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**The Oshkosh-VisLab joint efforts on UGVs: architecture, integration, and results**

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Unmanned Ground Vehicle (UGV) technology plays a key role in Oshkosh Truck Corporation's (Oshkosh's) efforts to supply the American military forces and their allies with the tools they need. The US Congress has set an aggressive goal, targeting that one-third of all operational ground combat vehicles will be unmanned by 2015. In working with the armed forces to meet this goal, Oshkosh continues to research both fully autonomous systems and leader-follower concepts. Autonomous or leader-follower technologies do not necessarily have to mean there are no soldiers in the cab: in some cases soldiers may still remain in the vehicle, but will be free to perform tasks other than driving the vehicle. Oshkosh believes that while UGVs should require less support from the soldiers, they cannot provide any less support to the soldiers. UGVs need to do everything that "conventional" vehicles can do—this includes operating on extreme terrains, hauling a load and even carrying a crew.

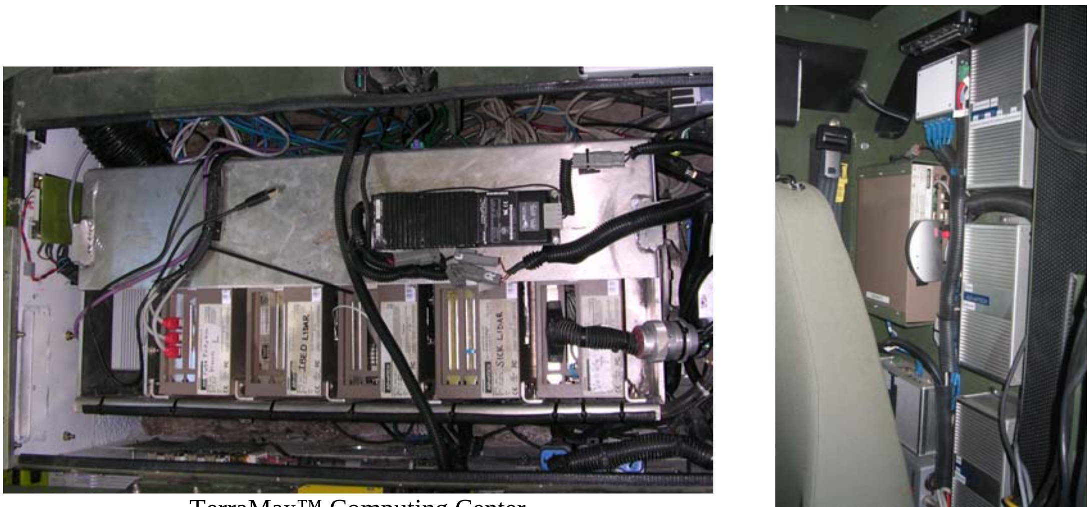
For over 15 years, the Artificial Vision and Intelligent Systems Lab (VisLab) of the University of Parma has been conducting research in the field of environmental perception for both on- and off-road applications. Cameras have been integrated on a plethora of different vehicle platforms with the aim of sensing the presence of obstacles, other road players, potential threats, locating road features such as lane markings and road signs, and even identifying the drivable path in off-road environments. Together with cameras, other sensors have been included in the on-board system. Data fusion techniques have been developed and successfully fielded on many vehicle prototypes. VisLab's ultimate goal is to apply the results of basic and advanced research in the development of UGVs for unmanned missions in real environments.

## The TerraMax™ Technology

Figure 1 shows two Oshkosh unmanned vehicles. The left side shows TerraMax™, the vehicle fielded by Oshkosh, the University of Parma, and Rockwell Collins in the Defense Advanced Research Projects Agency's (DARPA's) 2005 Grand Challenge. This vehicle was based on Oshkosh's Medium Tactical Vehicle Replacement (MTVR) MK23 truck. The MTVR was designed for the Marine Corps, providing hauling capability (7.1/15 ton off-/on-road payload) with high mobility (70% off-road mission profile). Oshkosh worked to integrate an autonomous navigation system (ANS) which could be developed as a "kit" capable of use on other platforms and which did not impact vehicle functionality. When integrated, the ANS did not limit payload capability or cab space for soldiers. The left side of Figure 2 shows the computing center installed in the seat box. Packaging of the ANS even preserved the transportability: Figure 1 shows the vehicle running at air transport (C130) height.

Shortly after the DARPA Grand Challenge ended, Oshkosh demonstrated the ANS "kit" on a much larger vehicle, using its Palletized Loading System (PLS) as the target platform. The PLS vehicle has a payload capability of 18 tons (16329 kg) and serves as one of the US Army's premier logistical workhorses. On the right side of Figure 1 one can see improvements in sensor integration on the autonomous PLS. Cameras for the vision system have now been discretely placed inside the cab. An upgraded computing center was installed, again without sacrificing passenger space. The right side of Figure 2 shows the computers tucked neatly behind the passenger seat. This was done in keeping with one of Oshkosh's guiding principles in autonomous system development: vehicle functionality should not be sacrificed for autonomy. Ground combat vehicles are working vehicles. Autonomous systems that cannot provide full functionality do not give armed forces the tools they need.

**Figure 1: Oshkosh Truck unmanned vehicles: TerraMax™, based on MTVR, (left) and autonomous PLS (right)**



TerraMax™ Computing Center

Autonomous PLS Computing Center

**Figure 2: Integration of computing center in seat of TerraMax™ (left) and upgraded computing center in Autonomous PLS (right)**

## TerraMax™ performance

DARPA Grand Challenge I and II have provided an important measuring stick against which Oshkosh and Parma (along with a host of other participants) have been able to chart their progress in the unmanned ground vehicle field. DARPA created the robotic vehicle competition as an open challenge intended to energize private industry to tackle the major issues confronting autonomous vehicle development. For the timed competition, DARPA designed a 132-mile (215 km) off-road desert course that each vehicle had to negotiate. The course was defined by an ordered list of geographic waypoints, a maximum speed for each waypoint and lateral boundaries that could not be crossed. Vehicles had to operate with full autonomy as they maneuvered around obstacles lining the desert course.

In the first Grand Challenge (March of 2004), Team TerraMax™ was one of only seven teams to successfully navigate the preliminary Qualifying Inspection and Demonstration (QID) events. However, like all other teams, Team TerraMax™ quickly realized just how "Grand" a Challenge DARPA had proposed: no team even completed 10% of the course. Over the next 18 months, Oshkosh, Parma and the rest of Team TerraMax™ continued their development efforts. In October of 2005 TerraMax™ was one of only 5 vehicles to complete the entire 132-mile course, and was the only one to reach the finish line using vision as a primary sensing technology.

## Sensors and technology

TerraMax™ used a combination of vision and laser-scanning to detect its environment, exploiting their complimentary sensing strengths. Laser-scanning sensors provide very accurate and precise range measurements. Laser-scanners can provide a sharp contrast between obstacles and non-obstacles. Vision systems provide complete data across the entire field of view, not just across a scanning line. This allows vision to identify obstacles with limited extent in one dimension (e.g. street signs or posts) regardless of orientation. Vision can also detect color contrast (e.g. road markings) in addition to dimensional contrast. To meet the needs of the Grand Challenge, a trinocular vision system was developed. The three cameras provided three distinct baselines, allowing accurate stereovision across a wide range of viewing distances. An integrated Global Positioning System (GPS)/Inertial Navigation System (INS) solution provided geo-location as well as basic state information (speed, acceleration, direction/heading, yaw, pitch and roll rates). Differential corrections enhanced the GPS precision. During extended GPS outages, wheel speed was also used to improve dead reckoning.

## Next Challenge

Oshkosh and the University of Parma have again partnered, joining with Teledyne Scientific and Imaging Sensors LLC, Auburn University and IBEO Automobile Sensor GmbH to compete in the 2007 DARPA Urban Challenge. This competition represents the next milestone in the development and demonstration of military unmanned ground vehicle technology. It will require vehicles to operate and maneuver in the presence of other moving vehicles in a mock urban environment. The competition will mimic a 60-mile (97 km) supply mission through a city, with a 6-hour time limit for completion. Requirements include obeying traffic laws, safe entry into traffic flow and passage through busy intersections.

The urban environment offers several new challenges. Driving on roads with traffic can require more precision than following an open trail. However, while precision is required, tall buildings could lead to extended operation with limited/impaired GPS service. Moving traffic means the vehicle must be able to sense not only obstacles that might lie in its path, but also moving obstacles whose paths might lie in its path. This greatly increases the sensing requirements. When dealing with only stationary objects sensors can primarily focus on the front of the vehicle; moving traffic requires much greater sensing capability behind and beside the vehicle. Team Oshkosh Truck will meet the extended localization and sensing needs by enhancing previous systems, adding new systems and seeking to better exploit synergistic combinations of different sensing systems.

IBEO will provide their latest laser-scanning system, including a fusion algorithm to provide a single “view” from several sensors. The vehicle will have an improved trinocular system, additional vision systems with different viewing orientations, and vision/laser-scanner fusion. Using multiple camera sets, each specialized for perception in a given direction, combined with laser-scanner technology should allow the vehicle to successfully negotiate the missions and sense all threats the Urban Challenge will pose. The complementary nature of these two technologies together with the choice of highly ruggedized sensors, computing engines, and vehicle integration will prepare TerraMax™ for another successful competition.