2017 Competitions: Magical, Manipulating, Mercurial Robots

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Each year, the IEEE International Conference on Intelligent Robots and Systems (IROS) organizes a series of competitions to showcase the current state of various important robot technologies for other roboticists, hobbyists, and the general public. For the participants, these competitions provide an excellent venue to test their systems outside of the laboratory and deal with unforeseen challenges in the respective environments.

Humanoid Robot Application Challenge

"Robot Magic" (RM) was the topic of the Fifth Humanoid Robot Application Challenge and the second time that the area of robot magic tricks was used as the application domain. The goal of the humanoid application challenge was to allow teams to demonstrate interesting research in robotics and human–robot interaction in a free-form event. The organizers realized that a fully open forum would be very difficult to judge, as entries ranged from individual novel servomotor modules to shared robot laboratory creations. After consulting with the teams, the organizers decided to focus on robot magic-trick applications as an interesting research domain with sufficient flexibility.

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Competition and Participants

As in previous years, teams had to submit a short paper describing the scientific, technical, and other contributions and a video of their magic trick. After review, eight teams (up from seven last year) qualified for the 2017 competition (Table 1). There was a good mix of old and new groups (50% each), which shows that the Humanoid Robot Application Challenge has managed to establish a presence in robotics circles. Funding and technical problems prevented some of the previous teams from submitting their qualification materials and also thwarted some of the qualified teams from displaying their magic tricks at IROS, so in the end six teams were actually able to compete (see Table 1).

Significant Research Developments

There were several interesting developments during this year's RM competition. First, all of the experienced teams recognized the importance of a good audio system for their performance, so most brought their own speaker and microphones. This improved the show dramatically because the audience was able to hear the responses from the robots.

Speech Recognition and Text to Speech

The teams also realized the importance of speech detection during an interactive event such as a magic show. PocketSphinx, developed by Carnegie Mellon University, is the most popular speech recognition engine for robotics teams. In 2016, most of the teams used it with its default parameters, but this year, almost all of the groups tuned the parameters,

Table 1. The qualifying teams in the 2017 IROS Humanoid Robot Application Challenge.

Team Name	Team Leader	Affiliation	
Taura Bots	Rodrigo da Silva Guerra	Universidade Federal de Santa Maria, Brazil	P
Team Proton	Aditya Sripada	SRM, India	N, P
Liquid Motion	Jacky Baltes	NTNU, Taiwan	P
AUT Magicians	Soroush Sadeghnejad	Amirkabir University of Technology, Iran	N
Seed Robotics	Jeehyun Yang	Seed Robotics, United Kingdom	P
Snobots	Meng Cheng Lau	University of Manitoba, Canada	P
ZSTT	Jaesik Jeong	NTNU, Taiwan/Korea	N, P
Marco Tempest	Marco Tempest	MIT Media Lab, United States	N

(P) Teams that were able to present their magic tricks during IROS 2017.
(N) Teams that qualified for RM for the first time in 2017.

created their own dictionaries with specific keywords, and trained their own voices. Even though some of the voice prompts were still missed by the computer, the performance went much more smoothly than last year.

Team Liquid Motion's entry recognized limited input from a random volunteer (e.g., the commands *left* or *right*) to select where to place cards. Team Snobots (see Figure 1) cleverly used speech cues to provide information to the robot. For example, if the selected card was a nine, the human assistant would say, "We have been working on this since September," whereas if the card was a ten, the human assistant would say, "We have been working on this since October."

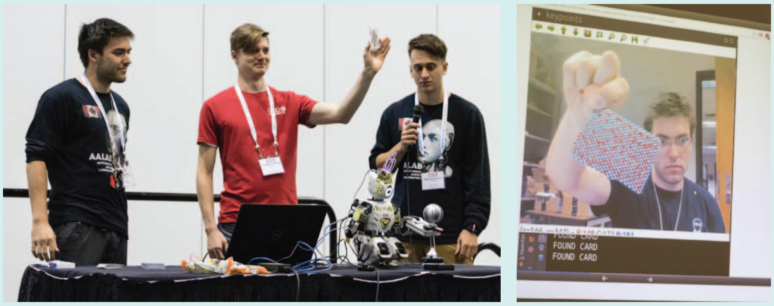


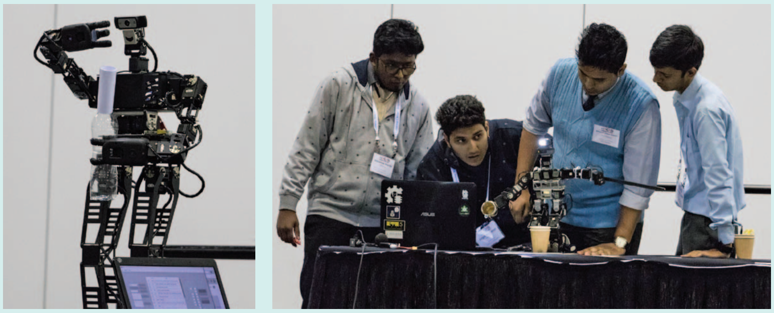
Figure 1. Some images of first-place Team Snobots from the University of Manitoba, Winnipeg, Canada. (a) A perplexed volunteer shows a recovered card. (b) A member explains the team's vision system for card detection.

Manipulation

Teams also introduced new ideas for handling objects commonly manipulated by magicians. Team ZSTT from the National Taiwan Normal University (NTNU), Taipei, used the accuracy of their grippers (developed by Seed Robotics, Inc.) to pick up and drop coins to good effect [Figure 2(a)]. Team Liquid Motion was able to demonstrate picking up single cards from a deck by wrapping their grippers with rubber balloons. Team Proton used a suction cup at the end of a stick to pick up a card from the table [Figure 2(b)].

Future Perspectives

The RM show is popular with participants and especially spectators (see Figure 3). On the last day, after the official competition, the RM teams presented their magic shows during the IROS coffee breaks and attracted large crowds. Based on this experience, the organizers plan to modify the RM competition to



(a) (b)

Figure 2. (a) The second-place Team ZSTT robot from the NTNU performs a coin drop trick. (b) The third-place Team Proton from India used a loaded die and sleight of hand in its magic act.

include busking (that is, street entertainment such as dancing, playing music, doing magic tricks, juggling, or performing comedy).

The current plan is to include audience feedback in the judging by providing spectators with a limited number of virtual coins that they can apportion to the robot tricks they particularly like. Next year, the robot that collects the most coins will receive a special certificate, and the number of coins collected may be used in future overall scoring.

Robotic Grasping and Manipulation Competition

The 2017 Robotic Grasping and Manipulation Competition (RGMC) had two tracks: service robotics and manufacturing. Six teams, some composed of both academic and industry partners, participated in both tracks: the University of Colorado and Robotic Materials, Inc.; Cothink Robotics; Sigma 7; the University of Kanazawa and Shinsu University; Feifan AI; and Tsinghua University and Intel Corporation. Another team, CambridgeARM, participated in only the service robotics track. Figure 4 shows photos of the seven teams taken during their preparation time.

The service robotics track had ten tasks: transferring a cup onto its saucer, arranging silverware, stirring water in a cup, pouring water into a cup, plugging a cord into a socket, tearing away one piece of paper towel, playing with a sorting board, hammering a nail, inserting a straw into a to-go cup with a lid, and opening a bottle with a locking safety cap. The tasks were selected from a pool of 36 daily-life functions. The tasks and their rules were designed in detail by our organizing committee members in 2016 and 2017. All ten were released one month before the competition day. The RGMC setups were accessible two days before the competition.

The manufacturing track had two tasks. The first was on a task board: adding and removing screws, gears, pegs, and male connectors. The second task was assembling a gear unit. The computer-assisted design models of all of the components in this track were provided two months before the competition. One month before the RGMC, Joe Falco of the National Institute of Standards and Technology, who designed the task board, shipped the boards and their components to all of the teams, while Prof. Yasuyoshi Yokokohji of Kobe University, Japan, who designed the gear assembly task, shipped the gear units to all of the teams.

Figure 5 shows the objects used in both tracks of the competition. All of the tasks in both tracks had to be performed autonomously without any human input. Teleoperation was not allowed. A detailed description of the tasks is available at the competition's website [1]. Figure 6 shows the tasks during the competition.

Results

In the service robotics track, it was possible to win a total of 235 points in 2 h. The victor, CambridgeARM, amassed 148 points and was awarded a US$3,000 check and a Righthand Robotics ReFlex 1 Gripper. Second-place Cothink Robotics won 135 points and received a US$1,500 check, while the Tsinghua University and Intel Corporation team garnered 113 points, winning third place and a US$500 check. Nearly every team used up its entire 2 h.

In the manufacturing track, a total of 600 possible points could be won. The teams were given 1 h for each task. The first-place winner was Feifan AI, with

(a) (b)

Figure 3. (a) The participants and judges in the IEEE IROS RM competition. (b) The magic show proved popular with spectators.

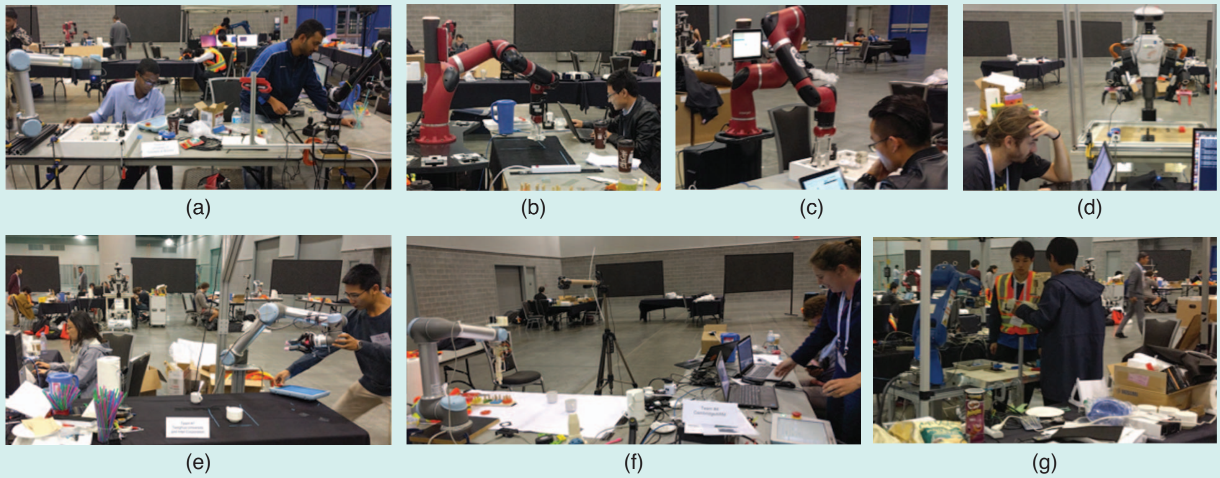


Figure 4. The teams participating in the IEEE IROS RGMC: (a) the University of Colorado and Robotic Materials, Inc., (b) Cothink Robotics, (c) Feifan AI, (d) Sigma 7, (e) Tsinghua University and Intel Corporation, (f) CambridgeARM, and (g) the University of Kanazawa and Shinsu University.

189 points, and the prize was a US$3,000 check. The University of Colorado and Robotic Materials, Inc., gained 179 points and won the second-place prize of US$1,500. Third place was taken by the University of Kanazawa and Shinsu University with 157 points, good enough for a US$500 check.

In the service robotics track, the following tasks were successfully performed by at least one team: transferring a cup onto its saucer, stirring water in a cup, plugging a cord into a socket, playing with a sorting board, hammering a nail, inserting a straw into a to-go cup with a

Figure 5. All of the objects used in the RGMC.

lid, and opening a bottle with a locking safety cap. However, even for the best teams, many of these tasks were attempted multiple times before they finally succeeded. No team was able to complete the remaining three tasks: arranging silverware, pouring water into a cup, and tearing away one piece of paper towel.

Compared to the previous year's competition, the 2017 teams were more competitive and were able to achieve better performance. However, grasping and manipulating in physically interactive tasks are still very challenging for robots, especially when there is a tight tolerance. High reliability and fine resolution in visual and force perception are crucial for these tasks.

Most teams used so-called human-friendly robotic arms. The grippers in the competitions had two or three fingers, and many of them were specially designed for the manipulation tasks. One team had multiple grippers and changed grippers automatically during tasks and between tasks. However, the grippers were all rigid. It is not known whether equipping soft fingers would lead to better performance in the tasks with tight tolerance. Because the models of the objects were provided to the teams but the locations and poses of the objects were arbitrary, it appeared that most teams predefined both the grasps and the manipulation motions, using the positions and poses of the objects that were estimated using vision sensors.

Autonomous Drone Racing

The Autonomous Drone Racing (ADR) event was inaugurated at IROS 2016 in Daejeon, South Korea, and the second such event was held at IROS 2017 in Vancouver, British Columbia, Canada. Unlike the popular remote-control drone racing by a human pilot with first-person view devices, ADR is fully autonomous drone racing where drones rely only on onboard sensing and computing systems for recognition, planning, and motion control. Each team was given two 15-min slots and could fly a drone autonomously as many times as team members wished in those periods. For the given total of 30 min, each team attempted to pass its robot sequentially through four open gates,

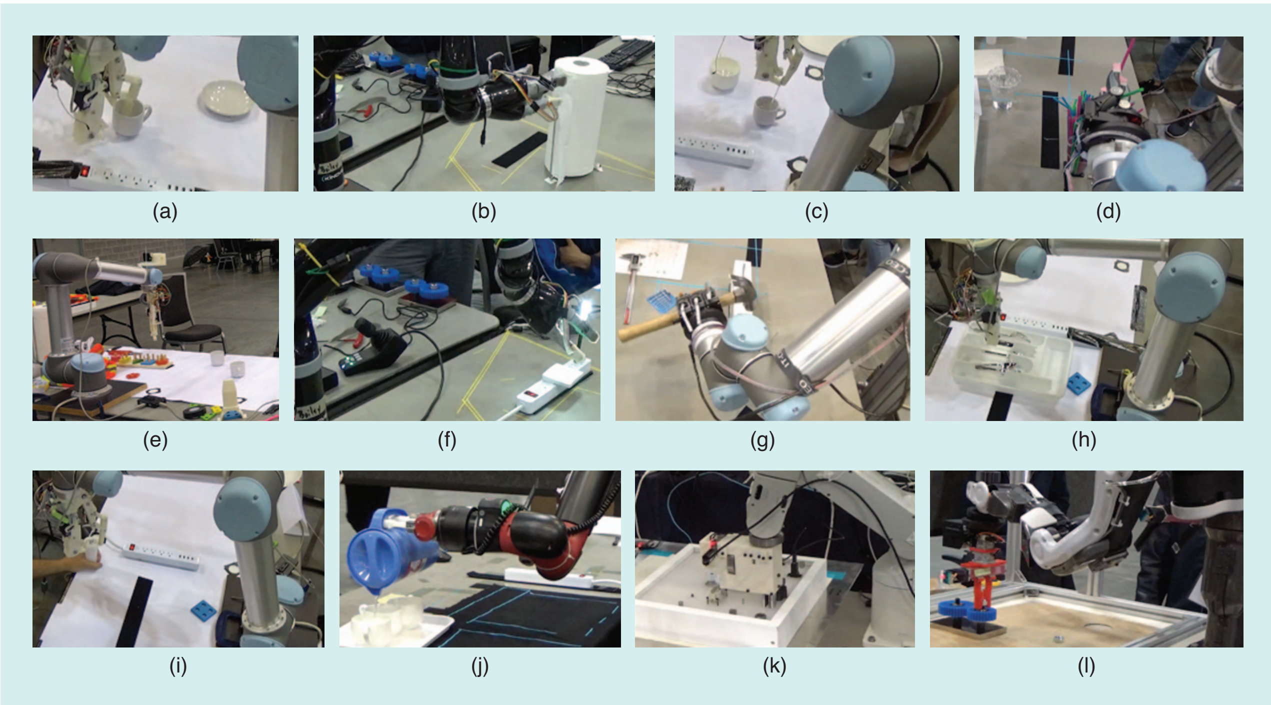


Figure 6. The 12 tasks in the two tracks of RGMC: (a) transferring a cup onto its saucer, (b) tearing away one piece of paper towel, (c) stirring water in a cup, (d) inserting a straw into a to-go cup with a lid, (e) playing with a sorting board, (f) plugging a cord into a socket, (g) hammering a nail, (h) arranging silverware, (i) opening a bottle with a locking safety cap, (j) pouring water into a cup, (k) putting on and removing components from a task board, and (l) assembling a gear unit.

eight closed gates, and one dynamic gate. During each attempt, the passing gate identity and time were recorded, and the official score was selected from the team's best attempt.

Racing Track

The IROS 2017 ADR competition arena was composed of four sections: a straight portion, a curve, a sharp curve, and a dynamic element (see Figure 7). The first section consisted of open gates [Figure 8(a)], stretched for about 25 m, and was divided into six possible straight paths, as shown in Figure 8(b). This section was for testing the speed of autonomous flight at a fixed altitude. Each far side was marked by hanging fabric strips. Although they were not rigid, they did the job of catching drones trying to pass through them.

The curve section was composed of five closed gates of different heights. This section was intended to test horizontal and vertical zigzag flight (see Figure 9). The sharp curve section was modeled after spiral stairs and tested altitude and direction control at the same time (Figure 10). Finally, the dynamic gate had a clock-needle moving part [Figure 9(d)] with a rotational speed of fewer than 30 r/min. The map information was given to the teams beforehand, and the racing track gates were arranged as accurately as possible. The location error of the gate installation was fewer than 10 cm. Figure 11 shows the setup at the arena. Detailed information on the track can be found at the competition home page [2].

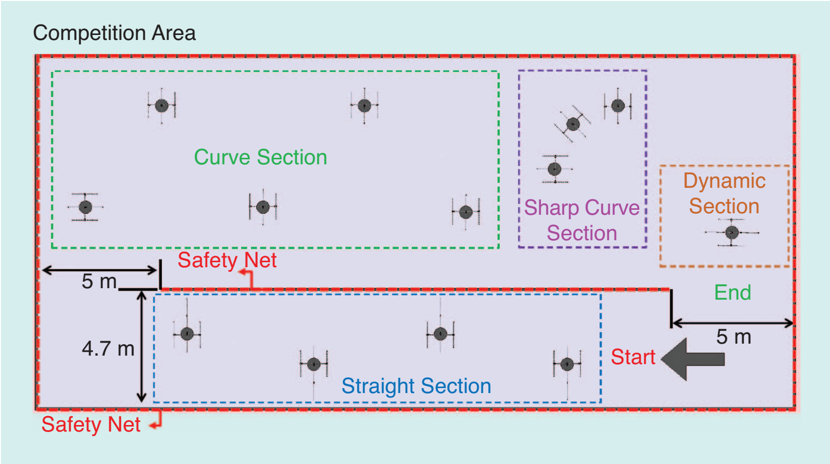


Figure 7. A top view of the ADR IROS 2017 racing track.

Competition Results

Initially, a total of 14 teams registered for the competition, but because of such

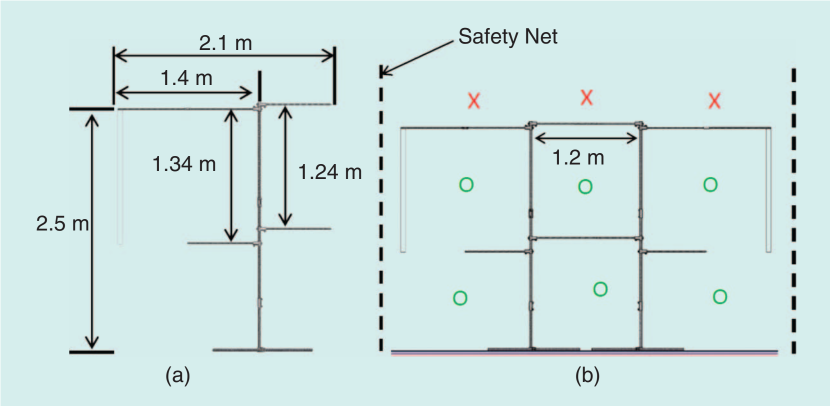


Figure 8. The ADR's straight section: (a) the dimensions of the open gate; (b) the six possible flight zones viewed from the "Start" position.

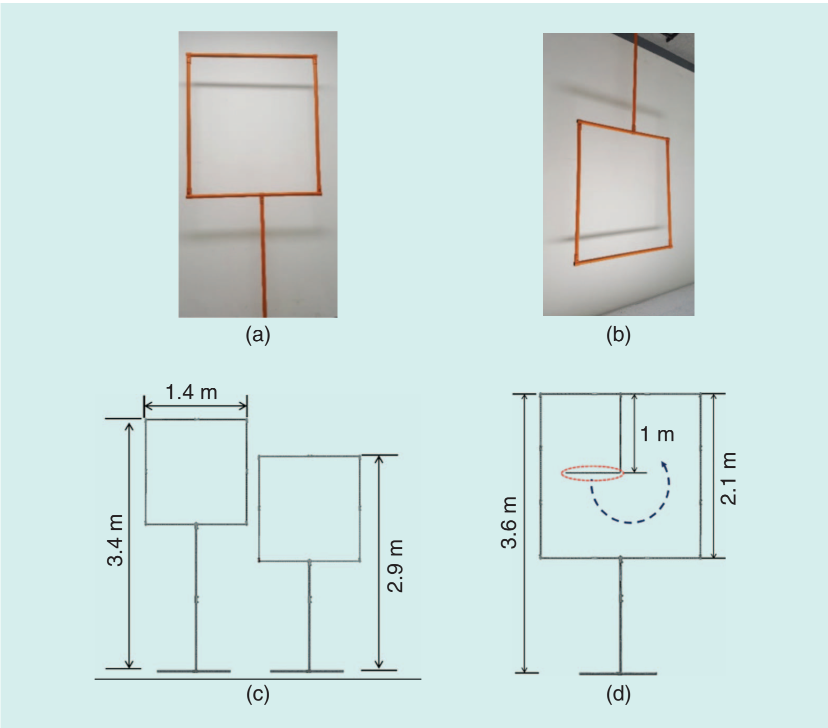


Figure 9. The ADR's closed gates: (a) a front view, (b) an oblique view, (c) the dimensions, (d) and the dynamic gate.

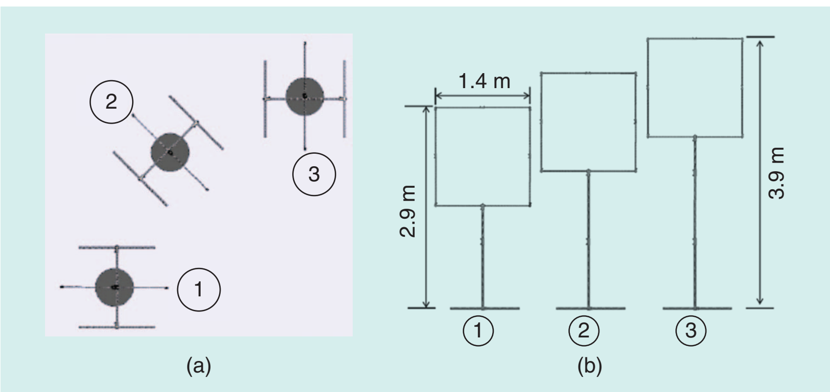


Figure 10. (a) The sharp curve section of the ADR and (b) the dimensions.

issues as fundraising and technical readiness, seven showed up at the event. Ultimately, five teams were able to actually compete in the arena (Team KAIST-UNIST, Korea; Team MAV-lab of Delft University of Technology, The Netherlands; Team Robotics and Perception Group, University of Zurich, Switzerland; Team First Commit from Bay Area hobbyists, United States; and Team QuetzalC++ from INAOE, Mexico). Team KAIST lost its vehicle and Team UNIST lost its flight controller during the practice day, so they decided to work together as one team, with the agreement of all of the participating teams and organizers. See Table 2 for a listing of the four winning teams.

Discussion

The number of registered teams increased from 11 at IROS 2016 to 14 at IROS 2017 (Figure 12). Again, however, not all teams could actually compete in the arena. Furthermore, because of system failures during the preparations for the main event, two Korean teams had to work together as one group at the last minute. All of this suggests that bringing robotics technology out of the laboratory is still a challenge.

Here are some interesting observations from the 2017 event. The winning team used an optic flow and waypoint tracking control based on visual simultaneous location and mapping rather than real-time path replanning. Team MAV-lab successfully implemented Kalman-filter-like tracking algorithms for the open gates, and their record of passing through the straight section was impressive. However, in turning corners, the team's drone tended to escape from the planned track toward the upcoming closed gate. The Team Robotics and Perception Group from the University of Zurich had the most cutting-edge technologies in terms of all of the teams' performance and showed very stable and safe autonomous flight based on visual perception. However, they could not reach the third section of the racing track.

Once again, all these observations imply that the state-of-the-art technologies verified in the laboratory environment

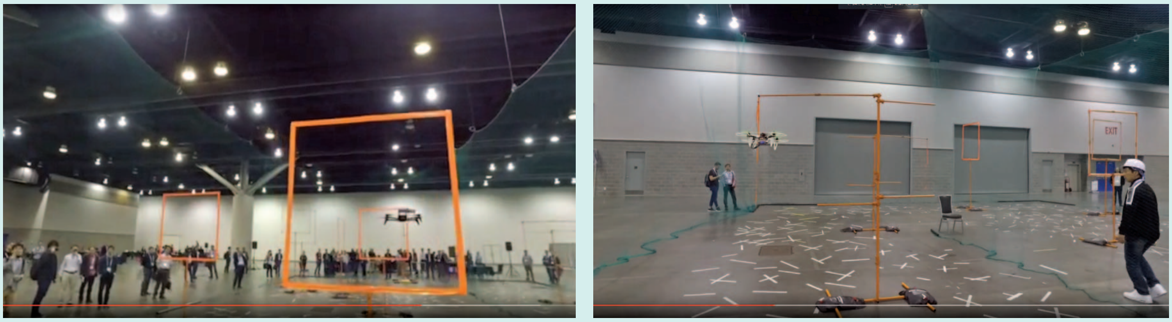


Figure 11. (a) The Team QuetzalC++ drone passes through gate 7. (b) The Team Robotics and Perception Group drone heads toward the fabric strip of gate 3.

Table 2. The 2017 IROS Autonomous Drone Racing Competition winners.

First Place: Team QuetzalC++, INAOE, Mexico	Record: 03:11.6 (gate 9)
Team members: Jose Martinez-Carranza, L. Oyuki Rojas-Perez, Aldrich A. Cabrera-Ponce, Roberto Munguia-Silva	
Second Place: Team Robotics and Perception Group, Switzerland	Record: 00:35.8 (gate 8)
Team members: Matthias Faessler, Alessandro Simovic, Titus Cieslewski, Davide Falanga, Elia Kaufmann, Toni Rosiñol Vidal, and Prof. Davide Scaramuzza	
Third Place: Team First Commit, United States	Record: 01:56.5 (gate 8)
Team members: Daniel B. Wilson, Michael Watson, David Jones, Nathan Heidt, Ali Haydar Goktogan	
Fourth Place: Team MAV-lab, The Netherlands	Record: 00:25.7 (gate 7)
Team members: G.C.H.E. de Croon, Christophe De Wagter, Michaël Ozo, Shuo Li, Coen de Visser, Isabella El Haij	

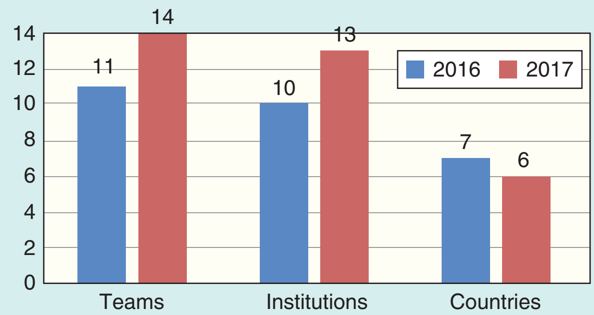


Figure 12. Some comparisons of the number of registrations in 2016 and 2017.

are not yet mature enough to be implemented in this kind of new environment, even though it is also artificial and designed by robotics developers themselves. This may be due to such elements as the lack of strong features, the tight paths, and the overlapping of the monotonic orange color of the gates. Technologies ought to be developed to avoid excessive fine-tuning of parameters for the success of racing competitions, and open-source solutions need to be tested more rigorously in many different environments.

Finally, Team First Commit was a group of robot enthusiasts from the San Francisco Bay Area. Although most of them are engineers in high-technology companies, their participation indicates that robotics technologies are no longer the domain solely of research institutes. As more robot-related services and products become available in our everyday lives and as more open-source software and hardware platforms become available to the public, the base of robotic technologies seems to be enlarged accordingly. Autonomous drones are emblematic of this trend.

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