



Does your car drive itself? **Ours does.**

PAVE (Princeton Autonomous Vehicle Engineering) is an undergraduate student-led research group at Princeton University dedicated to advancing and promoting the field of robotics through competitive challenges, self-guided research and community outreach while providing extracurricular learning and leadership opportunities to student members.

There are many reasons that **PAVE** is a truly unique organization. Most notably, it is the only research group at Princeton University in which undergraduate students lead all aspects of operation: planning, design, implementation, testing, logistics, publicity and fundraising.



Building on the success of our 2008 IGVC endeavor, **PAVE** plans to continue the tradition of innovation through competitive robotics challenges by participating in the 2009 IGVC with a redesigned robot.

PAVE is currently enhancing the reliability and robustness of the electromechanical systems onboard *Prospect Twelve*, as well as improving the software algorithms and augmenting the vehicle's capabilities. Our goal is to create a fully autonomous vehicle capable of navigating via GPS to any destination, while obeying all traffic laws. One major milestone along the way will be passing the New Jersey State driver's exam, which we are targeting to complete in November, 2009.

PAVE is strongly committed to outreach activities in our community that help raise awareness of robotics. On-campus events include study breaks, presentations and a robotics lecture series. Off-campus, **PAVE** has demonstrated our vehicles at local middle schools, summer camps, and high school robotics competitions.

To date, **PAVE** has participated in numerous robotics competitions at the national and international level. **PAVE** participated in the 2005 DARPA Grand Challenge with a GMC Canyon pickup truck, which we named *Prospect Eleven*. In 2007, **PAVE** entered the DARPA Urban Challenge with a Ford Escape Hybrid named *Prospect Twelve*. Subsequently, **PAVE** competed in the 2008 Intelligent Ground Vehicle Competition (IGVC) with *Kratos*, a smaller ground robot custom-built from scratch.



Be a part of this exciting endeavor!

The breakthrough developments at **PAVE** are only made possible through the generosity of our sponsors. We seek various levels of sponsorship and partnership with organizations or individuals. Past donors have provided us with sensors, replacement parts, technical support, and funding.

<http://pave.princeton.edu>

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President

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March, 2009

Dear Potential Sponsor,

PAVE (Princeton Autonomous Vehicle Engineering) is an undergraduate student-led research group at Princeton University dedicated to advancing and promoting the field of robotics through competitive challenges, self-guided research and community outreach while providing extracurricular learning and leadership opportunities to student members. Founded in 2004, **PAVE** consists of undergraduate students across several different academic majors, including departments in Princeton's School of Engineering and Applied Science.

PAVE participated in the 2005 Grand Challenge and the 2007 Urban Challenge, both sponsored by DARPA (Defense Advanced Research Projects Agency), part of the Department of Defense. In 2005 we modified a donated GMC Canyon pickup truck to navigate desert terrain by using a stereo camera to detect obstacles and a GPS for global navigation. We fitted the vehicle with drive-by-wire actuators and developed our own systems for processing the sensor data. For the 2007 challenge, we adapted a donated Ford Escape hybrid SUV with a series of stereo and monocular cameras for detecting obstacles and lane markings, allowing it to navigate simulated urban test courses. **PAVE** applied the principles learned from the DARPA challenges and custom-built a small robot to participate in the 2008 Intelligent Ground Vehicle Competition. For more detailed information on these projects, please see the enclosed sheet about our vehicles or visit our website to see videos of our vehicles in action (<http://pave.princeton.edu>).

PAVE provides an excellent opportunity for students to work on interdisciplinary, hands-on projects that are challenging, educational, and comparable to real-world engineering tasks. Building on our past successes and looking into the future, we plan to continue the development of our Urban Challenge vehicle and participate in further robotics competitions. **PAVE** is actively involved in outreach activities, raising awareness about robotics and technology in our community. **We need your support in order to accomplish these goals.** Past sponsors have provided us with sensors, equipment, technical support, testing sites, and funding. Please see the attached bill of financial needs for specific ways in which you can help us.

Thank you for your time.

Sincerely,

Derrick Yu
President, Princeton Autonomous Vehicle Engineering



Our Vehicles

Prospect Eleven

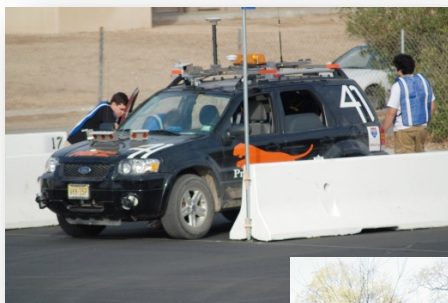
The 2005 DARPA Grand Challenge required vehicles to navigate a 132-mile course through desert terrain, avoiding static obstacles such as boulders, tire stacks, and navigating through gates and tunnels. **PAVE's** vehicle, a GMC Canyon named *Prospect Eleven*, earned 10th seed out of 23 teams participating in the Final Event held on October 8, 2005. *Prospect Eleven* was able to successfully traverse 9.6 miles of the course autonomously, finishing 19th and ahead of teams from Cornell and Caltech. A bug in the obstacle detection software caused the vehicle to stray off course.

The members of **PAVE** returned later that year to the Mojave Desert after fixing the one-line software bug. *Prospect Eleven* was able to successfully traverse the full Grand Challenge course autonomously.

Right: *Prospect Eleven* in the evening Mojave Desert sun



Left: *Prospect Eleven* operating autonomously during the 2005 DARPA Grand Challenge



Left: Team members prepare *Prospect Twelve* for an autonomous run during the 2007 DARPA Urban Challenge NQE



Right: Close-up of *Prospect Twelve* in front of the PAVE garage

Prospect Twelve

After the 2005 Grand Challenge, DARPA upped the ante with the DARPA Urban Challenge. For this challenge, vehicles would have to autonomously navigate a simulated urban environment, driving down roads with lane markings, parking, passing stopped vehicles and even negotiating four-way stop intersections.

Prospect Twelve was one of 35 vehicles chosen from around 90 entrants to qualify for the Urban Challenge National Qualification Event, held from October 26 to November 1, 2007. Although **PAVE** was not selected as one of the 11 teams to participate in the Final Event, we made a strong showing next to teams which had budgets upwards of ten times ours. *Prospect Twelve* continues to serve as **PAVE's** primary research vehicle.

Kratos

After the DARPA Urban Challenge, several team members decided to compete in a smaller-scale robotics competition, the 2008 Intelligent Ground Vehicle Competition (IGVC). The IGVC competition has three primary challenges: navigating between several GPS waypoints while avoiding obstacles in an obstacle field, running a course designated by lane markings and littered with obstacles, and a technical design presentation. For the competition, **PAVE** custom-built a 200-pound autonomous robot named *Kratos*. At the 2008 IGVC, **PAVE** finished 1st, 4th, and 6th in the Design, Navigation, and Autonomous competitions respectively, netting a 3rd place overall finish (out of 47 teams) and the Rookie of the Year award.



Above: Three team members on the 2008 IGVC team pose with *Kratos* and award certificates

PAVE Facts

PAVE has been innovating in the field of autonomous robotics since 2004.

PAVE's vehicles rely primarily on cameras coupled to image processing algorithms to perceive the environment. **PAVE** uses both monocular cameras and stereo cameras, which process image data much in the same way that humans do.

PAVE operates on an extremely tight budget. Including the donated value of sensors, computing equipment, and the car itself, our entire budget for the 2007 Urban Challenge was under \$100,000—less than one tenth of what many of the eleven finalist teams spent.

Below: *Prospect Eleven* appeared in an article published in the *Daily Princetonian*, Princeton's student newspaper.



Left: Students debug software aboard *Kratos* while testing at the 2008 Intelligent Ground Vehicle Competition.



PAVE is the only research group at Princeton University in which undergraduate students lead all aspects of operation: planning, implementation, logistics, fundraising, testing and publication.

PAVE regularly demonstrates its vehicles at a variety of events. Recent presentations include a science festival at Montgomery Middle School in New Jersey, a technology fair at the Javits Convention Center in New York City during the New York FIRST regional competition, a Sigma Xi meeting at Princeton, and various Princeton parent and alumni events.

PAVE alumni have gone on to work at companies such as Boeing, MIT Lincoln Lab, and Google, and have continued their graduate studies at institutions such as Cornell and Stanford.

Below: Students and parents gather around for a look inside *Prospect Twelve* during the 2008 high school FIRST Robotics New York Regional at the Javits Center.



Above: *Prospect Eleven* at the start gate of the 2005 DARPA Grand Challenge Final Event.

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Supporting PAVE

One of **PAVE**'s fundamental principles is working within the constraints of a tight budget. We constantly seek design solutions that are cost-effective, elegant, safe, and robust.

PAVE is a wholly academic team. Although we have access to Princeton's outstanding facilities, all our day-to-day operations and purchases must be handled through either sponsorship or donation. **PAVE** is extremely grateful to those who support it—you make our work possible.

Sponsors are recognized both on our website and in our publications, increasing your corporation's visibility among Princeton engineering students. **PAVE**'s developments receive significant press coverage, and we frequently give presentations to students, alumni, and professional groups on and around campus. Where applicable, **PAVE** provides technical feedback for products and services.

Levels of Sponsorship:

Platinum – \$15,000 and up

- Invitation to interact closely with **PAVE**'s students and projects
- Logo featured prominently on the vehicle
- Recognition in interviews, articles, **PAVE** publications, and at **PAVE** events
- Priority access to **PAVE**'s vehicles for exhibitions or demonstrations
- Listed as a Platinum sponsor on our website and t-shirts

Gold – \$5,000 to \$14,999

- Invitation to interact closely with **PAVE**'s students
- Logo featured on the vehicle
- Recognition in interviews, articles, **PAVE** publications, and at **PAVE** events
- Access to **PAVE**'s vehicles for exhibitions or demonstrations
- Listed as a Gold sponsor on our website and t-shirts

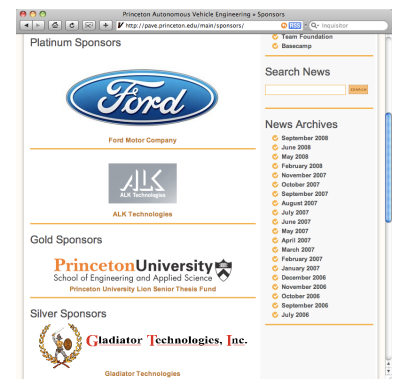
Silver – \$2,000 to \$4,999

- Logo featured on the vehicle
- Listed as a Silver sponsor on our website
- Recognition in **PAVE** publications and at **PAVE** events

Bronze – \$500 to \$1,999

- Listed as a Bronze sponsor on our website
- Recognition in **PAVE** publications and at **PAVE** events

Below: Screenshot of the sponsor page on the **PAVE** website



To donate, please make a check out to “**Princeton University**” with “**PAVE**” in the memo line, and mail it to the following address:

Princeton University
Attn: Prof. Alain Kornhauser, ORFE Dept.
229 Sherrerd Hall
Princeton, NJ 08544

All contributions are tax deductible. We thank you for your support.

<http://pave.princeton.edu>



Financial Needs

PAVE exists as an umbrella organization to support robotics-related research projects as well as organize and participate in robotics-related outreach activities. Projects are run independently from each other, but share the common capital and resources provided under **PAVE**, such as tools, workspace, and knowledge base.

Sponsors may choose to support either a specific project or **PAVE** as a whole. Funds designated for **PAVE** as a whole will be allocated towards capital improvement, outreach and marketing, and individual projects as needed.

We have been fortunate to have much of our equipment donated to us or provided at a discount from a wide assortment of companies. However, we still need cash donations to cover miscellaneous expenses such as hardware for sensor mounting systems, hand tools, replacement parts, prototyping, and promotional materials.

Condensed Project Budgets 2008:

Approximate cost:

PAVE

Testing and Safety Equipment	\$2,500
Capital Equipment	\$3,000
Gas	\$1,000
Promotional materials	\$500
Misc. Tools	\$500

Prospect 12

Sensing Equipment	\$5,000
Actuators	\$2,000
Computers & Electronics	\$3,000
Logistics	\$500

IGVC

Sensing Equipment	\$2,000
Robot Chassis/Drivetrain	\$2,000
Computers & Electronics	\$1,000
Travel & Logistics	\$3,000

Sample items that have been donated to us in the past:

Approximate value:

2005 Ford Escape Hybrid SUV	\$27,000
MEMS IMU	\$10,000
Stereo camera	\$3,000
GPS	\$1,500
High Resolution Optical Encoder	\$1,200
Debugging Software	\$400

