Knowledge Integration within an Applied Mobile Robot Summer Course

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Abstract – **This paper presents the use of a mobile robot platform as an innovative educational tool in order to promote and integrate different curriculum knowledge. Hence, it is presented the acquired experience within a summer course named "*Applied Mobile Robotics*". The main aim of the course is to integrate different subjects as electronics, programming, architecture, perception systems, communications, control and trajectory planning by using the educational open mobile robot platform PRIM. The summer course is addressed to a wide range of student profiles. However, it is of special interests to the students of Electrical and Computer Engineering around their final academic year. The summer course consists of the theoretical and laboratory sessions, related to the following topics: *Design & Programming of Electronic Devices*, *Modelling and Control Systems*, *Trajectory Planning and Control*, and *Computer Vision Systems.* Therefore, the clues for achieving a renewed path of progress in robotics are the integration of several knowledgeable fields, such as computing, communications, and control sciences, in order to perform a higher level reasoning and use decision tools with strong theoretical base.**

Index Terms – mobile robotics, multidisciplinary education, Electrical and Computer Engineering, integration of knowledge.

I. INTRODUCTION

Future directions in education are pointing towards the ability of understanding the technical details of a wide variety of disciplines [1]. In this sense, mobile robot platforms can be used as educational tools in order to promote and integrate different curriculum knowledge. Hence, control system society and computer science share a mutual interest on robotics. However, despite of the enormous progress in robotics over the last half century, this field is still in its infancy. For instance, the robot behavior is much simpler compared with the human behavior, in which its ability to move, to understand complex sensorial inputs, or to perform higher level reasoning, is limited. The clues for achieving a renewed path of progress are the integration of several knowledgeable fields, such as computing, communications, and control sciences, in order to perform a higher level reasoning and use decision tools with strong theory base [2]. Moreover, developed experimental environments have helped to breathe life into various control theories found in text books and have thereby greatly changed the educational experience of students [3]. Thus, students react positively to realism, since the models used for such experiments are in general accurately described by some relatively simple differential equations. Within this framework, the challenge of mobile robots is clearly exhibited. Within the educational community, the Robotics Education Lab becomes a resource to support courses of academic curriculum in a broad range of subjects. Some important institutions such like the Carnegie Mellon University have developed various teaching activities by introducing the mobile robots as a necessary academic tool from a broad sense in order to extend the acquired knowledge of the students. Moreover, other related activities are developed, such as the mobile robot competitions or some special summer programs like RoboCamp, which permit the students to do themselves the design, programming and construction of the autonomous robots. This paper presents the educational aspects of the developed summer course "*Applied Mobile Robotics"*. The course started in the summer of 2005 at the Polytechnic School of University of Girona. It was proposed by a group of faculty members belonging to the teaching areas of Control and Computer Engineering and sharing a common background that involves the research on mobile robots. The main aim of the course is to integrate different subjects as electronics, programming, architecture, perception sensors, communications, control, computer vision and trajectory planning by using the educational open mobile robot platform PRIM [4]. The academic skills are attained by the students in a broad sense; hence experiments are used to reinforce previously introduced knowledge by integrating relationships among different academic subjects. Thus, as a practical approach, the majority of the teaching activities of the course are carried out at our university labs. The students are greatly motivated by working on such a robotic platform, which permits them to consolidate the acquired knowledge and to extend their complementary curricula. The paper is organized as follows: In section I, the main ideas and research objectives are presented. Section II shows the community of students suitable for this teaching activity within the context of our university framework. The used robotic platform and the summer course program are presented from a wide scope concerning about the multidisciplinary teaching. Section III presents the detailed program related to the educational content of the summer course. Especially, attention is paid to describe the different experiments designed in order to fulfill the process of knowledge learning. The Section IV presents the main conclusions attaining future research directions as a feasible way to improve the student's feedback. Finally, the opinions of students are also outlined

II. THE EDUCATIONAL FRAMEWORK

This section presents the profile of related student's community to which the course is addressed. The headlines and schedule as well as the mobile robot platform used in the course are also introduced.

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A. Schedule of the Course and Student Curricula

The summer course is addressed to a wide range of student profiles. Both undergraduate and graduate students can take this course to consolidate their complementary study curriculum. However, it is of special interests to the students of Electrical and Computer Engineering around their final academic year. It is recommended that the student who wants to pursue the course had acquired previously basic skills in some fundamental issues as electronics, programming, control and perception systems. Moreover, it is provided a self-guided lab practice manual that includes the theoretical introduction concerning to the related issues. In this way, it is guaranteed that those students, being of different educational frameworks with different curricula, can follow the summer course without any difficulty. The number of students is limited to 12, accordingly with the lab reality and the need of a mutual relationship and contact between the students and teachers. Furthermore, the presence of two lab teachers allows the students to acquire different level of skills with an adequate assistance, accordingly with their educational background, through a continuous evaluation process. The summer course was developed during two weeks in July, with 4.5 hours everyday. The students passing successfully the course will be awarded to 3 credits that correspond to 45 hours of teaching activities. It consists of the theoretical (T) and laboratory (L) sessions, related to the following different topics:

- DPED: Design & Programming of Electronic Devices;
- MCS: Modeling and Control Systems;
- TPC: Trajectory Planning and Control;
- CVS: Computer Vision System.

The schedule of the course is shown in Table 1.

B. The Mobile Robot Platform

The mechanical structure of the robot PRIM, shown in Fig.1, is made of aluminum, with two independent wheels of 16cm diameters actuated by two dc motors. The distance between two wheels is 56.4cm. A third spherical omni-directional wheel is used to guarantee the stability of system. The maximum continuous torque of each motor is 131mNm. The gear reduction proportion for each motor is 86:1 and thus the total force actuating on the robot is near 141N. Shaft encoders, with 500 counts/rev, are placed at the motor axes, which provide 43000 counts for each turn of the wheel.

A set of PLD (programmable logic device) boards is connected to the digital outputs of the shaft encoders. The printed circuits boards (PCB) are used to measure the speed of each motor at every 25ms. Another objective of these boards is to generate a signal of 23khz PWM for each motor. The communication between the central digital computer and the boards is made through the parallel port. The speed is commanded by a byte and thus it can generate from 0 to 127 advancing speed commands. The maximal speed is near 0.5m/s. A set of microcontroller boards (MCS-51) is used to read the information available from different connected sensors. The distance between objects is provided by an array of 8 sonar sensors, which are based on ultrasound sensors within a range of measurement from 3cm to 6m. The data provided by these boards are gathered through the serial port in the central computer. The rate of communication with these boards is 9600 b/s. An absolute counter provides the counts in order to measure the robot position by the odometer system. Fig. 2 shows the electronic and sensorial system blocks. The data gathering and control by digital computer are set to 100ms, running in a embedded PC of 700 MHz. The proposed educational open hardware has its advantages in many aspects. First, the use of a structure similar to that employed by students at the laboratories can enable their easy understanding and prototyping of a new hardware of low level. Furthermore, the reinforcement of the teaching activities can be achieved through the knowledge integration of different subjects. The system flexibility is increased with the possibility of connecting it with other computer systems through a local LAN. Hence, in this research a network server has been implemented, which allows the different lab groups to make their remote connection with the mobile robot during different practices.

FIRST WEEK

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8:30-11:00	Welcome DPED (T)	DPED (L)	DPED (L)	MCS (L)	MCS (L)
Coffee break					
11:30-13:30	DPED (L)	DPED (L)	MCS (T)	MCS (L)	MCS (L)

SECOND WEEK

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8:30-11:00	MCS (T+L)	TPC (T)	TPC (L)	CVS (T)	CVS (L)
Coffee break					
11:30-13:30	MCS (L)	TPC (L)	TPC (L)	CVS (L)	Final demo

Table 1: Schedule of the teaching activity developed in the summer course.

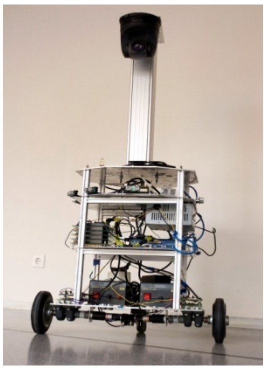


Fig. 1: Mobile robot educational platform PRIM.

III. THE MULTIDISCIPLINARY TEACHING PROGRAM

In this section it is developed the course program that consists of the theoretical and laboratory sessions, related to the following different topics:

Design & Programming of Electronic Devices. This bloc presents the robot architecture and the PLD (programmable logic device) and µp use. Finally, by using high level language from the PC labs, students can learn about how to use the created functions to realize the remote inter-actuation with the robot sensors and actuators.

Modelling and Control Systems. It is presented the concerned basic control theory related to experimental modelling, classic PID controllers design and optimal observers.

Trajectory Planning and Control. This bloc presents the strategies of trajectory planning as well as trajectory tracking by using techniques of speed control or MPC.

Computer Vision System. The last bloc introduces the computer vision as an advanced perception system that can improve the robot environment knowledge.

A. Design and Programming Electronic Devices

This subsection presents the DPED teaching bloc concerning about the architecture of the mobile robot PRIM. The basic devices to be programmed are the PC, the microcontrollers and the PLD boards. The sensor system, actuators and power drivers are also introduced. The theory addressed can be covered by concerning references as [5-6]. Once, these theoretical aspects are described and a set of practices are developed in order to consolidate the knowledge presented. The set of practices are divided in PLD, microcontrollers, and PC issues.

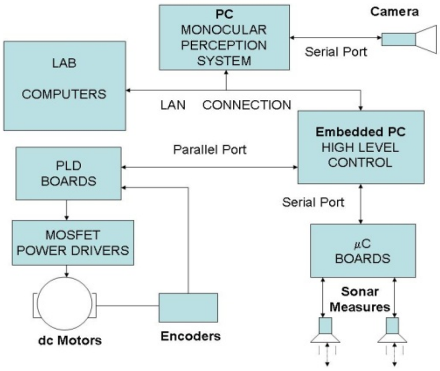


Fig. 2: Sensorial and electronic system blocs.

The proposed PLD practices are conducted to implement a PWM signal and odometer system approaches. The laboratory material used consists of logical trainers with multiple inputs and outputs, as switches, led (light emission diodes) and displays, which allow testing the different performed practices. The logical trainer includes the ispLSI1032E device used to program the different circuit tested. The set of PLD practices introduce the logic digital design by creating different basic blocs as a one bit magnitude recursive comparison and binary counters. Once it is done, students can perform different practical approaches as PWM (Pulse Width Modulation), Odometer system (robot position and speed) designs. Hence, the Fig. 3 shows the equations of one bit recursive magnitude comparison and the corresponding electronic scheme. By using previously developed basic blocks, students can approach to closer on-robot developments. Hence, for instance, the Fig. 4 shows the 4 bits PWM implementation, where the inputs (d0, d1, d2, d3) denote the selected value for the output PWM signal. The first microcontroller practice objectives are the knowledge of the hardware and software environment used with the 80C552 devices. The microcontrollers have integrated special functions as PWM, ADC (analog digital converter), or serial interface. Once again the knowledge is pursued using educational trainers used in different curriculum teaching subjects. The environment knowledge is accomplished by implementing short C code programs that will be used in an integrated final practice, in which the students will learn how to edit, compile, link and program the code as well as the serial communication, the analog/digital conversion, and PWM signal generation. Finally the use of a PC as a high level device is presented from two different points of view, consisting in PC high level programming by using VBASIC language and the TCP/IP protocol net knowledge that allow running on-robot LINUX created functions by the use of the laboratory LAN. Hence, lab personal computers become a flexible and easy tool that allows communicating with the on-robot devices by the use of WIFI connections. The proposed practices firstly introduce VBASIC language by creating short source codes that include protocol with created objects to perform TCP/IP communication with the robot. Students learn client-server protocol by programming the follow steps: Server connection, receive and transmit commands, server disconnection and to close the socket. Finally it is proposed the on-robot sonar sensor reading practice in order to test the remote robot connection.

$$f(A_i = B_i) = \left(\overline{A_i \oplus B_i}\right)E_{i-1=}$$

$$f(A_i > B_i) = A_i\overline{B}_i + \left(\overline{A_i \oplus B_i}\right)E_{i-1>}$$

$$f(A_i < B_i) = \overline{A}_i B_i + \left(\overline{A_i \oplus B_i}\right)E_{i-1<}$$

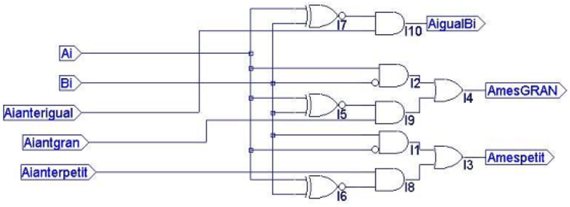


Fig. 3: Equations and electronic scheme of one bit recursive magnitude comparison.

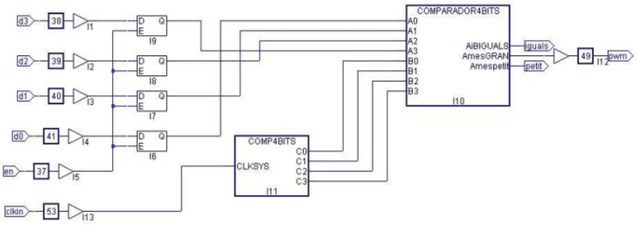
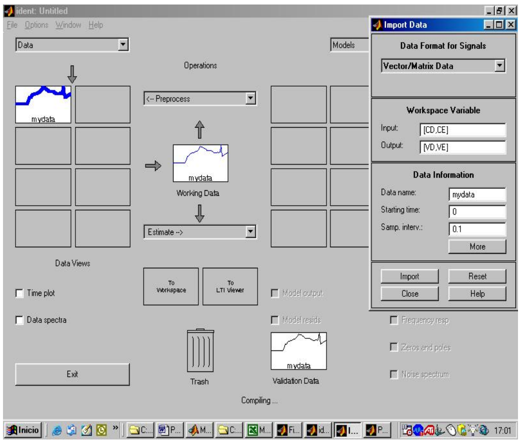


Fig. 4: The 4 bits PWM implementation.

B. *Modelling and Control Systems*

The MCS bloc presents the concerned basic control theory related to experimental modeling, classic PID controllers design and optimal observers. Students have acquired a similar background concerning about the basic classical control theory in continuous-time [7-8]. However, it is not a homogeneous aspect and some discrepancies arise from the difference in academic profiles. For example, additional knowledge is given to the Electrical Engineering students through some advanced materials in control theory [9-10], while Computer Engineering students show obviously better experience in their programming skills. The above discrepancy in educational background is solved by providing to students a self-guided lab practice manual that includes the theoretical fundamentals of the summer course. Students try to obtain the model experimentally, make the controller design on the computer by using the MATLAB program and validate finally the results on the robot. The first lab control practice begins with the experimental parametric model identification [11-12]. Hence, the model is obtained by sending different PRBS (Pseudo Random Binary Signals) to the robot for the low, medium and high speeds. The students select the adequate speed model and load the experimental data to MATLAB environment. Each data group has 5 different arrays containing the time, right consign, right velocity, left consign and left velocity, respectively. Then, they obtain the time response of the inputs and outputs. The system identification is carried out by using the MATLAB toolbox *"ident"*, shown in Fig.5, selecting a second-order ARX model and importing the necessary workspace data that should be identified. Tendency suppression and data filtering are suggested.


Data Format for Signals: Vector/Matrix Data

Workspace Variable
Input: [CD,CE]
Output: [VD,VE]

Data Information
Data name: mydata
Starting time: 0
Samp. interv.: 0.1

Fig. 5: System identification toolbox of MATLAB

The obtained complete MIMO (multiple input multiple output) discrete-time model will be used by students for validating the control effectiveness. The second practice consists in finding a simplified robot model. The continuous-time model is introduced into the SIMULINK environment, as shown in Fig. 6. Several studies concerning about the importance of coupling terms are carried out by students through the analysis of stationary gains, while the order reduction is done by searching for dominant poles. The students can learn from the obtained results that the MIMO model can be approximated by two SISO (single input single output) models. Thus, it is proposed the coupled system analysis using analytical and experimental data. The frequency response, and BODE analysis can provide a dominant pole existence, which can reduce the system order. Finally, the reduce SISO systems should be validated by considering the static gain and simulating reduced and complete robot models.

The third practice consists in obtaining a controller based on the simplified SISO models. The students will try to make the controller design by using the pole placement techniques and the MATLAB design facilities. For instance, students can use the MATLAB "sisotool" to design the controller by importing first the transfer functions corresponding to both robot wheels. Then, they depict the open loop frequency response without compensator. Afterwards, students learn to add a PI controller to the system in order to achieve the desired response. The control performance is verified by using the complete MIMO model of the robot in the presence of several perturbations.

The students will analyze the uncontrolled and controlled system response. The advanced students are also encouraged to consider the case in which the measurement noise is involved. Kalman filter is designed based on the model knowledge and is implemented in SIMULINK environment,. The on-robot speed control is a subject of the last MCS practice. The students transform firstly the controller from continuous to discrete time. Then, they use the robot remote network server to send the PID controller parameters to the robot in order to test the speed control performance.

C. *Trajectory Planning and Control*

TPC theory introduces the trajectory planning techniques through concepts as C-space and robot wide-path [13].

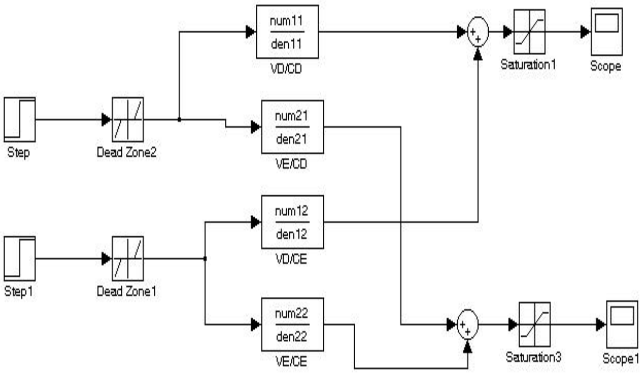


Fig. 6: MIMO robot model in SIMULINK environment.

The path planning approach consists in following a sequence of straight lines and considering the vertex of obstacles and the desired final configuration [14]. Thus, the trajectory tracking can be performed through either straight lines following or turning actions [15]. The trajectory control tracking is attained by introducing discontinuous control laws and MPC [16-17]. The discontinuous control approaches are presented to students as an in-lab robot demo, while the MPC strategies are simulated at the laboratory by using the methods and software developed by our teaching members participated in the course [18]. In the MPC design, students will try to find the optimal input sequence taking as design parameter the input constraints, prediction horizon, and cost function weights. The MPC simulation software provides to students a set of files and facilities to draw the results, and consequently the students can represent the files containing the cost function values, for different available set of inputs, corresponding to different moments of the simulation. The computation of optimal cost can be done by using the complete input search and gradient descent approaches. The prediction horizons between 0.5s and 1s were proposed and the computation time for each LMPC step was set to less than 100ms, running in the embedded PC of 700MHz. The simulated results, for the trajectory tracking of a 2m straight line, are shown in Fig. 7. It is depicted two simulated results with two prediction horizons: 1s, n=10 (in red) and 0.5s, n=5 (in blue). The final TPC practice consists in implementing a high level program code for achieving the reactive obstacle avoidance, in which the students should avoid obstacle collisions by sending the speeds commands to both wheels of the robot by means of sonar sensor measures.

D. Computer Vision System and Final Demos

The CVS teaching bloc briefly introduces to students some applied aspects as color constancy and image energy filters. The concerning theoretical aspects can be covered by using related bibliography [19-20]. Hence, computer vision features are introduced from a wide scope. Image formation based on basic paraxial optic is also shown. The image segmentation is depicted as a way to obtain the image relevant areas. Thus, segmentation is a previous steep in order to obtain a binary image where the interest area is split of the rest of the image. The image representation is considered in continuous and discrete spaces. The Fourier Transform is studied as a meaningful tool in order to develop frequency filters. Therefore, the radiance energy measures are studied as a way to obtain object boundaries.

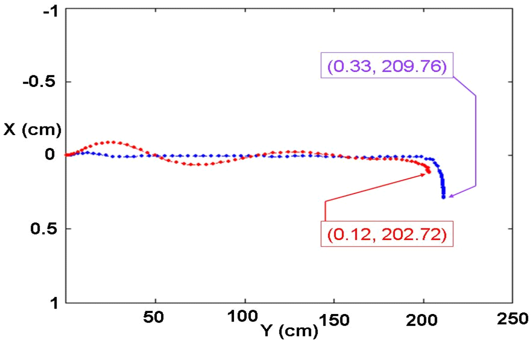
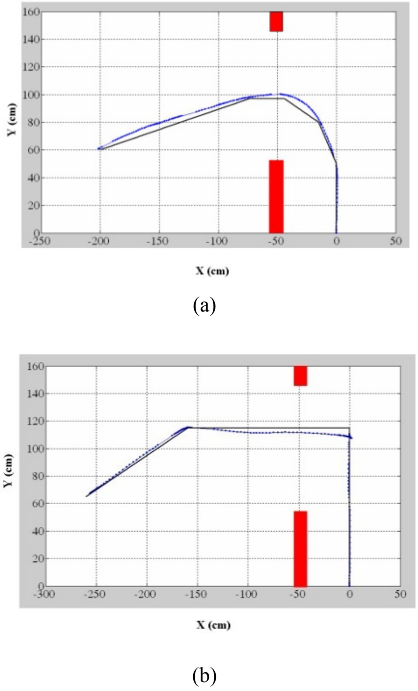


Fig. 7: Trajectory tracking simulation with two different prediction horizons

The CVS practices are focused by using the facilities provided by the MIL libraries of Matrox running under VBASIC source code. The code is implemented by using previously acquired frames. Firstly some basic functions, as space memory management, image acquisition and visualization, are introduced. Once it is done, students learn how to process RGB color images by using 3 different buffers. Thus, the use of 3 different histograms can allow efficient color segmentation. Other MIL facilities as HSI color space conversion are also proposed to students. Hence, results should allow segmenting a featured color object from the rest of the scene. Application aspects as noise are introduced by using existing functions as blob analysis that can filter small particles. The last practice consists in object boundaries detection by using frequency filters. The design of filters is presented by performing image convolutions through either the use of existing MIL filters or the creation of arbitrary filters. Students can analyze the effects of filters by comparing histogram results. The course ends with some final demonstrations concerning about the trajectory tracking and advanced perception features. The accuracy of trajectory tracking using MPC technique is also discussed. Fig. 8 shows the experimental results obtained when the robot of 35cm wide-path passes across a lab door of 80cm width. The effectiveness of different applied machine vision systems tested during the robot navigation are also presented. By using previously computed floor radiance energies, the one bit of depth is used to perform obstacle detection and the obstacle avoidance navigation strategies with reactive robot behavior are experimented and commented [21]. The robot tracking abilities are also shown by using a color featured target. Therefore, the final demonstrations are used as a way to experiment previously introduced and tested concepts as color segmentation and constancy. The Fig. 9 shows the robot color tracking experience.



(a)

(b)

Fig. 8: (a) the robot moves always is advancing sense. (b) The robot turns around itself.

III. CONCLUSIONS

The integration of the different knowledge is presented through an adequate robotic framework that acts as an educational multidisciplinary tool in the course. The teaching experience gained from the summer course has shown the usefulness of the mobile robot as an important experimental platform for education. The course framework has allowed a different level of knowledge learning according to the students' academic background. They can acquire a higher level of skills by integrating different subjects related to electronics, control system, computer science, communication, etc. It should be mentioned that the developed lab practices related to the theoretic counterparts have greatly increased the motivation of the students and have achieved the multidisciplinary knowledge consolidation of the proposed objective.

In this context the student's evaluation is developed by considering the educational background but also the degree accomplished in the different proposed practices. Hence, basic and advanced practices are evaluated by considering the previous level of the students. The correctness of the solutions and their independence and decisions are also contemplated within a continuous evaluation laboratory process. According to the students' feedback to the course, the average opinion of 27 students about the summer course is 4 over 5. They remark the interests and attractive educational and practical aspects as the relevant characteristics of the course. One of the suggestions is to augment the course hours in order to perform better the theoretic analysis, lab practices and algorithm implementation.

In the future, the teaching staffs from different research areas will try their best to promote the evolution and consolidation of the course so that the teaching quality can be further enhanced. In this process, the student opinions are important enough to encourage this work. Therefore, the clues for achieving a renewed path of progress in robotics are the integration of several knowledgeable fields, such as computing, communications, and control sciences, in order to perform a higher level reasoning and use decision tools with strong theoretical base.

Fig. 9: Featured color object tracking performed during the final demonstration.

ACKNOWLEDGEMENT

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