successfully trained in Image Processing (Krithivasan et al., 2016), 3D modelling and Designing (Karia, 2018) and much more.

Following the same model, a complex theme entitled **Hungry Bird** was introduced in eYRC 2018 which aims to teach participants a general understanding of control system design by Waypoint navigation using parallel PID controllers on an external control loop based on marker-based localization to command velocity of a nano-drone in reference to its pitch, roll, yaw and throttle. Participants were taught marker-based localization using WhyCon (Nitsche, Krajnik, Cizek, Mejail, & Duckett, (2015) and ArUco (Babinec, Jurišica, Hubinský, & Duchoò, (2014) markers, Computing global path using OMPL (Sucan, 2012), Waypoint navigation using PID controller (Åström, 1995) and methods to tune PID parameters. The competition also aims to give students exposure towards Scripting languages such as Python and Lua, open source simulation platform V-REP (Rohmer, 2013) and middleware, ROS (Quigley et al., 2009). This theme was also an experiment in auto evaluating submissions of a large number of students. This paper focuses on the design aspects of tasks and learning outcome of this theme.

This theme showcased the diligence of parent birds by conveying a story of a bird feeding its young. A drone represented the bird whose job was to autonomously fly through a series of (hula) hoops to signify gathering and subsequently feeding fledglings. This paper describes how we designed and deployed these concepts as a series of tasks. Each task aims to impart certain skills which helps the participants to solve the Final problem statement.

28,976 students registered for the competition in teams of 4 thus amounting to 7244 teams from colleges across India, Nepal and Bhutan. The teams have to first pass a selection test which tests them for knowledge of basic electronics, basic programming and aptitude. Following this shortlisting criteria, 1544 teams qualified to participate in the competition out of which 208 teams were assigned this theme.

COMPETITION DEPLOYMENT AND INSIGHTS GAINED

The Hungry Bird theme was conducted in two stages as illustrated in Figure 1.

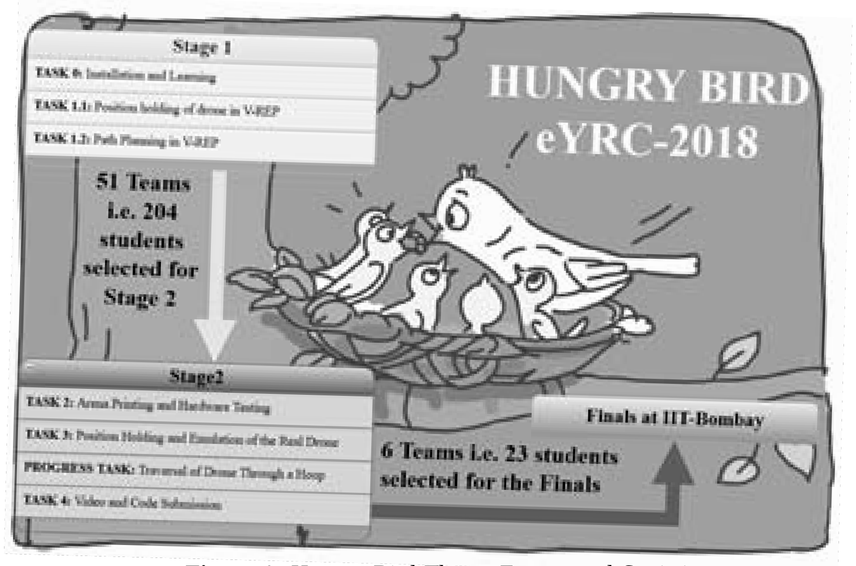

Figure 1: Hungry Bird Theme Format and Statistics

Stage 1 : Participants compete using a drone model in a Simulator

Stage 1 consists of two tasks, viz., Installation and Learn (Task 0) and Implementation of the theme in the simulator, V-REP (Task 1).

Task 0 : Installation and Learn

This task aims to introduce participants to Robot Operating System (ROS) and V-REP (Virtual Robotics Experimentation Platform). Participants are taught about the Marker Based Localization system using Whycon and ArUco markers. Tutorials to learn Linux, Python, Basics of ROS and V-REP[1] and ROS packages[2] for interfacing V-REP and ROS, WhyCon and ArUco markers were provided to the teams. The task involves computing position of WhyCon and ArUco markers using the feedback from an overhead vision sensor in V-REP. The task was graded in a binary way if they have successfully displayed the output or not.

Figure 2: Drone model in V-REP

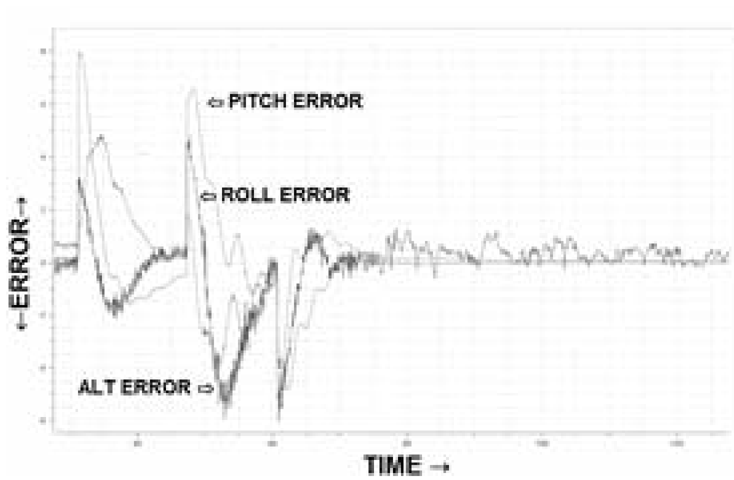

Figure 3: Plotting errors for debugging

Task 1 : Implementation of the theme in the simulator, V-REP

Task 1 consisted of two sub-tasks, viz., Position holding of drone in V-REP (Task 1.1) and Path planning in V-REP (Task 1.2).

Task 1.1 : Position Holding of Drone in V-REP

This task aims to teach participants about PID control by implementing algorithms in V-REP. A well designed drone model named "eDrone" as shown in Figure 2, which responds to ROS commands, is provided to the team. The task involves implementation of a PID algorithm to control the drone via ROS commands to hold its position at a given setpoint using the Localization system which the participants have learned in Task 0. Video tutorials[3] were provided to learn how to implement the control algorithm and how to effectively tune the PID parameters. Classical PID algorithm and ways to improve the algorithm to the task requirement are

1 https://youtu.be/l5RDBuIM3U8, https://youtu.be/ioNNvy805-4, https://youtu.be/DylQbGCF5ps, https://youtu.be/WB0zCufrHOM

2 https://github.com/fayyazpocker/vrep_ros_interface, https://github.com/lrse/whycon, https://github.com/pal-robotics/aruco_ros

3 https://youtu.be/BJ-hkJ2kdR4, https://youtu.be/7KcMoazeeTM, https://youtu.be/SNO_Vm7bpio

also taught. They are taught how to interpret the effectiveness of the algorithm using real time plotting of errors as shown in Figure 3**.** Use of Ziegler-Nichols (Ziegler, 1942) method to tune PID parameters and in-flight tuning of PID parameters using ROS topics are also taught.

Teams were instructed to submit a log file (rosbag) which contains information of the pose of the drone throughout the run. The log file was automatically evaluated based on an algorithm which takes the parameters like time taken by the drone to reach the setpoint, overshoot of the drone from setpoint and stability of the drone at setpoint. Code submitted by the teams were evaluated based on computation of error, Proportional, Derivative and Integral Term in PID and Sampling time of PID. This task comprised 40 marks of which 20 marks were based on automatic evaluation of the rosbag file and 20 marks were based on evaluation of code.

Task 1.2 : Path planning in V-REP

This task helps participants learn to compute global path using OMPL plugin available in V-REP. A V-REP scene as shown in Figure 4 with obstacles and target locations are provided to teams. The task is to control the drone to reach each target point represented by blue, green and red spheres whilst avoiding obstacles. Required video tutorials[4] for the completion of the task were provided. Learnings in Task 0 and Task 1.1 will help in completing this task. Similar to Task 1.1, the log file submitted by the participants were used for automatic evaluation of the submission considering parameters like time taken by the drone to cover all targets, the number of targets the drone covered and the deviation from the optimal path. This task comprised of 60 marks out of which 40 marks were based on automatic evaluation of rosbag file and 20 marks for code evaluation. Cumulative marks of Task 1.1 and Task 1.2 were considered for selection for Stage 2. Figure 5 shows mark distribution graph for Stage 1 of 208 teams. The cut off for selection to Stage 2 was set to 50 marks. Out of 208 teams, 51 teams got selected.

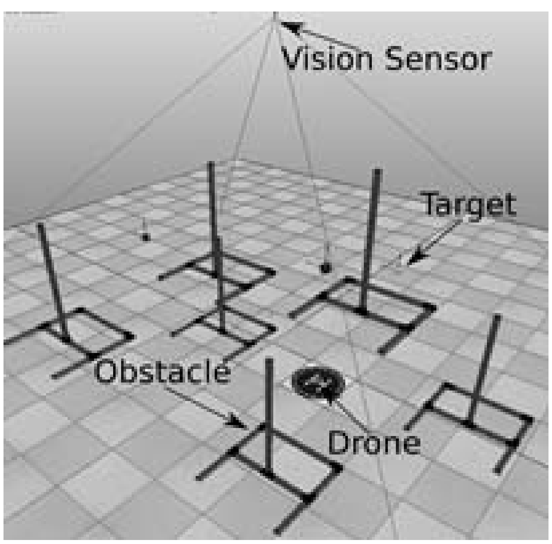

Figure 4: V-REP scene for Task 1.2

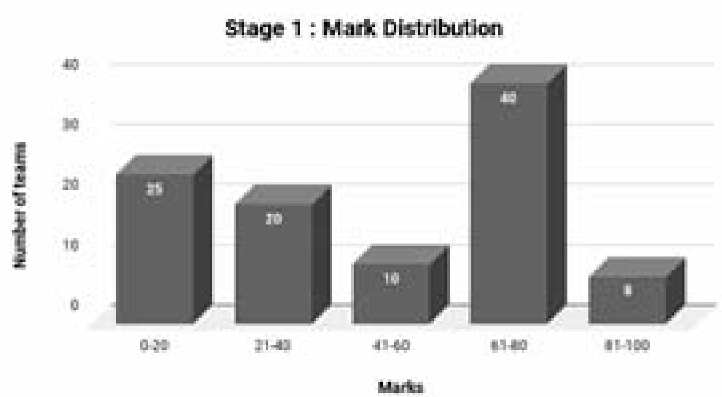

Figure 5: Mark distribution in Stage 1

4 https://youtu.be/F9U-cCAoBM8, https://youtu.be/beHLO-E6bgI

Stage 2 : Participants compete with given drone kit

Stage 2 consisted of four tasks, viz., Arena Printing and hardware testing (Task 2), Position holding and emulation of real drone (Task 3), Traversal of drone through a hoop (Progress Task) and Video and Code submission (Task 4). The selected teams were sent a PlutoX drone[5] along with hula hoops. PlutoX drones are connected wirelessly to a laptop and controlled using ROS commands, same as how a drone model is controlled in V-REP in Stage 1. Teams are given a Rulebook[6] which gives detailed rules and information regarding theme implementation. It describes how to set the arena, rules to be followed and a formula to be used to evaluate their submissions. The arena is a representation of a Jungle as shown in Figure 6. The drone termed "Bird" must navigate through hula hoops of different colours which represents different types of trees based on the feedback from a camera placed at ceiling height as shown in Figure 6.

Task 2 : Arena Printing and Hardware Testing

In this task, teams print the given arena on a flex sheet and setup the arena as per the Rulebook. Teams were provided with sample videos and manuals to test the drone. This task aims to teach the participants pose estimation of hoops using ArUco markers. They were given a task to programmatically emulate hoops set in a given position and orientation in real world into V-REP, on completing which they had to submit a screenshot having both image output from the overhead camera and the top-view of the V-REP scene as shown in Figure 7. This task carried 20 marks & was graded based on successful emulation of hoops.

Task 3 : Position Holding and emulation of real drone

This task aims to teach the participants implementation of PID algorithm on a real drone. In this task teams had to implement Task 1.1 with a physical drone. They have to hold the position of the drone at a given setpoint with reference to WhyCon frame i.e. [0,0,20] as shown in Figure 8. They also had to emulate the drone in V-REP using what they learnt in Task 2. Students also had to submit an assignment answering various technical and implementation related questions. The submission criteria and evaluation method were the same as Task 1.1. This task comprised of 100 marks out of which 60 marks were based on the automatic evaluation of rosbag file, 10 marks to successful emulation in V-REP and 30 marks for the assignment**.**

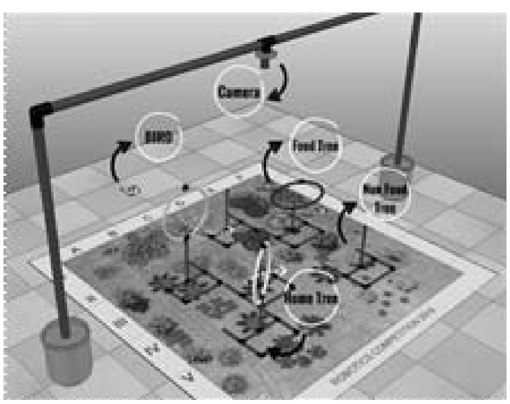

Figure 6: Hungry Bird arena setup

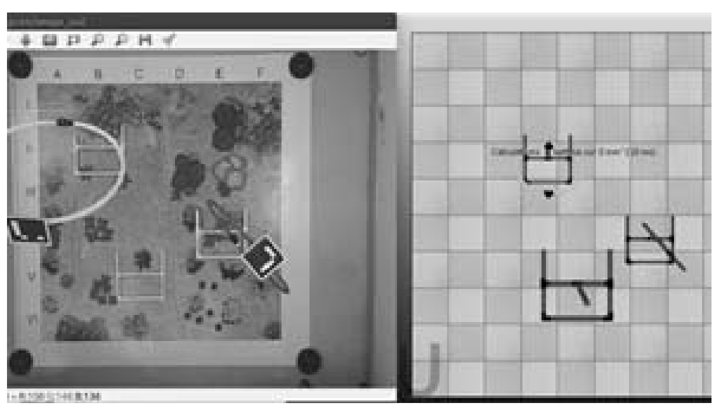

Figure 7: Emulation of real world in V-REP

[5] https://www.dronaaviation.com/plutox/

[6] https://drive.google.com/file/d/1IPPPzwfyCT0YsWydXEgytTdhSYa_iDfH/view?usp=sharing

Progress Task : Traversal of drone through a hoop

This task aims to teach the participants waypoint navigation of Nano drone through each path points in the generated global path. In this task, the teams are to control the drone to steer it through a hoop set at a given position and orientation as shown in Figure 9. The task carries 100 marks and was graded on the basis of the time taken to complete the task, emulation of the hoop using an ArUco marker, emulation of drone using a WhyCon marker, computation of the path and the number of collisions.

Figure 8: Position holding of Drone in Task 3

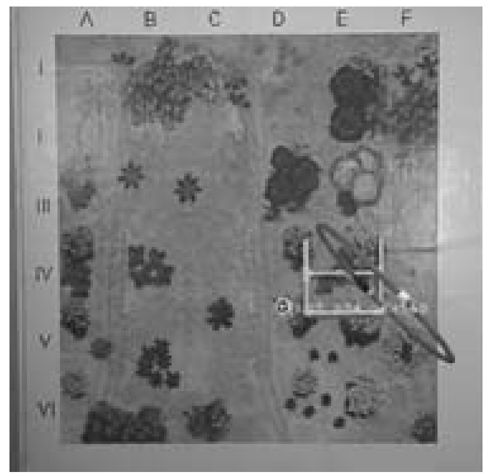

Figure 9: Traversal of drone through hoop

Task 4 : Video and Code Submission

In this final task of the competition, teams had to upload a video demonstrating their solution. Two configurations of arena setup were provided, one with less number of traversals and obstacles and a harder, optional bonus one. A run is considered successful if the drone traverses through hoops as per the given configuration without any collision. This task was graded based on a formula specified in the rulebook and evaluation of the final code. Cumulative marks of Task 4 and Progress Task were considered for selection in Finals.

Finals : Demonstration of theme at IIT Bombay

Six teams that demonstrated the best run (using the formula given by us in the Rulebook) for both configurations were chosen as Finalists to compete the Finals held at IIT Bombay.

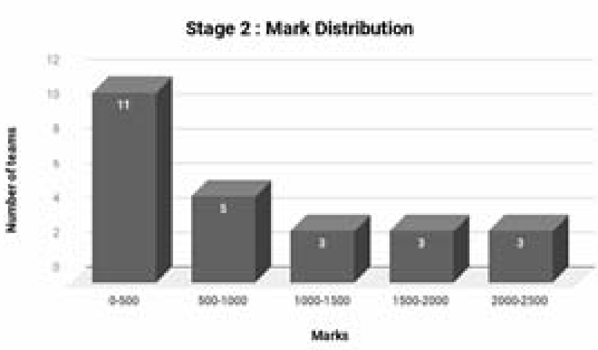

Figure 10: Mark distribution in Stage 2

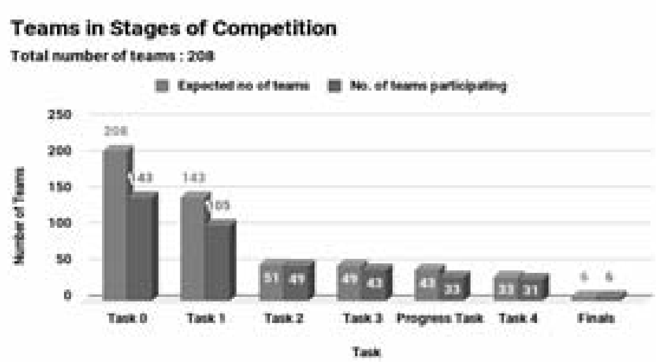

Figure 11: Teams in stages of the competition

ANALYSIS OF IMPACT AND EFFECTIVENESS

The primary objective of this competition was learning control system design and navigation using Nano-drone. Through this theme, students are given exposure towards Linux, Python, Lua, ROS, V-REP, PID tuning and automatic path planning.

We started with 208 teams for Hungry Bird theme. Figure 11 presents details of the number of teams participating in various stages of the competition. Expected numbers of teams are those who have made submissions of previous tasks. For instance, In Task 1, there are 143 expected teams as they have submitted the previous task, Task 0. 51, i.e. 24.51%, of the total teams selected for the theme were shortlisted for Stage 2. Hence 51 teams are expected to submit Task 2. As six teams were to be chosen as finalists, the expected number of teams for finals are six. Number of teams participating are the teams who have made a submission for the corresponding tasks.

Level *	Level Description *	Task	Skills Acquired
Imparting Knowledge	Recognition and understanding of facts, terms, definitions, etc.	Task 0: S/W Installation and Getting familiar with V-REP and ROS	• Installation & basic learning of V-REP and ROS • Learning Pose estimation using WhyCon and ArUco markers
Application of Knowledge	Use of knowledge in ways that demonstrate understanding of concepts, their proper use, and limitations of their applicability	Task 1.1: Position holding of Drone Task 1.2: Path planning in V-REP	• Implementation of PID to control drone in V-REP • Waypoint navigation of drone in V-REP • Learn to compute global path using OMPL
Critical Analysis	Examination and evaluation of information as required to judge its value in a solution and to make decisions/ selection of technology accordingly	Task 2: Arena printing, Hardware Testing Task 3: Position holding and emulation of drone	• Implementation of PID controller on a real drone • Real time emulation of drone in V-REP
Extension of Knowledge	Extending knowledge beyond what was received, creating new knowledge, making new inferences, transferring knowledge to usefulness in new areas of applications	Progress Task: Traversal of drone through a hoop Task 4: Video and Code Submission	To have a final working demo of the drone traversing through the hoops with given configurations

Table 1: Mapping level of learning outcomes to Tasks and Statistics

* Levels and Description of levels are taken from (Davis et al, 1997)

Table 1 summarizes the knowledge imparted to the participants from the competition in each task. Table 1 and Figure 11 shows that 68.75%, i.e. 143 out of 208 teams, have learned the basic concepts of ROS and V-REP. It also shows that 50.48% of total teams, i.e. 105 out of 208 teams, have participated actively in Stage 1 and have implemented PID controller to navigate the drone through the computed path in the Simulator. 24.5%, i.e. 51 out of 208 teams, had hands-on-experience with a real drone. 60.8%, i.e. 31 out of the selected 51 teams, actively participated throughout the remaining tasks and made final submission. It is interesting to note that once the student teams qualified for Stage 2, more than 75% participated throughout the tasks indicating less number of dropouts compared to Stage 1.

To learn the effect of our theme on the participants, we took feedback from them at the end of Stage 1 and Stage 2. 451 out of 832 and 141 out of 204 participants gave responses for Stage 1 and Stage 2 feedback respectively. Figure 12 shows that 77.8% of participants who have responded to the feedback feel that the tutorials were efficient enough to cover all the relevant topics involved in the theme. Figure 12 also tells that this theme has helped 86% of participants to have a better understanding of all the concepts and tools involved in the theme. Even though according to Figure 13, 71.6% of participants found the tasks difficult, more than 50% of the total teams have actively participated in Stage 1. This indicates that the tutorials and the guidance the participants received from Piazza was able to help them overcome these difficulties. 73.5% of participants (Figure 13) who feel that the response of the mentors from Piazza helped them to solve tasks further establishes that fact.

Students were also asked what were the most important things they liked about the competition. Many of them liked the way in which the problem statement was split into different tasks and the fact that completion of each task helps in bringing them a step closer towards solving the final problem statement. Apart from gaining technical knowledge, participants says that the competition helped them gain skills like team spirit, time management and leadership qualities.

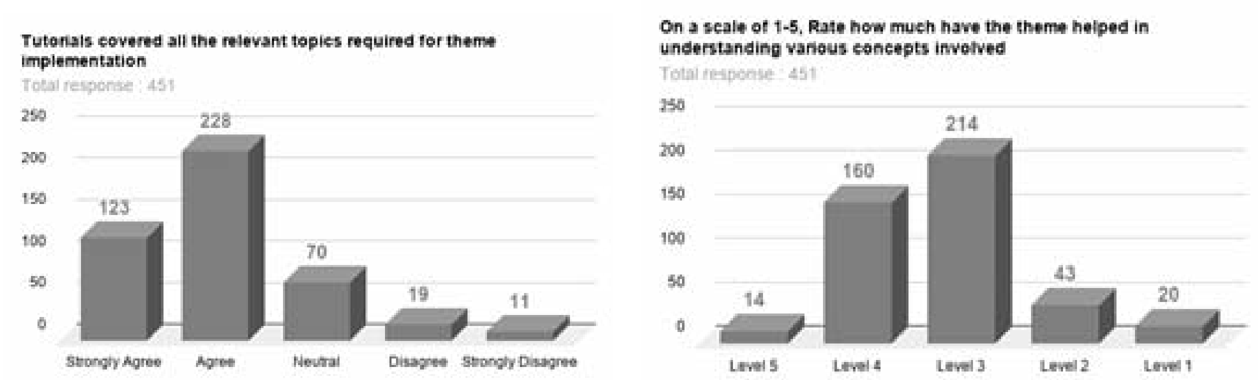

Figure 12: Responses from survey conducted after Stage 1

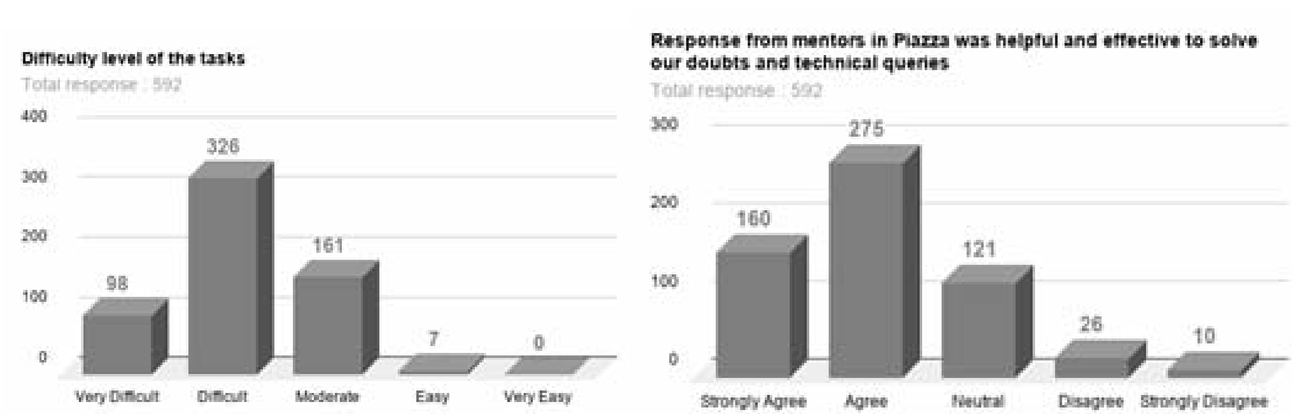

Figure 13: Responses from survey conducted after Stage 2

CONCLUSION

The analysis and the feedback from the participants validates the effectiveness of our ICT-enhanced, project based learning approach. It shows that the participants through the competition had a better understanding of control algorithms and have learned tools like V-REP and ROS. Exposure towards such platforms can help them in future to validate a project in a simulator and then implement it in the real world. Also, the model of splitting the project into various tasks can help participants to address a problem or project in a similar way in future. Alongwith effectively imparting technical skills, the competition also helps in improving team spirit and leadership skills. As most of the tasks are automatically evaluated, the model also opens up the door to scale the competition to a large number of students and we are hoping to teach college students at an ever larger scale in forthcoming editions of the e-YRC. Our success is seen in the participation levels since the competition began in 2012. Registrations have grown as follows: 4384, 6324, 12428, 19568, 22608, 23728 to 28672 registrations in 2018 - in spite of a 30% YoY reduction in engineering college seats since 2015.

ACKNOWLEDGMENTS

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