The 23RD Annual Intelligent Ground Vehicle Competition: Building Engineering Students into Robotists

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Abstract

The Intelligent Ground Vehicle Competition (IGVC) is one of four, unmanned systems, student competitions that were founded by the Association for Unmanned Vehicle Systems International (AUVSI). The IGVC is a multidisciplinary exercise in product realization that challenges college engineering student teams to integrate advanced control theory, machine vision, vehicular electronics and mobile platform fundamentals to design and build an unmanned system. Teams from around the world focus on developing a suite of dual-use technologies to equip ground vehicles of the future with intelligent driving capabilities. Over the past 23 years, the competition has challenged undergraduate, graduate and Ph.D. students with real world applications in intelligent transportation systems, the military and manufacturing automation. To date, teams from over 80 universities and colleges have participated. This paper describes some of the applications of the technologies required by this competition and discusses the educational benefits. The primary goal of the IGVC is to advance engineering education in intelligent vehicles and related technologies. The employment and professional networking opportunities created for students and industrial sponsors through a series of technical events over the four-day competition are highlighted. Finally, an assessment of the competition based on participation is presented.

Figure 1: *California State University, Northridge - El Toro the 2015 Overall Winner.*

Introduction

The Intelligent Ground Vehicle Competition (IGVC) is one of four, unmanned systems, student competitions that were founded by the Association for Unmanned Vehicle Systems International (AUVSI). The IGVC is a multidisciplinary exercise in product realization that challenges college engineering student teams to integrate advanced control theory, machine vision, vehicular electronics and mobile platform fundamentals to design and build an unmanned system. Teams from around the world focus on developing a suite of dual-use technologies to equip ground vehicles of the future with intelligent driving capabilities. Over the past 23 years, the competition has challenged undergraduate, graduate and Ph.D. students with real world applications in intelligent transportation systems, the military and manufacturing automation. To date, teams from over 80 universities and colleges have participated. This paper describes some of the applications of the technologies required by this competition and discusses the educational benefits. The primary goal of the IGVC is to advance engineering education in intelligent vehicles and related technologies. The employment and professional networking opportunities created for students and industrial sponsors through a series of technical events over the four-day competition are highlighted. Finally, an assessment of the competition based on participation is presented.

Figure 2: *Hosei University – Orange2015, presenting during the Design Competition.*

The objective of the competition is to challenge students to think creatively as a team about the evolving technologies of vehicle electronics, controls, sensors, computer science, robotics, and systems integration throughout the design, fabrication and field testing of autonomous intelligent mobile robots. The competition has been highly praised by faculty advisors as an excellent multidisciplinary design experience for student teams, and a number of engineering schools give credit in senior design courses for student participation. Intelligent vehicles have many areas of relevance for both civilian and military applications. Vehicle intelligence can be applied to civilian applications in automating future highways or enhancing the safety of individual automobiles and trucks. For the Department of Defense (DoD), intelligent vehicles have the potential to greatly increase the effectiveness of the Army's Future Force by removing Soldiers from high risk tasks, as well as a desirable high payoff potential in multiplying combat assets, thus increasing unit combat power. Technology objectives identified in both DoD and Department of Transportation (DoT) programs have been used to structure the IGVC.

Based on the IGVC technical objectives, a number of co-sponsors have joined to help, fund and promote the IGVC. Present and past co-sponsors include the AUVSI, U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC), Oakland University (OU), Society of Automotive Engineers (SAE) Foundation, Fanuc Robotics, the Automated Highway Systems (AHS) Consortium, General Dynamics Land Systems (GDLS), the United Defense Limited Partnership (UDLP), the DoT, Ford Motor Co., General Motors (GM), Chrysler, Applied Research Associates (ARA), Science Applications International Corp. (SAIC), Lockheed Martian (LM), QinetiQ North America, PNI Sensor Corporation, National Defense Industrial Association (NDIA), Theta Tau, Motorola, CSI Wireless, Microsoft Robotics, Raytheon, DeVivo Automated Systems Technology (AST), Dassault Systèmes (DS) SolidWorks, Northrop Grumman, Continental, Takata, Valeo, Magna, Molex, FEV, TORC Robotics, American Elements, Women in Defense (WID), the Michigan Economic Development Corporation (MEDC), the Defense Advanced Research Projects Agency (DARPA), the DoD Joint Ground Robotics Enterprise (JGRE), the U.S. Air Force Research Laboratory (AFRL), Robotic Systems Joint Project Office (RS JPO) and the Joint Center for Robotics (JCR). A common interest of all these organizations is intelligent vehicles and their supporting technologies.

The IGVC challenges the students to design, develop, build, demonstrate, report, and present integrated systems with intelligent technologies which can lane-follow, avoid obstacles, operate without human intervention on slopes, natural environments, and simulated roads, autonomously navigate with Global Positioning System (GPS) and to perform leader-follower applications. The civilian aspect of this dual use technology is underpinned by the automotive applications. The IGVC has three components: a Design Competition, the Auto-Nav Challenge and the Interoperability Profile (IOP) Challenge. The total award money amount of all three competitions is over $30,000. In the Design Competition, judges determine winners based on written and oral presentations and on examination of the vehicles. While in the Auto-Nav Challenge, the robotic vehicles negotiate an outdoor obstacle course approximately 200 meters long and navigate to a number of target destinations using GPS waypoints. The Interoperability Profile (IOP) Challenge requires vehicles to use the standard messages and data buses to determine compliance with the architecture and complete a timed course where the vehicle needs to reach several points.

Figure 3: *Embry-Riddle Aeronautical University – Zero2, reprograming the vehicle.*

The Competition Events

The Auto-Nav Challenge event requires a fully autonomous unmanned ground robotic vehicle to negotiate around an outdoor obstacle course under the prescribed time of five minutes while staying within the one mile-per hour (mph) minimum and ten mph maximum speed limit and avoid obstacles on the track. The course consists of a 1,200 foot long, ten foot wide lane with white lane markings on grass with a large field area in the center. During the start and the end of the course the robot must navigate using its sensors to stay between the lines. While in the center of the course there are no lines and it must navigate by GPS waypoints. Obstacles cover the entire course and consist of various colors (white, orange, brown, green, black, etc.) and include five gallon pails, construction drums, cones, trash cans, pedestals and barricades that are used on roadways and highways. Natural obstacles such as trees or shrubs and manmade obstacles such as light post or street signs could also appear on the course. The obstacles will be part of complex arrangements with switchbacks and center islands. Their locations will be adjusted between runs and the direction of the course may also be changed between heats. The vehicles are judged based on their ability to perceive the course environment and avoid obstacles. A human operator cannot remotely control vehicles during competition. All computational power, sensors, and control equipment must be carried on board the vehicle to achieve autonomous driving. Judges will rank the entries that complete the course based on shortest adjusted time taken. In the event that a robot does not finish the course, the judges will rank the entry based on longest adjusted distance traveled. Adjusted time and distance are the net scores given by judges after taking penalties, incurred from obstacle collisions, pothole hits, and boundary crossings, into consideration. The vehicle that travels the farthest on the course, or completes the course in the shortest time wins; award money for this event totals $15,500.

Figure 4: Oakland University - Mantis, during the Design Competition.

The Design Competition expects all teams will design and equip their vehicles to compete in the Auto-Nav Challenge and design reports will be judged accordingly. Failure to qualify for the performance events will result in only nominal prize awards in the design competition. Although the ability of the vehicles to negotiate the competition course is the ultimate measure of product quality, officials are also interested in the design process that engineering teams follow to produce their vehicles. Design judging is performed by a panel of experienced engineering judges and is conducted separate from and without regard to vehicle performance on the test course. Judging is based on a 15 page written report, a 10 minute oral presentation and an examination of the vehicle. In the interest of engineering discipline, design reports that are received after the deadline date are penalized in the judging, as are oral presentations running longer than the specified time. The award money for this event totals $7,500.

The Interoperability Profile (IOP) Challenge verifies that teams are using a standardized message suitable for controlling all types of unmanned systems, and is the SAE-AS4 unmanned systems standard, commonly known as JAUS. Participation in the challenge is voluntary, but the challenge is standardized over all of the AUVSI student unmanned competitions. Teams that completed the challenge will send a request for identification to the Common Operating Picture (COP) once every 5 seconds. The COP will respond with the appropriate informative message and request identification in return from the team's JAUS interface. After the identification report from the COP, the team entry will stop repeating the request. This transaction will serve as the discovery between the OCU via an RF data link and the vehicle. The vehicle that travels the farthest on the course, or completes the course in the shortest time wins; award money for this event totals $7,500.

The Competition Rules (in brief)

Vehicles must be fully autonomous and cannot be controlled by a human operator during competition. All computational power, sensing, and control equipment must be carried on board the vehicle; except there must be both a manual and wireless remote emergency stop capability meeting strict specifications. Chassis can be built from scratch or commercially bought (all-terrain vehicle, golf cart, lawn tractor, electric wheel chair, etc.). Overall dimensions cannot exceed seven feet in length, five feet in width and six feet in height. Propulsion must be by direct mechanical contact with the ground, and power must be supplied either electrically or by combustible fuel. Vehicles must maintain a minimum of one mph and a maximum speed of ten mph for safety and must carry a 20 pound load during competition.

The Auto-Nav Challenge consists of two courses laid out on a grassy area. The two courses are the Basic Course and the Advanced Course. The Basic Course will be primarily sinusoidal curves with series of repetitive barrel obstacles. A waypoint pair for the course will be provided prior to competition. It is mandatory for a team to complete the Basic Course to move to the Advanced Course. Maximum time for the Basic Course will be 5 minutes with a measured distance of approximately 500 feet. Pending successful running of the Basic Course the team will move on to the Advanced Course. For the Advanced Course there will be complex barrel arrangements with switchbacks and center islands. These will be adjusted for location between runs. Direction of the obstacle course will change between runs. Maximum time for the Advanced Course will be 10 minutes with a measured distance of approximately 1,200 feet.

Figure 5: Teams on the Auto-Nav Pratice Course.

These distances are identified so teams can set their maximum speed to complete the course pending no prior violations resulting in run termination. Track width will vary from ten to twenty feet wide with a turning radius not less than five feet. Both course outer boundaries will be designated by continuous or dashed white lines approximately three inches wide, painted on the grass. Track width will be approximately ten feet wide with a turning radius not less than five feet. Alternating side-to-side dashes will be 15-20 feet long, with 10-15 feet separation. A minimum speed will be required of one mph and verified in each run. Competitors should expect natural or artificial inclines with gradients not to exceed 15% and randomly placed obstacles along the course. The course will become more difficult to navigate autonomously as vehicle progresses. Obstacles on the course will consist of various colors (white, orange, brown, green, black, etc.) of construction barrels/drums that are used on roadways and highways. Natural obstacles such as trees or shrubs and manmade obstacles such as light posts or street signs could also appear on the course. The placement of the obstacles may be randomized from left, right, and center placements prior to every run. There will be a minimum of five feet clearance, minimum passage width, between the line and the obstacles; i.e., if the obstacle is in the middle of the course then on either side of the obstacle will be six feet of driving space. Or if the obstacle is closer to one side of the lane then the other side of the obstacle must have at least six feet of driving space for the vehicles.

For each competition, points will be awarded to each team, placing first through sixth. The team with the most points at the end of the competition wins the Grand Awards which consist of three traveling trophies, the Lescoe Cup, the Lescoe Trophy and the Lescoe Award for first through third place respectively. The point breakdown structure for all four events is listed in Table 1.

Place	Auto-Nav Challenge	Design Competition	IOP Challenge
1	48	24	24
2	40	20	20
3	32	16	16
4	24	12	12
5	16	8	8
6	8	4	4

Table 1: Grand Award point distribution.

Safety is a prime concern; vehicles that are judged to be unsafe are not allowed to compete. Therefore, participating vehicles must conform to specific safety regulations. These safety requirements include the following criteria, speed limit, E-Stop (manual and a wireless remote) and indemnification agreements. Minimum performance requirements are also required and include lane following, waypoint navigation, obstacle detection and avoidance. These safety and performance requirements will be tested during the Qualification event; all vehicles must qualify to compete in the performance events.

Figure 6: *University of New South Wales – Pepper on the Auto-Nav Course.*

Team Technologies

All of the vehicles entered into the IGVC are unique and different in design. Most of the vehicles entered in the competition can be broken down into three main subsystems, mechanical, electrical and software. Fabrication of such a vehicle requires engineering knowledge from various disciplines. The most well rounded teams will employ engineers from several different fields to handle the needs of the projects scope of work. Some teams even employ business and marketing students to help them make contact with industry and the military for both financial backing and durable goods needed for the project. Mechanical subsystem teams are typically responsible for the chassis, propulsion system and body. The chassis designs for the robots are only limited by the design team's imagination and manufacturing capability. Some teams build small inexpensive robots which are designed solely for the competition itself, entering multiple robots to increase the number of computer algorithms available to challenge the courses. Other teams build elaborate mechanical designs which are robust enough to be used for multiple robotic competitions. Regardless of which design philosophy a team uses, it is important to document the entire build process as the robot is built. Documentation can greatly improve reports required for the Design Competition.

Before building the robot chassis a team must decide what their strategy for completing courses will be. The object of the Auto-Nav challenge is to navigate obstacles on a curved course, over ramps, and through sand. Therefore, the vehicle requires the mobility to steer around obstacles, and the power to carry a 20 pound payload over ramps. It also uses GPS waypoints to navigate the robot to get from point A to point B as quickly as possible, without going over the ten mph speed limit. For obstacle avoidance on the Auto-Nav Challenge course a team can choose from steering controls such as Ackermann, differential, articulation and omnidirectional steering. All steering strategies have been tried in past IGVC competitions with success limited only by the robustness of the chassis. A properly designed Ackermann or articulating robot can navigate obstacles as well as omnidirectional and differential steering robots. A team should choose whichever steering strategy they feel will best complement the robot's software control.

After choosing a basic steering design the team should consider how they will store and convert energy on their vehicle. Typically the robots are battery powered electric drive. However, there are examples of internal combustion engine and hydrogen powered fuel cell vehicles in the past. So long as the design of the robot is structurally sound and energy transmission complies with relevant industry standards, a team can derive their power from batteries, fuel or fuel cells. Teams should investigate the safe handling practices of each type of energy storage before choosing their power source. Also, a team should research the logistics of their energy source, to make sure it is the best source for their design. For example, gasoline has a high energy density, but converting the energy into rotational and electrical power typically requires more equipment which may mitigate weight savings. Another example, lead acid batteries have a very low energy density, but they are less expensive and easier to maintain than lithium ion batteries. Current platforms must be able to maneuver through several different types of terrain. The majority of the Auto-Nav Challenge course is freshly cut grass. There are parts of the Auto-Nav Challenge course which could consist of sand, wood or tarmac. The terrain may also be wet and muddy. Differential tracked vehicles should be designed to have enough traction to propel them forward, while having enough slippage to control the direction of the vehicle's under steer. All platforms must have enough power to carry itself and the 20 pound payload across the terrain gradients up to 15%. It is important to design the vehicle to carry extra power because a team cannot replace batteries or refuel once they start a performance event.

Figure 7: *Students from University of Michigan, Dearborn and California State University, Northridge getting ready to Qualify.*

Braking is sometimes mechanical, but often results simply when power to the motors is cut off, and/or the very high gear ratios are used between motors and wheels. Suspension systems vary widely from sophisticated shock absorber/spring assemblies to solid mounting. Computers and electronic components are often soft-mounted. Majority of the vehicles are electrically powered, but some have also been powered by internal combustion engines and hydraulic drive. Most vehicles have wheels, either three or four, but some have had two wheels or tracks similar to an army tank. Bodies are sometimes made of composite materials in very stylish, artistic, and creative forms, while others have no body covering at all and look like rolling laboratories.

Electrical subsystem teams are generally responsible for most of the components on the vehicle, such as batteries, computers, sensors, cameras and actuators. A typical vision system consists of a one or several color video or still cameras positioned on top of the vehicle that have to be interfaced with a computer. Frequently used sensors include SICK laser range finders, digital compasses, differential global position systems (DGPS), diffuse sensors, non-contact optical sensors and proximity sensors. Controllers are used for the motors, speed and actuators for steering and suspension. Most vehicles have several computers, though they are not always onboard, they are used for programming and vehicle diagnostics and are connected via hard wire or through a wireless local area network (LAN) connection.

Software teams are responsible for writing the software that controls all of the individual mechanical and electrical devices on the vehicle. Several different languages are used to write the code for the vehicles including C, C++, Visual Basic, LabVIEW and Java. Some teams are even making their vehicles compliant with JAUS; this is significant because JAUS is emerging as the DoD standard for all unmanned systems. The purpose of JAUS is interoperability between various unmanned systems and subsystems for both commercial and military applications. This year a number of teams have started to implement ROS (Robot Operating System) which provides open source libraries, divers and other tools.

Most teams use a closed-loop system for controlling their vehicles. A computer and controller feed information to motor controllers, which send electrical or mechanical energy to power the motors. This moves the vehicle, which is observed by encoders that can measure either the motors movement to determine where and how far the vehicle moved, or can measure the environment to determine how far it has traveled. These encoders then send that data back to the computer which uses it, among other data in determining what to do next. A typical example of a vehicle's software system can often be broken down into main sub systems; for example main navigation algorithm, lane following algorithm, obstacle avoidance algorithm and waypoint algorithm. The main sub systems will take data from the other algorithms and use it to plan its path using 3D mapping to determine go and no go areas to choose an ideal case where there are no uncertainties, using tools such as differential equations and Extended Kalman Filter algorithms to determine the best path in light of the data and uncertainties in the situation. Many robots used both video camera, single or stereo cameras and laser range data to create these 3D maps of the area. The laser range finders are often mounted less than a foot above the ground, looking parallel to the ground.
The video cameras however, are often mounted several feet above the ground, looking downward at a 45 degree angle. This presented a problem to the teams, requiring them to determine how to integrate both sensors into the map and still utilize the sensors' capabilities. One way to do this was to convert the video data into laser range data format, and place it on the semicircle map created by the laser range finder.

The laser range finder map is converted into a form of x-y coordinates, which are then used to plan the path of the vehicle, looking forward at future movements and plotting its course on this 3D map. To do this, decision-making algorithms try to find a path to the end of their sensor range. If they cannot do this, they find the best possible path at a closer range, where new sensor data may generate new paths. Otherwise, like human drivers, the vehicles will back up and try another path. Teams often incorporated a lane-continuation algorithm into their controllers, so that if a lane on either edge of the path disappeared for a distance, it would "extend" that line and maintain its course within that line as if it were still observed. Several teams are now using a systems engineering team to link all the subsystems together and make sure that all the pieces fit together. If systems are conflicting their responsibility is to determine what is causing the problem. Then they can address the problem by either eliminating unnecessary equipment or software, or they can determine a new unique solution to solve the problem. The engineering challenge is to successfully build, integrate, test, tune and control the vehicle to meet the competition challenges within the time and resource constraints.

The 2015 Competition

The 20th Intelligent Ground Vehicle Competition was held on June 5-8, 2015 at Oakland University in Rochester, Michigan. This year it drew 36 teams to attempt the challenge. This year's event was international, as teams from the US, Canada, Japan, India and Australia competed. Throughout the practice and qualification weekend, additional hardware and computer issues left 13 teams qualifying for the Basic Course and 7 teams completing it to make the Advanced Course.

The Auto-Nav Challenge, this year was split into a Basic Course and Advanced Course, both requiring the robots to drive a grass course, performing line-following and obstacle avoidance while driving past stationary obstacles (construction barrels, cones, etc.), following GPS waypoints and navigating through open terrain. University of New South Wales's Pepper completed 1032 feet of the course in 3:52 and received $5,000 in award money. California State University, Northridge's El Toro completed 1032 feet and timed out at 10:00 minutes and received $4,000 in award money. University of Michigan, Dearborn's OHM 3.0 came in third place with 756 feet in 6:46 to received $1000 in award money. All the teams fell short of the money barrel.

The complete Advanced Auto-Nav results were: first place University of New South Wales, Pepper with 1032 feet and 6 waypoints in 3:52; second place California State University - Northridge, El Toro with 1032 feet and 6 waypoints in 10:00; third place University of Michigan - Dearborn, OHM 3.0 with 756 feet and 6 waypoints in 6:46; fourth place United States Naval Academy, Robogoat with 633 feet and 2 waypoints in 8:55; fifth place École de technologie supérieure, CAPRA6 with 172 feet in 5:59; sixth place Oakland University, Mantis with 166 feet in 1:47; seventh place Lawrence Technological University, Bigfoot with 161 feet in 1:19.

The complete Basic Auto-Nav results were: first place University of New South Wales, Pepper with 510 feet and 2 waypoints in 1:27; second place California State University-Northridge, El Toro with 510 feet and 2 waypoints in 1:58; third place Oakland University, Mantis with 510 and 2 waypoints in 2:34; fourth place University of Michigan-Dearborn, OHM 3.0 with 510 feet and 2 waypoints in 3:26; fifth place United States Naval Academy, Robogoat with 510 feet and 2 waypoints in 3:33; sixth place 6 École de technologie supérieure, CAPRA6 with 510 feet an d2 waypoints in 4:28; seventh place Lawrence Technological University, Bigfoot with 510 feet and 2 waypoints in 5:00; eight place Embry-Riddle Aeronautical University, Zero2 with 430 feet and 2 way points in 5:00; ninth place Trinity College, Q with 290 and 1 waypoint in 5:00; tenth Hosei University, Orange2015 with 284 feet and 1 waypoint in 4:11; eleventh place Université de Moncton, Break Point with 157 feet in 2:45; twelfth place University of Detroit Mercy, Thor Pro with 85 feet in 1:36; thirteenth place Bluefield State College, Apollo with 60 feet in 0:19.

The Design Competition component of the IGVC has been held for 21 of the 23 years that the competition has been in existence. Judges for this competition are chosen to reflect commercial and military applications of intelligent vehicles. Two weeks prior to the IGVC, teams send their technical papers to the judges for review. The teams were then randomly split into either Design Group A, B or C. During the competition each Design Group presented their design to a different group of independent judging panels. Each panel selected their top two teams and those teams presented their design presentation to all of the judges to score the top six finalists to determine a winner. The presentations and technical papers are evaluated and scored on a 1200 point scale and the design finalist on a 480 point scale. Embry-Riddle Aeronautical University's Zero2 won first place and $3,000 in award money; Oakland University's Mantis took second place and $2,000 in award money and University of École de technologie supérieure's CAPRA6 took third and $1,000 in award money.

Figure 8: *University of Detroit Mercy – Thor Pro on the Practice Course making adjustments to their vehicles.*

The complete Design results: Design Finals: first place Embry-Riddle Aeronautical University, Zero2 with 432.22; second place Oakland University, Mantis with 408.11; third place École de technologie supérieure, CAPRA6 with 402.78; University of British Columbia, Snowflake with 394.78; fifth place Bluefield State College, Apollo with 393.44; sixth place Hosei University, Orange2015 with 388.44. Design Group A: University of British Columbia, Snowflake with 1136.00; second place École de technologie supérieure, CAPRA6 with 1107.67; third place University of New South Wales, Pepper with 1097.67; fourth place California State University - Northridge, El Toro with 1042.33; fifth place University of Michigan - Dearborn, OHM 3.0 with 1004.33; sixth place Lawrence Technological University; Bigfoot with 948.33; seventh place Indian Institute of Technology - Kharagpur, EKLAVYA 4.0 with 852.33; eigth place University of Cincinnati, Dokalman with 697.67; ninth place Universite' de Moncton, BreakPoint with 659.67; tenth place University of West Florida, The Wobbler with 630.00; eleventh place Oakland University, Octagon with 209.33. Design Group B: first place Bluefield State College, Apollo with 1080.67; second place Hosei University, Orange2015 with 1068.00; third place Lawrence Technological University, TurtleBot with 1022.67; fourth place Georgia Institute of Technology, Mistii with 1010.67; fifth place United States Military Academy, IGGY with 958.00; sixth place The Citadel, The CAR with 956.67; seventh place Southern Illinois University - Edwardsville, Roadrunner with 932.33. Design Group C: first place Embry-Riddle Aeronautical University, Zero2 with 1137.00; second place Oakland University, Mantis with 1125.00; third place University of Illinois - Chicago, Scipio with 1063.67; fourth place University of Central Florida, Little MAC with 1055.00; fifth place University of Detroit Mercy, ThorPro with

1015.33; sixth place Trinity College, Q with 878.67; seventh place United States Naval Academy, RoboGoat with 751.33; eight place Michigan Technological University, Bishop with 718.67.

The IOP Challenge is in its second year, verified that teams were using a standardized message suitable for controlling all types of unmanned systems, were sent a request for identification to the COP every few seconds. The COP then responded with the appropriate informative message and request identification in return from the interface. After the identification report from the COP, the vehicles stopped repeating the request. This transaction served as the discovery between the OCU and the vehicle. Then the OCU would send the teams waypoints for the vehicles to visit in a specific order in the shortest amount of time. California State University, Northridge's El Toro came in first, scoring 24 points and receiving $3,000 in award money. Lawrence Technological University's Bigfoot placed, scoring 20 points and receiving $2,000 in award money. Trinity College's Q was third with a score of 16 and receiving $1,000 in award money.

Figure 9: *École de technologie supérieure – CAPRA6 in front of the Auto-Nav Course.*

The complete IOP results: first place California State University - Northridge, El Toro with 24 points; second place Lawrence Technological University, Bigfoot with 20 points; third place Trinity College, Q with 16 points; fourth place University of New South Wales, Pepper with 12 points; fifth place University of British Columbia, Snowflake with 4 points; sixth place Hosei University, Orange2015 with 4 points.

The Rookie-of-the-Year Award is given out to a team from a new school competing for the first time or a school that has not participated in the last five competitions. To win the Rookie-of-the-Year Award the team must be the best of the eligible teams competing and perform to the minimum standards of the following events. In the Design Competition you must pass Qualification and in the Auto-Nav Challenge you must pass the Rookie Barrel. University of New South Wales entered the IGVC for the first time, beating several other teams to win the Rookie-of-the-Year Award and $1,000 in award money.

The Grand Award this year went to California State University, Northridge's El Toro with a total of 64 points taking home the Lescoe Cup. Second place went to University of New South Wales's Pepper with 60 points. There was a three way tie for third place and the Lescoe Award between École de technologie supérieure's CAPRA6, Embry Riddle Aeronautical University's Zero2 and Oakland University's Mantis each with 24 points. Table 6 has a breakdown of all the teams that scored points toward the Grand Award.

The complete Grand Award points: first place California State University - Northridge, El Toro with 64 points; second place University of New South Wales, Pepper with 60 points; third place École de technologie supérieure, CAPRA6 with 24 points; third place Embry-Riddle Aeronautical University, Zero2 with 24 points; third place Oakland University, Mantis with 24 points; sixth place Lawrence Technological University, Bigfoot with 20 points; seventh University of Michigan - Dearborn, OHM 3.0 with 16 points; seventh place Trinity College, Q with 16 points; ninth place United States Naval Academy, RoboGoat with 12 points; tenth place University of British Columbia, Snowflake with 10 points; eleventh place Bluefield State College, Apollo with 8 points; eleventh place Hosei University, Orange2015 with 8 points.

Conclusion

The Intelligent Ground Vehicle Competition has changed astonishingly over the past 23 years. Hundreds of students from dozens of universities in several different countries excel each year in the application of cutting-edge technologies in engineering and computer science that have direct application in transportation, military, manufacturing, agriculture, recreation, space exploration, and many other fields. They have utilized professional design procedures and performed hands-on fabrication and testing. At the same time they have learned to work in teams and to understand the full product realization process. They have been creative and have at times demonstrated system and technology brilliance. The students are ready for full careers in the Intelligent Transportation Systems (ITS) engineering community. The IGVC is currently preparing for its 24^{TH} competition on June 3-6, 2016 at Oakland University in Rochester, Michigan. Visit the IGVC website at www.igvc.org for more information.

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Additional Sources

Complete rules and other information about the IGVC can be obtained from the website www.igvc.org.

Author Biography

Mr. Theisen received his MS in mechanical engineering from Oakland University and works for the U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC). Mr. Theisen is currently the Technical Manager for the Autonomous Mobility Appliqué System (AMAS). His team is responsible for the joint Army and Marnie Corps architecture for robotic kits for tactical wheeled vehicles (TWV).

Figure 10: *The teams lined up at the Awards Ceremony.*