The Intelligent Ground Vehicle Competition (IGVC): A Cutting-Edge Engineering Team Experience

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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 in the 1990s. The IGVC challenges engineering student teams to integrate advanced control theory, machine vision, vehicular electronics, and mobile platform fundamentals to design and build an unmanned system for competition against both U.S. and international teams. IGVC teams focus on developing a suite of dual-use technologies to equip ground vehicles of the future with intelligent driving capabilities. Over the past 10 years, the competition has challenged both undergraduates and graduates, including Ph.D. students. To date, teams from 35 universities and colleges have participated. Participants in the 10th annual IGVC held in July, 2002 included Virginia Tech, West Point, Hosei University in Tokyo, Trinity College, Oakland University, the University of Cincinnati, the University of Alberta, and nine other schools. The IGVC is showcased in a design competition sponsored by the Society of Automotive Engineers. For participating, students earn up to two semesters of senior design credit from some schools. The primary goal of the IGVC is to advance engineering education in intelligent vehicles and related technologies.

The IGVC has four components: a mandatory Design Competition, the Autonomous Challenge, the Navigation Challenge, and the Follow the Leader Competition. The total dollar amount of all four competitions is currently $23,000. In the Design Competition, judges determine winners based on written and oral presentations and on examination of the vehicles, while in the Autonomous Challenge, autonomous 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, and the Follow-the-Leader Competition requires technology that allows vehicles to follow one another autonomously at distances as short as two meters. The rules for these competitions are posted on the IGVC website at http://www.igvc.org/deploy/.

In this paper, we describe some of the applications of the technologies required by this competition, and discuss the educational benefits from multiple college and university perspectives and experiences. The employment and professional networking opportunities created for students and industrial sponsors through a series of technical events over the three-day competition are highlighted. Finally, an assessment of the competition based on participant feedback is presented.

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

Introduction

Founded and sponsored by the Association for Unmanned Vehicle Systems International (AUVSI), the Intelligent Ground Vehicle Competition (IGVC) has for the past 10 years challenged university student teams to develop, test, and compete with their intelligent vehicles, focusing on a series of autonomous mobility objectives.

Intelligent vehicles have many areas of application 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 force effectiveness of the Army's Objective Force through 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 Society of Automotive Engineers (SAE), Oakland University, 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, Motorola, CSI Wireless, the Defense Advanced Research Projects Agency (DARPA), the DoD Joint Robotics Program, and the U.S. Air Force Research Laboratory. 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, as well as to autonomously navigate with global positioning systems (GPS) and to perform lead-following. The civilian aspect of this dual use technology is underpinned by the automotive applications.[1,2]

Competition Description and Challenges

There are four competition events at the IGVC.

1. **Autonomous Challenge Event**. A fully autonomous unmanned ground robotic vehicle must negotiate around an outdoor obstacle course under a prescribed time while staying within the five mile-per-hour speed limit and avoiding obstacles on the track. The vehicles are judged based on their ability to perceive the course environment and avoid obstacles. Vehicles cannot be remotely controlled by a human operator 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.

Figure 1. The autonomous challenge course

2. **Navigation Challenge Event.** Navigation is a practice that is thousands of years old. Procedures have continuously improved from line-of-sight or dead-reckoning 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, given 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 and obstacle detection to find and reach the targets.

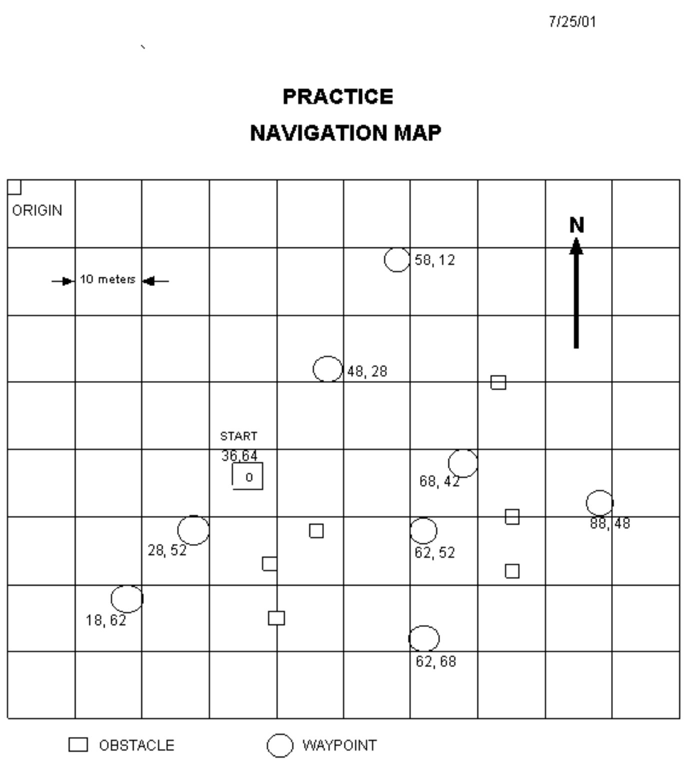

Figure 2. Practice navigation map

3. **Follow-the-Leader Challenge Event.** Automated highway systems require technology that allows vehicles to form and maintain "platoons," in which vehicles autonomously follow each other with very short headways, as short as two meters. The following vehicles must adhere to a fixed distance range from the leading vehicles and maintain that headway accurately under varying speeds, acceleration, braking, and emergency stops while steering along highway lane markers. The military application of this event relates to convoys in which only a lead vehicle is manned, while following vehicles not only maintain headway but also follow the leader wherever it might go in a trackless course. This competition is designed to simulate both of these real-world applications. The vehicle thus needs to incorporate object pattern recognition technology.

Figure 3. Follow-the-leader event

4. **Design Competition Event**. Participation in the design competition is a mandatory part of the IGVC. Participation in the three performance challenges is optional. However, failure to fully qualify for the Autonomous Challenge will result in only nominal prize awards in the design competition and the other two performance events. 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 written report, an oral presentation, and examination of the vehicle.

Figure 4. Design presentation and vehicle inspection

Vehicle Safety
Safety is a prime concern in engineering practice. Vehicles that are judged to be unsafe are not allowed to compete. Therefore, participating students get experience in designing their vehicle to conform to safety regulations. They must also conform to legal requirements, including the following criteria:

- **Speed Limits -** A maximum vehicle speed of five miles per hour (5 mph) is enforced. All vehicles must be governed not to exceed this maximum speed.
- **E-Stop -** Each vehicle must be equipped with both a manual and a wireless (RF) remote emergency stop (E-Stop) capability. The wireless E-Stop must be effective for a minimum of 50 feet.
- **Indemnification Agreement -** Each team and university must sign an indemnification agreement that protects them and IGVC from potential litigation.

Engineering and Technology Challenges Inherent in the IGVC
To meet the competition challenges, a vehicle needs to be equipped with advanced mechatronics technologies and intelligent computer control schemes. A typical technology make-up for an autonomous vehicle is illustrated in Figure 5.

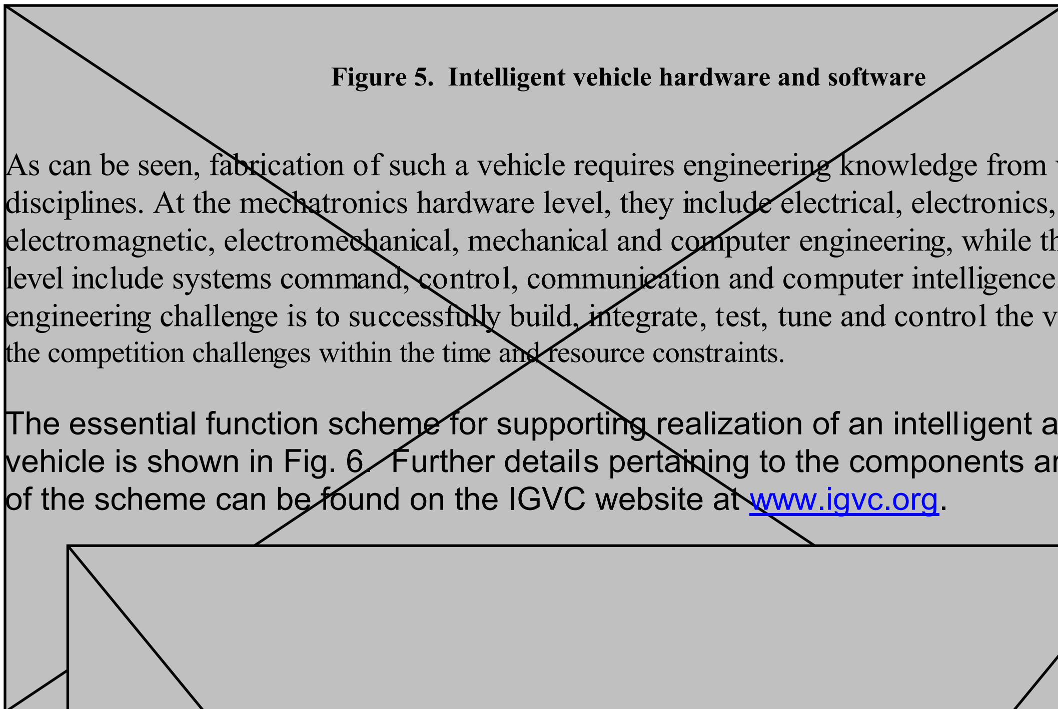

Figure 5. Intelligent vehicle hardware and software

As can be seen, fabrication of such a vehicle requires engineering knowledge from various disciplines. At the mechatronics hardware level, they include electrical, electronics, electromagnetic, electromechanical, mechanical and computer engineering, while the software level include systems command, control, communication and computer intelligence. 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 essential function scheme for supporting realization of an intelligent autonomous vehicle is shown in Fig. 6. Further details pertaining to the components and functions of the scheme can be found on the IGVC website at www.igvc.org.

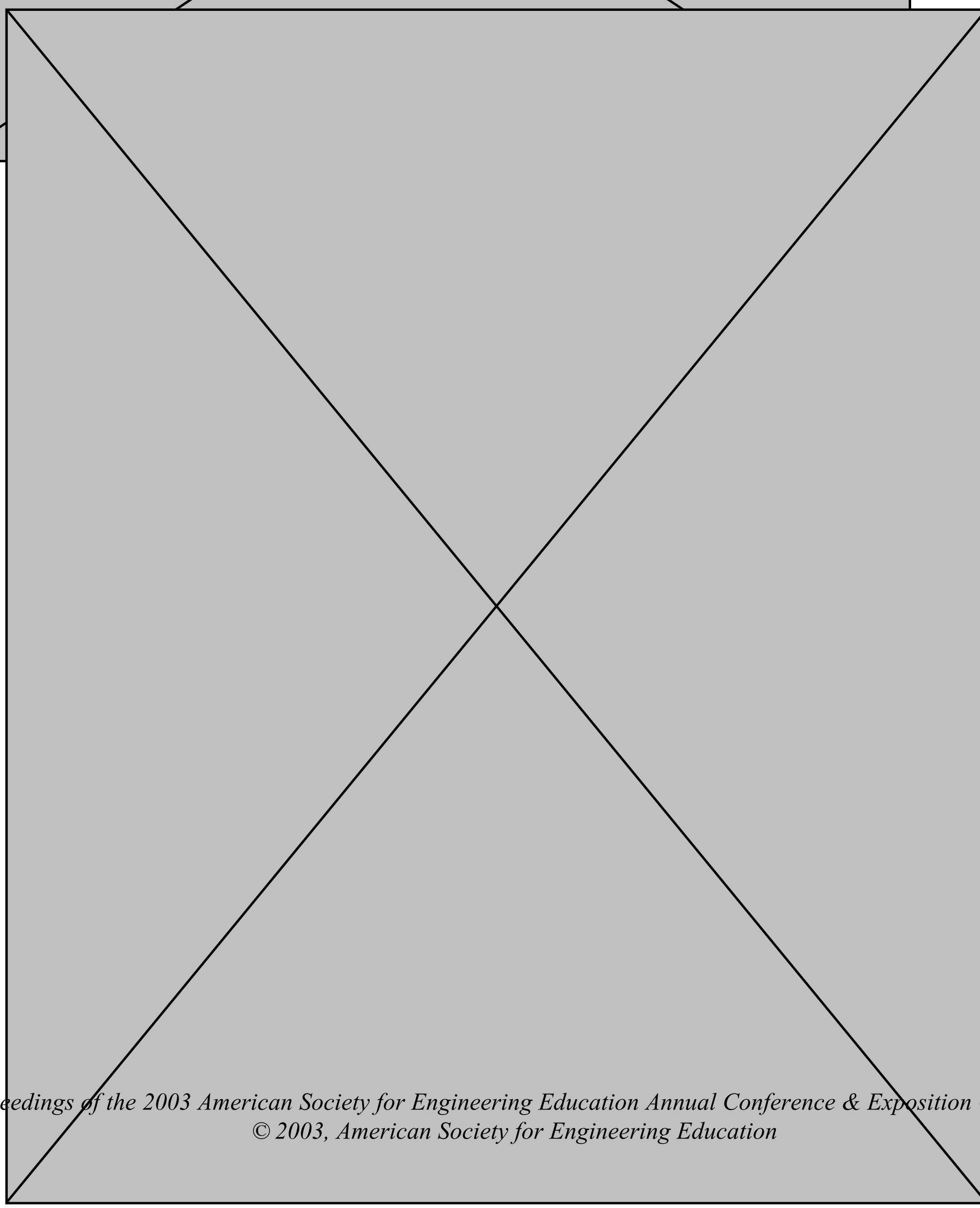

Figure 6. Function scheme

The Impact of the IGVC on Undergraduate and Graduate Engineering Design Projects

The IGVC offers a design experience that is at the very cutting edge of engineering education. It is multidisciplinary, theory-based, hands-on, team implemented, outcome assessed, and based on product realization. It encompasses the very latest technologies impacting industrial development and taps subjects of high interest to students. The design and construction of an intelligent vehicle fits well in a two-semester, senior year design capstone course, or as an extracurricular activity earning design credit. Most participating undergraduate and graduate students use the technical challenges posed by the competition as guidelines for their engineering projects. Under the supervision of faculty advisors, participating students can register and receive grades for up to eight credit hours of coursework towards fulfillment of their degree requirements.

The deadline of an end-of-term competition is a real-world constraint that includes the excitement of potentially winning recognition and financial gain. Students at all levels of undergraduate and graduate education can contribute to the team effort, and those at the lower levels benefit greatly from the experience and the mentoring by those at higher levels. Team organization and leadership are practiced, and there are roles for team members from business and engineering management, language and graphic arts, and public relations. Students solicit and interact with industrial sponsors that provide component hardware and advice, and in that way get an inside view of industrial design, as well as make contacts that may be valuable in gaining future employment. In building a vehicle to meet the IGVC challenges, students work as a team and experience what it takes to accomplish an engineering feat. Valuable knowledge such as the availability and cost of parts, and experiences such as dealing with vendors and performing internet searches, are acquired from doing actual construction of the vehicle. Students learn quickly how to manage time, budgets, other team members, unexpected situations or delays, and frustrations stemming from Murphy's Law.

The Effect of ABET Criteria on the IGVC

From the perspective of the Accreditation Board for Engineering and Technology (ABET), the IGVC challenges serve the students as well as their schools. Students working on an IGVC vehicle are presented with ample opportunities to apply their knowledge and learn on the job. At the same time, the schools can showcase the outcomes of their curriculum objectives to ABET reviewers. With successful IGVC vehicle projects, prospective engineering graduates demonstrate the value of the education they have received, as well as their ability to apply their learned skills. A well-trained engineering student must demonstrate that they have:

- An ability to apply knowledge of mathematics, science, engineering

- An ability to design and conduct experiments, as well as to analyze and interpret data
- An ability to design a system, component, or process to meet desired needs
- An ability to function on a multi-disciplinary team
- An ability to identify, formulate, and solve engineering problems
- An understanding of professional and ethical responsibility
- An ability to communicate effectively
- The broad education necessary to understand the impact of engineering solutions in a global and societal context
- A recognition of the need for, and an ability to engage in, lifelong learning
- A knowledge of contemporary issues
- An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

For the past decade, the IGVC has served many engineering curricula in universities around the world, and helped students achieve invaluable engineering training that satisfies most if not all the above ABET criteria.

Department of Defense Interest

The DoD has invested in Intelligent Unmanned Systems for the last two decades. The Defense Advanced Research Projects Agency (DARPA) initiated the Autonomous Land Vehicle (ALV) program in 1984. As the name implies, its focus was autonomous mobility with a program plan to progressively advance the autonomous capabilities. The U.S. Army then initiated two complimentary programs to apply, demonstrate and evaluate the battlefield utility of ALV autonomous mobility advances--the Reconnaissance Surveillance and Target Acquisition (RSTA) program and the Robotic Command Center (RCC) program. The Advanced Ground Vehicle Technology provided intelligent platforms which the Army evaluated to determine their applicability to RSTA missions. The RSTA program was chosen because it sets the performance benchmark for battlefield mobility requirements. The RCC program integrated autonomous mobility into multiple robot vehicles to address force multiplication advantages. Since the 1980s, DARPA and the U.S. Army have made steady progress in advancing the autonomous mobility capabilities. Intelligent Unmanned Ground Systems are a critical part of the Army's Future Combat System (FCS). DoD research investments in intelligent, unmanned mobility are increasing every year. The Army has identified near-term applications of intelligent mobility and focused battlefield demonstrations on a Robotic Follower Advanced Technology Demonstrator for the FCS program. In addition to the application of intelligence to unmanned systems mobility, the Army has initiated the application of autonomous mobility to automate the driving function of the FCS with the goal of reducing the crew size required for its operation. The IGVC was designed, and has evolved, to parallel the DoD research objectives in Intelligent Unmanned Ground Systems. Several leading DoD robotics organizations sponsor and staff the IGVC on a yearly basis. The relevancy of the IGVC challenges orients participating students toward careers in the unmanned systems technology area.

The Society of Automotive Engineers' Interest in the IGVC

The SAE, as a supporter of the automotive industry, is primarily concerned with automotive vehicles such as passenger cars, trucks, busses, and off-road vehicles, as well as the features that can enhance their use. Safety is a major concern, thus obstacle detection and avoidance technology is of interest. Computer-controlled lane-following and platooning are both important for future automated highways, and the on-board sensors and control hardware to accomplish these functions are under development.

Even before fully automated highways are established, some of this technology is already near production as aids and/or warning systems for drivers. For example, GPS systems are already mounted on many cars and offer mapping services to drivers as well as emergency location in case of accidents or vehicle failure. Agricultural vehicles are beginning to use GPS for controlling the paths of machine operations in fields. The SAE is devoted to advancing all these technologies by providing communication among all the organizations involved in their development. SAE is also has a major concern with education in these technologies and, in particular, ensuring that a sufficient number of engineering students are familiar with these technologies and capable of working in these areas when they graduate. The SAE also has an interest in promoting the understanding and use of the new technologies to the general public. These interests of SAE are all addressed in the IGVC.

The Department of Transportation's Interest in the IGVC

The U.S. Department of Transportation is concerned with many of the same things as the automotive industry, but has somewhat more focus on the transportation infrastructure. It, too, has a major interest in safety. With respect to automated highways, the DoT aim is to ensure the safety of such systems and also to relieve traffic congestion as much as possible. GPS offers the possibility of aiding drivers avoid serious congestion by indicating their immediate location relative to traffic tie-ups and by indicating quickly to traffic controllers the location of accidents. The DoT is actually a supplier of Differential GPS correction signals to the nation and, like the SAE, is interested in promoting GPS understanding and use among the general public. The IGVC offers a good opportunity for the DoT to find and recruit bright young engineers well-versed in the technologies they need to perform their function.

The 2002 Competition

The 10th Intelligent Ground Vehicle Competition (IGVC) was held in 2002 at the Coronado Springs Resort in Walt Disney World, Florida, in conjunction with AUVSI Unmanned Systems 2002 Symposium. Symposium registrants and others watched highly intelligent robot vehicles compete on two separate courses--the autonomous and navigation challenges.

Figure 7. The University of Michigan at Dearborn's entry on the practice course

This year drew the highest number of teams registering, 23. As expected, hardware, graduation ceremonies, and new jobs reduced the number of participants who actually arrived at the competition to 17. Throughout the practice and qualification weekend, additional hardware and computer realities eliminated six more participants for a total of 11 competing teams.

Figure 8. Oakland University's entry running the navigation challenge

The Design Competition component of the IGVC has been sponsored by the Society of Automotive Engineers (SAE) for 8 of the 10 years the competition has been held. Judges for this competition are chosen to reflect both commercial and military applications of intelligent vehicles. Two weeks prior to the IGVC, all 17 teams sent their technical papers to the 2002 judges for review. The presentations and technical papers (in SAE format) were evaluated and scored. Virginia Tech's Bi-Planar design won first place and $2,000, while second place and $1,000 went to the University of Alberta. Third place and $500 went to Virginia Tech's Daedulus design.

The Autonomous Challenge, an IGVC original event, requires the robots to drive a grass course, performing line-following and obstacle avoidance while driving over simulated blacktop and keeping between dashed line markings. Hosei University finished first, passing the Money Barrel to win a grand prize of $4,000. The University of Colorado at Denver, which won first place in 2001, placed second for a prize of $1,000. Third place went to the University of Cincinnati, which received $500.

Figure 9. Hosei University team from Tokyo, Japan, tuning their vehicle on the practice course

The Navigation Challenge for the second year demonstrated agile maneuvers based on navigating between a set of nine different GPS waypoints. This year, the challenge was enhanced by deliberately setting obstacles between the waypoints. Teams now had to optimize their routing while integrating machine vision to avoid the obstacles. Hosei University finished in first place by making eight out of nine waypoints to win a total of $2,500 in prize money. Embry-Riddle Aeronautical University from Daytona, Florida placed second, finding seven waypoints and receiving $1,500. Third place went to the University of Colorado at Denver, finding six waypoints and taking home $500.

The following table gives the results of all the challenges.

Place	Design Competition	Autonomous Challenge	Navigation Challenge
1ST	Virginia Tech - Biplanar	Hosei University - Amigo 2002	Hosei University - Amigo 2002
2ND	University of Alberta - ARVP Kodiak	University of Colorado at Denver	Embry-Riddle Aeronautical University
3RD	Virginia Tech - Daedalus	University of Cincinnati - Bearcat III	University of Colorado at Denver
4TH	University of Florida - UF Eliminator	University of Florida - UF Eliminator	University of Cincinnati - Bearcat III
5TH	Embry-Riddle Aeronautical University	University of Michigan Dearborn	University of Florida - UF Eliminator
6TH	Trinity College - ALVIN III	Bluefield State College	Oakland University - Grizzly
7TH	Hosei University - Amigo 2002	Trinity College - ALVIN III	Bluefield State
8TH	Ecole de Technologie Superieure	Embry-Riddle Aeronautical University	Trinity College - ALVIN III
9TH	Oakland University - MARC	University of Alberta - ARVP Kodiak	
10TH	West Point - MAGIC 2002	West Point - MAGIC 2002	
11TH	Tennessee State University	Ecole de Technologie Superieure	
12TH	Bluefield State College		
13TH	University of Cincinnati - Bearcat III		
14TH	University of Michigan Dearborn		
15TH	Oakland University - Grizzly		
16TH	University of Colorado at Denver		
17TH	University of Central Florida		

Table 1. Final standings for the 10th Annual IGVC competition

The IGVC is currently preparing for its 11th competition to be held at Oakland University in Rochester, Michigan on May 30, 2003. The 2003 competition will bring back the leader-follower competition to address the renewed interest by the DoD to integrate that capability into the Future Combat System.

The University of Cincinnati's Participation in the IGVC

The University of Cincinnati (UC) engineering students have historically participated in practical challenges that have both intellectual merit and a broad impact. The UC Robot Team is an example of one of its university-wide student organizations that welcomes students of all disciplines and levels. The design, construction and testing of an autonomous vehicle provides an excellent opportunity to learn, with hands-on experience, many of the topics covered in UC's engineering and computer science courses, as well as to obtain and apply practical leadership and management skills.

For example, before the design begins, the students must raise the funds needed to purchase supplies to build their entry. During the design stage, they obtain experience in finding the best technology available at the lowest cost. The use of computer-aided engineering design tools has proved very helpful at this stage to ensure not only that the components fit into the vehicle frame, but also provide stress and strain calculations. System modeling of the high level intelligent components is done by simulation and analysis. A proper design using engineering design programs can provide good solutions to the various design problems encountered. A number of manufacturers have sponsored the team by providing software for selecting the control parameters.[3]

The requirements of the competition provide excellent opportunity to apply theory-based knowledge gained from UC's engineering curriculum. For example, lane-following requires the use of real time vision guidance with many possible approaches. Obstacle avoidance is also needed, and both ultrasound and laser scanners have been used. Considering two or more motors in the steering angle control provides an opportunity to use state space formulations, fuzzy logic and even neural network control. The state space formulation is a vector approach to the control problem and shows that for steering position control, desired positions, velocities and even acceleration measurements would be helpful. The fuzzy logic control problems are encountered in selecting a steering angle that is dependent on both the angle heading of the robot and its distance from the center of the boundary lines. GPS navigation with obstacle detection is an example requiring mastery of an unstructured environment. Implementing more than one sensory reactive control can use principles of fuzzy logic, artificial neural networks, genetic algorithms or a combination of these. Learning to deal with the terrain variations or unknown parameters for an autonomous vehicle and to do so in an unstructured environment in a safe manner is a tremendous challenge that has provided several students with thesis, presentation, and journal article topics.[4-8]

The University of Cincinnati has participated in all 10 IGVC's since 1993. Some of the fundamental topics UC teams have applied to their entries include:

- Mechanical design of a robot vehicle
- Electrical design of all the components, from power to communications and control
- Mechatronics design of motors and gearboxes
- Computer design and interfaces
- Motion control of digital filters for control compensation
- Robot vision and sensors for line following, laser scanning, and sonar sensing
- Intelligent systems theory and applications

In general, the IGVC has proved to be a tremendous opportunity for engineering and technology students to design, construct, and compete with their autonomous, intelligent vehicle. The safe automobile, a robot that can transport humans in hospitals, or a robot that can clean a facility are still awaiting creative solutions by the future engineers and scientists of tomorrow, perhaps by students who have participated in the IGVC.

Trinity College's Participation in the IGVC

Trinity is a highly selective, independent undergraduate liberal arts college that offers an ABET-accredited B.S. in Engineering and that sponsors the Trinity College Fire-Fighting Home Robot Contest (TCFFHRC), a widely known annual robotics competition [9-11]. Based on experience gained through the TCFFHRC, a team of four senior engineering students designed Trinity's first IGVC robot Alvin I during the 1999-2000 academic year as the capstone design project for their engineering degrees. Other undergraduates, members of the Trinity Robotics Study Team (RST), competed in the 2001 and 2002 IGVC events.

The RST was organized in 1996 to develop autonomous fire-fighting robots to compete in the TCFFHRC. Continued development of TCFFHRC robots and improvement of the IGVC Alvin robots are the primary current goals of the RST. Membership of the RST consists of students, from all four undergraduate classes, who meet as a weekly seminar and receive independent study credit. Until the 2000-2001 academic year, every RST student joined a subject-oriented group (electronics, mechanical, software, or sensors), each group responsible for designing and implementing a part of every robot and reporting progress weekly. This arrangement was changed in 2001-2002; now, the team is divided into project-defined groups. At this writing, the RST has two four-member project groups, one working on Alvin IV, a robot that will compete in the 2003 IGVC, and another developing an autonomous fire-fighter for the 2003 TCFFHRC Expert Division. Each group has developed its own capability within the four key subject areas. Student-taught hands-on workshops in such areas as three-dimensional CAD with SolidWorks, PIC processor development, PCB design, machining, and LabView have equipped every RST member with a basic set of robot design tools.

Each year Trinity's level of success in the IGVC has improved. Alvin I entered the 2000 IGVC at Disney World, but component failures, chiefly to the drive system, kept Alvin from competing. Improvement to the drive system and the vision system led to a seventh place finish by Alvin II (Fig. 1) in the 2001 IGVC autonomous challenge. The incorporation of higher-torque, lower-weight motors in 2002 brought Alvin III's total weight, with payload, to less than 100 pounds. Alvin III took seventh place in the autonomous challenge, and the Trinity team earned sixth place in the 2002 IGVC design competition. The robot's performance in 2002 indicated that the Alvin group needed to focus efforts for 2003 primarily on improving the vision software and the GPS navigation software. The 2002 mechanical system, including motor controllers and drives, operated in a stable and reliable way and needed less attention.

Although no formal evaluation of the IGVC experience has been carried out, students have learned many lessons by developing the Alvin series of IGVC robots. The RST's experience in developing fire-fighting robots led to an accumulation of knowledge on the team that could be applied to developing Alvin. Although it is not simply a scaled-up version of a fire-fighting robot, Alvin and its fire-fighting cousins have many components in common—motor control systems, mechanical systems, software to handle sensor data in real time, and power distribution systems. Moreover, design of both kinds of robots requires knowledge of feedback control, sensor interfacing, and software design. The IGVC has further exposed Trinity students to the design and application of vision systems and GPS devices.

Participation in the IGVC has provided many other benefits and challenges. The review of Alvin by IGVC judges and the oral presentation required by the design competition provided a challenging introduction to the "real" world of engineering, an important linkage for students from a small liberal-arts college. A second challenge was securing sponsorship and physical resources to support robot development and competition. Benefits included an introduction to new technologies and opportunities to travel and to interact with students from larger engineering schools. The Alvin design project has motivated and rewarded a number of Trinity's best engineering students, encouraged original work, and provided a platform for implementing and evaluating design ideas.

Summary of IGVC Participants

The table that follows depicts 10 years of college and university participation in the IGVC. A number of schools return repeatedly over the years, while others take a year off between competitions to rebuild their teams when key members graduate. The competition criteria are essentially constant, so professors are able to integrate the requirements into their curricula. Sponsorship has grown over the years, with DoD interest increasing in the last two years. The IGVC is expected to continue evolving as a cutting edge engineering team experience in attracting, challenging, and growing multi-disciplined student teams.

The Intelligent Ground Vehicle Competition		
Team	Teams	Competitions
Bluefield State College	2	2
Cedar College – Ohio	3	3
Cleveland State University	2	2
Colorado School of Mines	3	3
DeVry Institute of Technology	2	2
Ecole Polytechnique De Montreal	3	3
Embry-Riddle Aeronautical University	3	3
Hosei University – Japan	8	7
Michigan Technological University	4	4
Northern Illinois University	6	6
Oakland University	17	10
Ohio State University	3	3
Princeton University	3	3
Tennessee State University	2	2
Trinity College	3	3
University of Alberta – Canada	5	5
University of Central Florida	1	1
University of Cincinnati	11	10
University of Colorado – Boulder	6	6
University of Colorado – Denver	8	8
University of Florida	1	1
University of Detroit Mercy	4	3
University of Maine	2	2
University of Maryland – College Park	1	1
University of Michigan – Ann Arbor	2	2
University of Michigan – Dearborn	2	2
University of Minnesota	4	4
University of North Dakota	2	2
University of Texas – Arlington	2	2
University of Tulsa	11	8
U.S. Military Academy at West Point	2	2
Virginia Polytechnic Institute and State University	19	7
Wayne State University	1	1
West Virginia University	4	4
Wright State University	1	1

Table 2. IGVC participation

IGVC Participant Feedback

Students have indicated the following benefits from participating in the IGVC on their feedback forms:

- Course credit in a regular or independent study course. Some extend their interest to a thesis or dissertation topic. URL: www.robotics.uc.edu
- An opportunity to implement and test ideas they have studied in classes
- An opportunity to meet and get to know students with similar interests from other universities in the US and from other countries such as Canada and Japan
- An opportunity to travel to an exciting contest
- An opportunity to design a state of the art solution to an important problem

- An opportunity to learn how to raise money and work with sponsors for their ideas
- An opportunity to learn how to spend money. It's not so easy to buy the right thing
- An opportunity to win or lose. Winning is more fun.
- A moment in the sun – if you win. Being on TV or written about in a magazine or newspaper is satisfying
- Something to talk about when you interview for a job
- Something to write a paper about for a topical conference in an exotic location such as Detroit or Orlando.

Several students want to select the AUVSI intelligent vehicle topic as their career area and apply for positions with sponsors companies or similar industries. The intelligent vehicle is a great career topic with many spin-off applications in defense, industry, space and medicine.

From faculty viewpoints, the contest provides great teaching opportunities for some complex topics in intelligent controls, a collaborative learning opportunity where students help each other learn, and an opportunity for students to contribute knowledge gained from experiences outside the classroom. Being tested against other teams from a great variety of universities is a kind of final exam with results that leaves little room for argument. The trophies and cash prizes add realism and impetus that parallel real world rewards.

Conclusions and Lessons Learned

The IGVC has been a remarkable success over the 10 years of its existence. Hundreds of students have learned a great deal about cutting-edge technologies in automotive engineering technologies that have direct application in transportation, the military, manufacturing, agriculture, recreation, space exploration, and many other fields. They have utilized professional design procedures and performed hands-on fabrication and testing. They have merged electrical and mechanical engineering along with computer science and physics. At the same time, they have learned to work in teams and to understand the full product realization process. They are ready for full careers in the automotive, engineering, robotics, and other communities.

The organizers have also learned a few lessons, as given in the following list.

1. Continually monitor and update the rules to maintain fairness among all participants
2. Arrange rules so they emphasize the promotion of education, but at the same time leave open the opportunity for students to learn on their own and to innovate
3. Design performance events which simulate real world activities as much as possible
4. Choose design judges from industry who are accomplished engineers with an interest in education
5. Listen to the advice and suggestions of faculty advisors

For the past decade, the IGVC has been used by many engineering curriculums in the U.S. and overseas to help students achieve invaluable engineering training. When properly executed, the engineering design projects pertaining to development of an IGVC vehicle can be used to demonstrate outcome of curricula that satisfy most if not all ABET criteria. It is estimated that the IGVC events has affected approximately 3,000 students over the years.

In conclusion, the Intelligent Ground Vehicle Competition (IGVC) has proven to be an effective and exciting platform to provide university students, faculty, sponsors and participants with a cutting-edge engineering team experience.

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