The 16TH Annual Intelligent Ground Vehicle Competition: Intelligent Students Creating Intelligent Vehicles

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ABSTRACT

The Intelligent Ground Vehicle Competition (IGVC) is one of three, unmanned systems, student competitions that were founded by the Association for Unmanned Vehicle Systems International (AUVSI) in the 1990s. 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 16 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 nearly 70 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.

Key words: intelligent robots, autonomous systems, ground vehicles, engineering education, IGVC.

Figure 1: University of Detroit Mercy – CERATOPS, 2008 IGVC 1ST place overall winner.

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14. ABSTRACT
The Intelligent Ground Vehicle Competition (IGVC) is one of three, unmanned systems, student competitions that were founded by the Association for Unmanned Vehicle Systems International (AUVSI) in the 1990s. 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 16 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 nearly 70 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.

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1. INTRODUCTION

The Intelligent Ground Vehicle Competition (IGVC) is one of three, unmanned systems, student competitions that were founded by the Association for Unmanned Vehicle Systems International (AUVSI) in the 1990s. 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 16 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 nearly 70 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: Princeton University – Kratos, 2008 Rookie-of-the-Year and 1ST place in 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), DaimlerChrysler (DCX), Applied Research Associates (ARA), Science Applications International Corp. (SAIC), National Defense Industrial Association (NDIA), Theta Tau, Motorola, CSI Wireless, Microsoft Robotics, Raytheon, the Defense Advanced Research Projects Agency (DARPA), the DoD Joint Ground Robotics Enterprise (JGRE), the U.S. Air Force Research Laboratory (AFRL) 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 systems (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 mandatory components and one optional event: a Design Competition, the Autonomous Challenge, the Navigation Challenge and the Joint Architecture for Unmanned Systems (JUAS) Challenge. The total award money amount of all four competitions is currently over $45,000. In the Design Competition, judges determine winners based on written and oral presentations and on examination of the vehicles. While in the Autonomous Challenge, the robotic vehicles negotiate an outdoor obstacle course approximately 200 meters long. The Navigation Challenge requires vehicles to travel from a starting point to a number of target destinations using global positioning system (GPS) waypoints. The JAUS Challenge has two aspects a written/oral presentation which will be added to the Design Competition and a practical demonstration to determine compliance with the architecture.

Figure 3: Lawrence Technological University - Viper, completed JAUS Level III Challenge.

2. THE COMPETITION EVENTS

The Autonomous 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 five mile-per-hour speed limit and avoid obstacles on the track. The course consists of a 600 foot long, ten foot wide lane with white lane markings on grass. Obstacles on the course will 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 man made 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. There locations will be adjusted between runs and the direction of the obstacle course may also be changed between heats. Artificial inclines with 15 percent gradients and a sand pit are placed on the course and must be negotiated. 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 with computer vision and obstacle detection technologies. Judges will rank the entries that complete the course based on shortest adjusted time taken. In the event that a vehicle 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 $10,500.

Figure 4: Bluefield State College – Anassa IV 1ST place in the Autonomous Challenge.

The Design Competition expects all teams will design and equip their vehicles to compete in the Autonomous and Navigation Challenges 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 $6,000.

The Navigation Challenge event is a practice that is thousands of years old. Procedures have continuously improved from line-of-sight to moss on trees to dead reckoning to celestial observation to the use of global positioning systems (GPS). The challenge in this event is for a vehicle to autonomously travel from a starting point to a number of target destinations (waypoints or landmarks) and return to home base, provided only a map showing the coordinates of those targets. Coordinates of the targets are given in latitude and longitude as well as in meters on an x-y grid. The vehicle thus needs to incorporate GPS technology with computer vision, obstacle detection and avoidance to find and reach the targets. The vehicle visiting the most waypoints in a given (or the shortest) time wins; award money for this event totals $7,750.

The JAUS Challenge verifies that teams are using a standardized message suitable for controlling all types of unmanned systems, and is becoming an SAE Aerospace Standard. Participation in the challenge is voluntary and teams could complete either the Level II or Level III Challenges. Teams that completed Level II last year, where not eligible to complete Level II this year, but all teams need to complete Level II to attempt Level III. Both challenges consisted of two separate aspects, first a description of the student teams' implementation in the Design Competition. Student teams that participated in JAUS were allotted one extra page in their report and two extra minutes during their oral presentation. The second aspect is a practical demonstration which will consist of JAUS messages begin sent to the vehicle from an IGVC developed operator control unit (OCU) via an RF data link. All teams successfully completing the JAUS will receive an award of $500, limit one award per school.

Figure 5: Hosei University – Omnix 2008, completing its 3RD place Navigation Challenge run.

3. THE COMPETITION RULES (IN BRIEF)

Vehicles must be entirely 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 have a maximum speed of five mph for safety and must carry a 20 pound load during competition.

The Autonomous Challenge course is laid out on grass with sections of simulated asphalt, a simulated sand pit, and an artificial incline with a 15 percent grade. Lane markers (lines) are painted white and are 10 feet apart. The turning radius is not less than five feet. One section has alternating dashed lines, while another section has no lane markers at all for 15 feet. Obstacles on the course will consist of various colors construction drums, cones, trash cans, pedestals and barricades that are used on roadways and highways. White-painted simulated and actual potholes need to be avoided. Traffic tickets or run terminations are made by the judges for various infringements on the course (crossing the lane markers, striking an obstacle, etc.). The course layout is changed every year and obstacles are moved between runs.

Figure 6: École de technologie supérieure – RS3 on the Autonomous Challenge.

The Navigation Challenge course is run on an unmarked one hectare field or paved parking lot. Waypoints vary in size from two to four meter diameter and are scattered around a single start/finish point, latitude and longitude of each of these targets is given to the participants. Construction barrels and other construction barriers are also located in the field so the vehicles cannot reach all waypoints by following straight lines without encountering an obstacle. Teams placing in the competitions are awarded with individual point values for a grand award for the team that represents best overall performance. 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. For completing JAUS Challenge Level II teams were award four points and six points for Level III, the point breakdown structure for the rest of the events is listed in Table 1.

Place	Autonomous Challenge	Design Competition	Navigation Challenge
1	48	24	36
2	40	20	30
3	32	16	24
4	24	12	18
5	16	8	12
6	8	4	6

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.

4. TEAM TECHNOLOGIES

All of the vehicles entered into the IGVC are unique and different in design. Though 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 autonomous 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. The Navigation Challenge only requires the robot to get from point A to point B as quickly as possible, without going over the five mph speed limit. For obstacle avoidance on the Autonomous 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 Autonomous Challenge course and possibly the entire Navigation Challenge course is freshly cut grass. There are parts of the Autonomous Challenge course which 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: Georgia Institute of Technology - Candii on the Practice Course.

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, and is currently part of the Operational Requirement Document (ORD) for the Future Combat System (FCS).

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.

Figure 8: Embry-Riddle Aeronautical University – Reagle on the Navigation Course.

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.

Figure 9: Senator Carl Levin welcomed the students and faculty as the keynote speaker in the opening ceremonies.

5. THE 2008 COMPETITION

The 16th Intelligent Ground Vehicle Competition was held on May 30 - June 2, 2008 at Oakland University in Rochester, Michigan. This year drew 47 teams to attempt the challenge, due to complications only 41 teams appeared at the competition. The teams were truly international, arriving from all or the U.S and Canada and from as far away as Japan. Throughout the practice and qualification weekend, additional hardware and computer realities eliminated 14 more participants for a total of 27 teams qualifying for the performance events.

The Autonomous Challenge, an IGVC original event, requires the robots to drive a grass course, performing line-following and obstacle avoidance while driving over a ramp, through a sand pit, avoiding simulated potholes and keeping between dashed line markings. Bluefield State College's Anassa IV was the only team to complete the 600 foot long course in three minutes and eight seconds and received $3,000 in award money. Lawrence Technological University's Viper completed 420 feet of the course before their five minute time limit expired, but still managed to take home second place and $2,500 in award money. The University of Michigan – Dearborn's Wolf came in third place with 355 feet 4 minutes and 49 seconds to edge by University of Detroit Mercy's CERATOPS who completed 354 feet before their five minute time limit expired and take home $2,000 in award money.

Place	School	Team	Distance	Time
1	Bluefield State College	Anassa IV	600	3:08
2	Lawrence Technological University	Viper	420	5:00
3	University of Michigan – Dearborn	Wolf	355	4:49
4	University of Detroit Mercy	CERATOPS	354	5:00
5	Embry-Riddle Aeronautical University	Reagle	223	2:37
6	Princeton University	Kratos	223	2:45
7	Trinity College	Q	201	5:00
8	École de technologie supérieure	RS3	193	3:01
9	Georgia Institute of Technology	Candii	185	1:59
10	The College of New Jersey	Spinster	181	1:27
11	University of Michigan – Dearborn	Raptor	158	2:24
12	Hosei University	Omnix 2008	80	1:28
13	Missouri University of Science and Technology	triMAXion	78	0:48
14	Oakland University	X-man	78	1:18
15	University of Buffalo	Athena	76	1:50
16	University of Massachusetts – Lowell	MCP III	72	0:46
17	University of Cincinnati	Bearcat Cub	65	1:32
18	Bob Jones University	Abel	65	1:55
19	University of Akron	Land ROOver	49	2:43
20	University of Delaware	Warthog	38	0:45
21	City College of New York	Bender	35	1:56
22	California State University – Chico	Step 5	23	1:10
23	Missouri University of Science and Technology	Aluminator	18	1:15
24	California State University – Northridge	LinBot	15	2:23
25	Pennsylvania State University	Nittalion Battalion	12	0:10

Table 2: Autonomous Challenge results

The Design Competition component of the IGVC has been sponsored by the Society of Automotive Engineers for 14 of the 16 years the competition has been held. Judges for this competition are chosen to reflect commercial and military applications of intelligent vehicles. Two weeks prior to the IGVC, teams sent their technical papers to the judges for review. The teams were then randomly split into either Design Group A or Design Group B. During the competition each Design Group presented their design to a different group of independent judging panels. Each panel selected their top three teams and those teams presented their design presentation to the other panel of judges. Then both judging panels merge to score the top six finalists to determine a winner. The presentations and technical papers (in SAE format) were evaluated and scored. Princeton University's Kratos design won first place and $2,000 in award money; University of Embry-Riddle Aeronautical University's Reagle took second place and $1,500 in award money and University of Detroit Mercy's CERATOPS took third and $1,000 in award money.

Design Finalist			
Place	School	Team	Score
1	Princeton University	Kratos	997.83
2	Embry-Riddle Aeronautical University	Reagle	988.58
3	University of Detroit Mercy	CERATOPS	986.67
4	California State University – Northridge	NorMAN	981.08
5	École de technologie supérieure	RS3	978.75
6	Missouri University of Science and Technology	triMAXion	929.33

Design Group A			
Place	School	Team	Score
1	University of Detroit Mercy	CERATOPS	990.00
2	Princeton University	Kratos	989.00
3	Embry-Riddle Aeronautical University	Reagle	963.67
4	University of Central Florida	Gamblore	962.33
5	University of Michigan – Dearborn	Raptor	960.00
6	Trinity College	Q	948.67
7	Pennsylvania State University	Nittalion Battalion	947.33
8	Hosei University	Omnix 2008	942.00
9	Bob Jones University	Cornelius	914.67
10	University of Wisconsin – Madison	Paradroid	910.00
11	University of Wisconsin – Madison	ReWIRED	890.33
12	Bluefield State College	Anassa IV	887.67
13	University of Illinois – Chicago	Achilles	884.00
14	Louisiana State University	MikeRobot	840.67
15	University of Massachusetts – Lowell	MCP III	832.00
16	Rochester Institute of Technology	AMOS III	755.33
17	Case Western Reserve University	Harlie	675.00
18	University of Michigan – Dearborn	Wolf	672.00
19	City College of New York	Bender	622.00
20	Bluefield State College	Archon	608.67
21	The College of New Jersey	Spinster	490.67
22	Bob Jones University	Abel	481.00
23	Rose-Hulman Institute of Technology	RATT	424.33
Design Group B			
Place	School	Team	Score
1	École de technologie supérieure	RS3	980.67
2	California State University – Northridge	NorMAN	979.33
3	Missouri University of Science and Technology	triMAXion	931.67
4	Oakland University	X-man	928.33
5	Elizabethtown College	Wunderbot IV	906.67
5	Lawrence Technological University	Viper	906.67
7	California State University – Northridge	LinBot	903.33
8	California State University – Chico	Step 5	901.33
9	University of Akron	Land ROOver	894.67
10	University of Buffalo	Athena	887.33
11	University of Texas – Arlington	Mav-Bot	886.33
12	Tennessee Technological University	Tech Bot	878.67
13	University of Cincinnati	Bearcat Cub	844.33
14	University of Waterloo	Q-BERT	843.67
15	University of Delaware	Warthog	804.00
16	Missouri University of Science and Technology	Stereo Opticon	798.00
17	Missouri University of Science and Technology	Aluminator	788.67
18	Georgia Institute of Technology	Candii	778.33

Table 3: Design Competition results.

The Navigation Challenge in its eight year demonstrated agile maneuvers based on navigating between a set of nine different GPS waypoints. The challenge was enhanced by deliberately setting obstacles between the waypoints. Teams had to optimize their routing while integrating machine vision to avoid the obstacles. University of Detroit Mercy's CERATOPS came in first, completing eight waypoints in two minutes and 43 seconds and receiving $2,500 in award money. University of Michigan – Dearborn's Wolf came in second place, by completing eight waypoints in four minutes and 56 seconds and receiving $2,000 in award money. Third place went to Hosei University's Omnix 2008, completing seven waypoints in two minutes and 26 seconds and received $1,500 in award money.

Place	School	Team	Points	Time
1	University of Detroit Mercy	CERATOPS	8	2:43
2	University of Michigan – Dearborn	Wolf	8	4:56
3	Hosei University	Omnix 2008	7	2:26
4	Princeton University	Kratos	7	3:33
5	Embry-Riddle Aeronautical University	Reagle	5	1:17
6	University of Delaware	Warthog	5	1:23
7	Pennsylvania State University	Nittalion Battalion	5	2:06
8	University of Cincinnati	Bearcat Cub	5	2:14
9	University of Buffalo	Athena	5	2:51
10	California State University – Northridge	LinBot	5	5:37
11	Bluefield State College	Anassa IV	4	1:02
12	Case Western Reserve University	Harlie	4	3:00
13	The College of New Jersey	Spinster	3	1:13
14	University of Akron	Land ROOver	2	1:20
15	Bob Jones University	Abel	2	2:19
16	University of Michigan – Dearborn	Raptor	1	0:14
17	Lawrence Technological University	Viper	1	0:15
18	Trinity College	Q	1	0:54
19	University of Massachusetts – Lowell	MCP III	0	0:00

Table 4: Navigation Challenge results.

The JAUS Challenge in its third year had 17 teams attempt one of the two challenges. Nine teams completed the Level II Challenge of starting the vehicle moving forward in the autonomous mode, stopping the vehicle from moving in the autonomous mode, activate a warning device (horn/light) and demonstrating that their vehicle's only accept messages intended for them and provide the Navigation Challenge waypoints upon request. Teams that completed the Level II Challenge and received the $500 award were: California State University – Northridge's LinBot, Elizabethtown College's Wunderbot IV, Embry-Riddle Aeronautical University's Reagle, Oakland University's X-man, Princeton University's Kratos, Trinity College's Q, University of Buffalo's Athena, University of Central Florida's Gamblore and University of Texas – Arlington's Mav-Bot. Only two teams completed the Level III Challenge of using a JAUS compliant payload to complete the Navigation Challenge. Teams that completed the Level III Challenge and received the $500 award were: Hosei University's Omnix 2008 and Lawrence Technological University's Viper.

The Rookie-of-the-Year Award is given out to a team from a new school competing for the first time ever 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, in the Autonomous Challenge you must pass the Rookie Barrel and in the Navigation Challenge you must make three waypoints. This year Princeton University returned to the competition after a 12 year hiatus with their Kratos vehicle to narrowly beat out Embry-Riddle Aeronautical University who has not competed since 2002, to take home the $1,000 in award money after.

The Grand Award this year went University of Detroit Mercy's CERATOPS with a total of 78 points taking home the Lescoe Cup. Second place and the Lescoe Trophy went to University of Michigan – Dearborn's Wolf with 62 points. Third place and the Lescoe Award went to the Princeton University's Kratos with 50 points. Table 5 has a breakdown of all the teams that scored points toward the Grand Award.

Place	School	Team	Total
1	University of Detroit Mercy	CERATOPS	78
2	University of Michigan – Dearborn	Wolf	62
3	Princeton University	Kratos	50
4	Bluefield State College	Anassa IV	48
5	Lawrence Technological University	Viper	46
6	Embry-Riddle Aeronautical University	Reagle	44
7	Hosei University	Omnix 2008	30
8	École de technologie supérieure	RS3	10
9	California State University – Northridge	NorMAN	6
10	California State University – Northridge	LinBot	4
10	Oakland University	X-man	4
10	Trinity College	Q	4
10	University of Buffalo	Athena	4
10	University of Central Florida	Gamblore	4
10	University of Texas – Arlington	Mav-Bot	4
10	Elizabethtown College	Wunderbot IV	4
10	Missouri University of Science and Technology	triMAXion	4
18	Bob Jones University	Cornelius	2
18	Rochester Institute of Technology	AMOS III	2
18	University of Wisconsin – Madison	Paradroid	2
18	University of Wisconsin – Madison	ReWIRED	2
18	University of Delaware	Warthog	2

Table 5: Grand Award results.

6. CONCLUSION

The Intelligent Ground Vehicle Competition made remarkable strides in the past 16 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 17^{TH} competition on June 5-9, 2009 at Oakland University in Rochester, Michigan. Visit the IGVC website at www.igvc.org for more information.

ACKNOWLEDGEMENTS

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ADDITIONAL SOURCES

Complete rules and other information about the IGVC can be obtained from the website www.igvc.org or by contacting us at (586) 574-8750.

Figure 10: University of Buffalo – Athena on the Qualification Course.