The Oshkosh-VisLab Joint Efforts on UGVs: Architecture, Integration, and Results

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ABSTRACT

This paper presents the past and current activities on which Oshkosh Truck Corp. and University of Parma's VisLab are jointly involved in the field of Unmanned Ground Vehicles. Oshkosh Truck Corp. and VisLab share a common vision on the promise of autonomous technology in the future of ground vehicles.

The paper describes the activities of each partner and shows some results of the cooperation, together with plans for the future which again sees Oshkosh and VisLab joining forces to compete in the next DARPA Urban Challenge.

1.0 OVERVIEW

Unmanned Ground Vehicle Technology

Unmanned Ground Vehicles (UGVs) represent new technology, with a history that scarcely covers more than 20-25 years. Some initial ideas and concepts were born in the 1960s, but the relatively immature technology of that early time could not meet the original goal of fully autonomous all-terrain all-weather vehicles. Documented prototypes of automated vehicles did not appear until much later, with a few groups developing functioning systems in the mid-1980s. The initial stimulus for these pioneering groups came from the military sector, where leaders envisioned a fleet of ground vehicles operating with complete autonomy.

After some of these early military prototypes, interest transferred to the civil sector. Governments worldwide launched several pilot projects that generated interest in and attracted a large number of researchers to these topics. Interest of the automotive industry in developing real products—and thus in investing real money in this new business—developed only after the government feasibility studies had successfully demonstrated the first prototypes. These early tests of autonomous vehicles on real roads in a real environment represent one of the most important milestones in the history of unmanned ground vehicles. These tests happened in the mid-to-late 1990s.

Due to many technological and legal issues, the automotive industry did not set full autonomy as a goal. Instead of automotive pilots, industry focused on equipping vehicles with supervised systems and ADAS (Advanced Driving Assistance Systems). Research on UGVs then slowed down, with neither industry nor government deeming it as a primary strategic area for investment. Departments of Transportation worldwide were in fact primarily interested in social, economic, or environmental objectives aimed at enhancing the efficiency of fuel, road network, and improving the quality of life in terms of mobility.

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However, the excellent results recently achieved by automotive ADAS have induced the military sector to give a new vigorous push to the original idea of automating its fleet of ground vehicles. The Defense Advanced Research Projects Agency (DARPA) Grand Challenge proved to be a very inspired concept. It attracted a large number of top-level research institutes to work with the million-dollar prize in mind and in doing so it helped the technical community take a considerable step forward.

The DARPA Grand Challenge catalyzed the joint efforts between Oshkosh Truck Corporation and the University of Parma's VisLab. The common interests shared by these two important players in the field of vehicles (Oshkosh) and environmental perception (VisLab) brought them together with the aim of participating and winning the Grand Challenge.

Of course, the previous description of UGV applications represents only a brief overview. Numerous other applications could benefit from unmanned vehicle technology and investigations into UGVs proceed on many fronts. The automation of road vehicles perhaps garners the most attention from the media and the most interest from the automotive industry. However, other domains such as agriculture, mine removal, rescue and dangerous applications in general look for UGV technology to help manage ever-increasing personnel costs. If a vehicle could move autonomously on a field to seed, enter in a mined field, or perform some other dangerous missions, the efficiency of the vehicle itself would be increased thanks to a 24/7 operational schedule. More importantly, many of these uses would drastically decrease the number of individuals put at risk.

This paper focuses on the design and development of TerraMax™, a UGV system that was fielded to participate at the DARPA Grand Challenge. Not only did TerraMax™ successfully complete the qualification to the race, but it concluded the whole course as well.

Environmental Perception

In the late 1980s and early 1990s, the scientific community started to research, develop and generally explore the field of Intelligent Transportation Systems (ITS). Previous military research into both ground and aerial autonomy had sparked the interest of academic and private research centers, inducing them to join together in a precompetitive research stage.

Autonomous systems pushed the limits of computing technology in that day. Most applications required that research groups develop custom architectures. Some built these architectures from off-the-shelf components; others built their systems from scratch, beginning with silicon. However, they all needed to be specialized to match the specific needs of the autonomous system, and even with that customization the computing systems often proved the limiting factor.

Researchers commonly opted for sensing technologies such as radar or acoustic sensors that could directly measure quantities of interest. The small amount of data fed by these devices did not require high computational capabilities. Conversely, vision sensors demanded a complex processing phase. However, while the computational requirements of vision posed many challenges, vision offered a rich and full description even in unstructured conditions. This great potential led researchers to continue development of systems that could handle the computational requirements of vision.

Initial results—despite being at an embryonic stage—demonstrated the viability of vision for intelligent vehicles. Dedicated hardware allowed vision based detection systems to run in real-time. These very early systems processed only grey-level images. Color images required processing of larger amounts of data, leading to unaffordable computational costs.

Results of the precompetitive phase showed great promise, inspiring pioneering projects at a few research centers. Concept development eventually transformed vehicles into bona fide intelligent vehicle prototypes. In this early explorative phase the scientific community had come to appreciate the potential of ITS, but interest from automotive industry had not yet coalesced to fund the research. Instead, research efforts resulted from the individual initiative of single groups or from institutions willing to invest in areas characterized by a high degree of risk. The three main examples of such pioneering projects were the VaMoRs prototype demonstrated by the Universität der Bundeswehr, Germany [1], the NavLab vehicle developed at the Carnegie Mellon University, U.S.A. [2], and the ARGO vehicle, developed by VisLab, Italy [3].

Technological solutions implemented in these projects differed greatly. Some research groups chose general purpose hardware (i.e. a more “off-the-shelf” solution), some turned to a completely customized processing engine, and others adopted a mixed solution. However all these projects chose to use machine vision as the main sensing system. Desire to minimize—or even eliminate—any invasion into the environment suggests the use of passive sensors to perceive the surroundings. Sensor cost also drives the development of driving assistance systems which could find use in common road vehicles. Use in mass-produced passenger vehicles demands that safety devices become very inexpensive additions.

These first tests (Munich-Odense, No Hands Across America, and the MilleMiglia in Automatico [1], [2], [3]) and other similar projects helped to demonstrate the possibility of performing vision-based automotive tasks in real-time with commercial hardware.

Oshkosh and VisLab Motivation for Past Efforts and Vision for the Future

Unmanned Ground Vehicle (UGV) technology plays a key role in efforts by the Oshkosh Truck Corporation (Oshkosh) 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 military 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.

2.0 THE TERRAMAX™ TECHNOLOGY

DARPA Grand Challenge Platform

To stimulate autonomous vehicle development and leverage ingenuity DARPA issued a Grand Challenge to the technical community. Oshkosh and their partners gave a big response: the first TerraMax™ vehicle. Figure 1 shows the first vehicle in Grand Challenge I (2004) configuration. The vehicle was based on Oshkosh’s Medium Tactical Vehicle Replacement (MTVR) MK23 truck. At a curb weight of 13.9 tons, an overall width of 8’2” and an overall length of 26’3,” the MTVR represents a much larger platform than any other DARPA contestant used. This extra size can pose additional challenges when negotiating narrow passes and tunnels. However, Oshkosh's autonomous vehicle development efforts have focused on applications that are logistically relevant. DARPA clearly had logistic military vehicles in mind when they developed the Grand Challenge. Oshkosh wanted to successfully compete in a vehicle that could truly provide the functionality DARPA intended, selecting a vehicle that could haul payloads of 15 tons on-road and 7.1 tons off-road. Vehicle design targeted severe off-road operation: at the full off-road payload the vehicle can still climb a 60% grade and negotiate a 30% side slope. Features such as the Tak-4™ independent suspension, central tire inflation system (CTIS) and all-wheel drive with locking inter- and intra-axle differentials help the MTVR meet its 70% off-road mission profile. A 425 hp Cat C-12 engine provides the power the vehicle needs, while a 7-speed Allison HD4070 transmission helps to deliver the power to the wheels across the wide range of speeds the MTVR's mission demands.

Figure 1: The first TerraMax™ vehicle in Grand Challenge I (2004) condition

Autonomous Actuation

The autonomous system created for TerraMax™ has been designed, developed and implemented as a "kit" that could be incorporated on other logistic vehicles. The autonomous kit must provide for an easy transition between "manual" and autonomous mode. One purpose of autonomy is to get humans out of harm's way and thus completely out of the vehicle. However, other uses keep the soldiers in the vehicle with the autonomous system freeing them to perform other tasks. This design philosophy means that autonomous actuation cannot prevent or interfere with a driver from operating the vehicle in a "conventional" fashion. The system should easily return "standard" of control engine and transmission to the driver. Moreover, the driver must always have overriding manual operation of safety critical systems such as steering and especially brakes.

As with most modern diesel engines, the Cat C-12 always uses "throttle" by wire. The autonomous system provides a pulse width modulated (PWM) signal which could replace the signal supplied by the accelerator pedal. Switching between manual and autonomous mode is a matter of changing between these two inputs to the engine control unit (ECU). The autonomous transmission control interfaces with the transmission control harness, pulling the outputs from the driver's keypad to appropriate levels. Disabling these extra signals will return control to the driver (via the keypad). Braking control used an electrically actuated pneumatic valve, shown in Figure 2, placed in parallel with the treadle valve (brake pedal). The parallel control circuits keep the driver's pedal functional at all times, and the use of the stock actuation and braking system (which has been tested and certified to all safety rules) guarantees that the system can meet federal motor vehicle safety standards (FMVSS).

A servomotor coupled into the steering wheel shaft so that the hand wheel and the servomotor always turned together at a fixed ratio. The mechanical advantage provided by the hand wheel renders any inertia and friction of the motor negligible when the servomotor drive is disabled. Additionally, there is enough mechanical advantage to allow the driver to override the servo when the drive is enabled. In 2004, TerraMax™ competed as a front-axle steering vehicle. Prior to the 2005 Grand Challenge, Oshkosh added steering to the vehicle's rear axles. This enhancement leveraged systems used on another MTVR variant, the MK31 tractor, and decreased the turning radius to 29 feet. Mechanical linkages coordinate front and rear steering. An additional dwell mechanism holds the rear wheels straight during moderate steering maneuvers, while higher gearing ratios allow the rear to quickly "catch up" with the front steering during sharp turns.

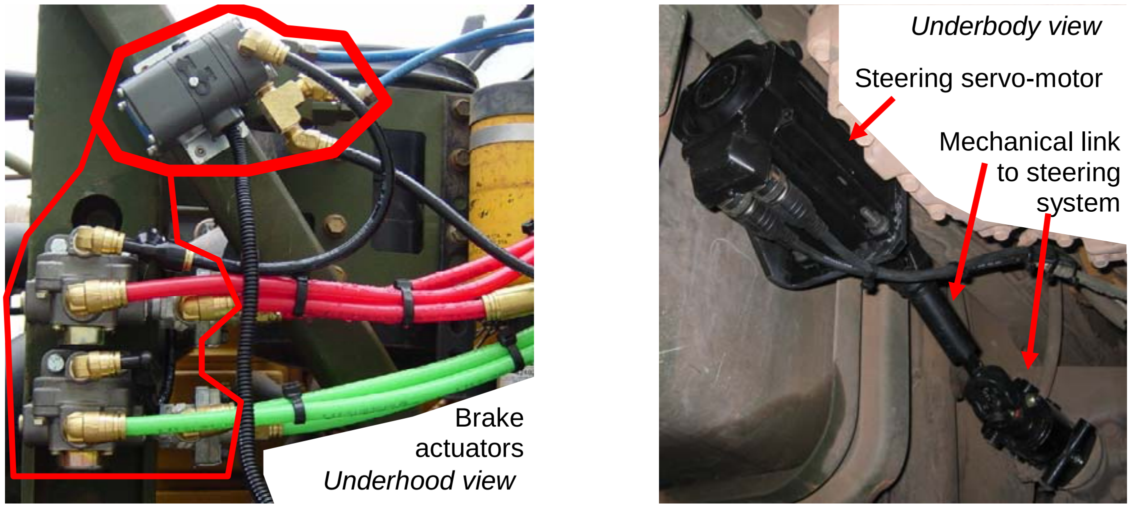

Figure 2: Autonomous control actuation for brake and steering

Vehicle Computers and Control

For Grand Challenge I (2004), the TerraMax™ computing center used industrial rack mounted computers in vibration damped weatherproof enclosures in the cargo bed. In the left hand side of Figure 3 one can see the enclosures in the front half of the bed. The computing system took up a considerable amount of the cargo space—with a negative impact on the hauling capacity of the vehicle. The 2005 Grand Challenge vehicle had an updated computing center designed to fit under the seat. On the right side of side of Figure 3 one can see the updated position, with the computers in a modular shock absorbing rack below (actually inside) the passenger seat. Mounting inside the cab frees up the cargo bed, restoring the hauling capacity; it also offers more protection for the computers.

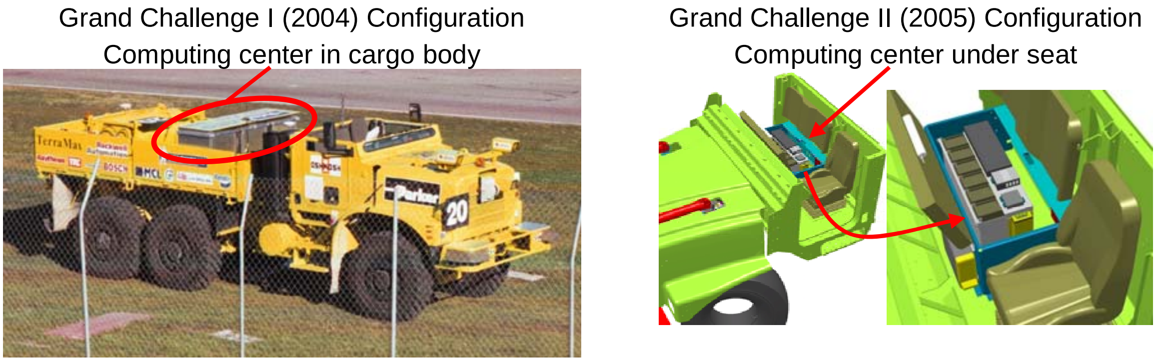

Figure 3: Original and updated computing center

Control development efforts use computer-aided modeling and simulation, with ultimate concept validation coming from on-vehicle testing. A detailed dynamic model of the vehicle was created in

ADAMS[1]—capturing the properties of the chassis as well as the suspension, steering and tires. Offline simulations help determine vehicle mobility and the ability of the vehicle to maneuver around or over various features. Figure 4 shows one such simulation studying the clearance as the vehicle traverses obstacles. Results of these simulations could be processed and then used to make real-time path planning decisions. ADAMS simulations also allowed evaluation of the vehicle's lateral stability, providing information about critical limits that the real-time controller could use. In addition, the real-time control system can directly use a more basic "bicycle model" as found in many vehicle dynamics texts, e.g. Gillespie [4] or Ellis [5], with some modifications for vehicles with more than two axles.

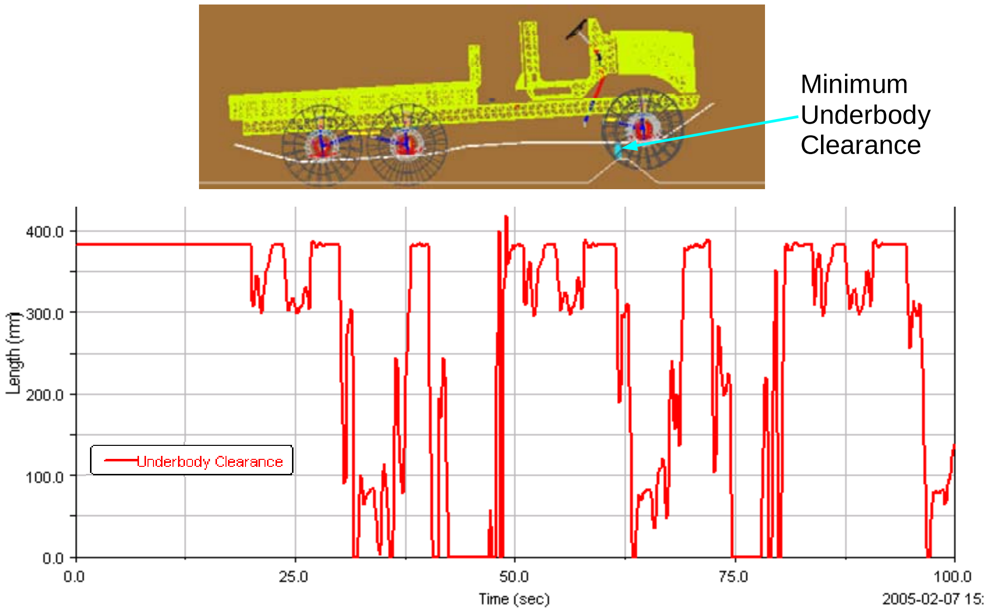

Figure 4: ADAMS simulation investigating obstacle clearance

Navigation and Localization

For the first Grand Challenge (2004) TerraMax™ used solutions from several different suppliers: two Novatel Propak GPS units, a Crossbow fiber-optic gyroscope (3 DOF accelerations and angular rates along with pitch and roll angles) and a Hewlett Packard magnetic compass, as well as vehicle wheel speed information. Part of the vehicle control system included an extended Kalman filter, implemented by team members at the Ohio State University, which used raw data from all of the sources to estimate vehicle state (position, pose, linear and angular velocities). GPS service used differential corrections from Omnistar's HP subscription service (position error of <=10 cm). In the second challenge (2005) Team TerraMax™ selected a more integrated approach, based on GPS/INS systems from Oxford Technical Solutions. The Oxford RT3100 includes a micro-electromechancical system (MEMS) based inertial measurement unit (IMU), a GPS receiver and a Kalman filter to use data from both the GPS and IMU to estimate state. Additionally, differential corrections can be used for increased precision and a wheel speed signal enhances dead reckoning during GPS interruptions. TerraMax™ (in its Grand Challenge II configuration) used two RT3100 units, one with WAAS differential GPS corrections enabled and one which received Omnistar's VBS (position error <=50 cm) subscription differential correction service from a Trimble receiver. Averaging position solutions from the two systems increased accuracy and robustness. Partners at Rockwell Collins developed an alternate dead reckoning algorithm using wheel speed and steering angle. This alternate algorithm has better error characteristics than the MEMS IMU based dead

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[1] Advanced Dynamic Analysis of Mechanical Systems, a rigid body dynamics simulation package from MSC for analysis of complex mechanical systems.

reckoning solution. The wheel speed/steering angle based solution has difficulties in some circumstances (sharp turns) and both dead reckoning solutions could only function for limited periods. However, in the open desert setting of the Grand Challenge, GPS interruptions were brief and generally limited to tunnels/underpasses (where limited turning occurs).

3.0 SENSING TECHNOLOGY

System Overview

TerraMax™ used a combination of vision and laserscanning to detect its environment, exploiting their complementary sensing strengths. Laserscanning sensors provide very accurate and precise range measurements. Laserscanners 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 spacings between the three different pairs of cameras. This camera to camera spacing is referred to as the baseline of a stereo-vision system. Three distinct baselines allow accurate stereovision across a wide range of viewing distances.

The sensors were carefully selected to provide the required navigation and perception capability. Figure 5 shows the sensor locations on TerraMax™. The sensors selected for the DARPA Challenge 2005 are as follows:

- Oxford GPS/INS
- Trimble GPS
- Single-plane laserscanners (LIDAR)
- Multi-plane laserscanners (LIDAR)
- Forward-looking Vision System

Laserscanning Systems

For the 2005 Grand Challenge TerraMax™ used three laserscanning (LIDAR) units: two single plane units and one multi-plane system. (In the actual competition, the vehicle carried an additional multi-plane unit as a backup.) Two SICK LMS-291 single plane laserscanners pointed obliquely downward, scanning an area near the vehicle. These served as the primary means for detecting negative obstacles (cliffs and fall-offs). The IBEO ALASCA [6] laserscanning unit provides four scanning planes separated by roughly four degrees. One ALASCA unit sat in the middle of the front bumper (with a spare just above the bumper). This unit looked for obstacles at a distance; the four scanning planes help ensure the unit could see at a distance of ~60m even as the vehicle pitched or the terrain slope changed.

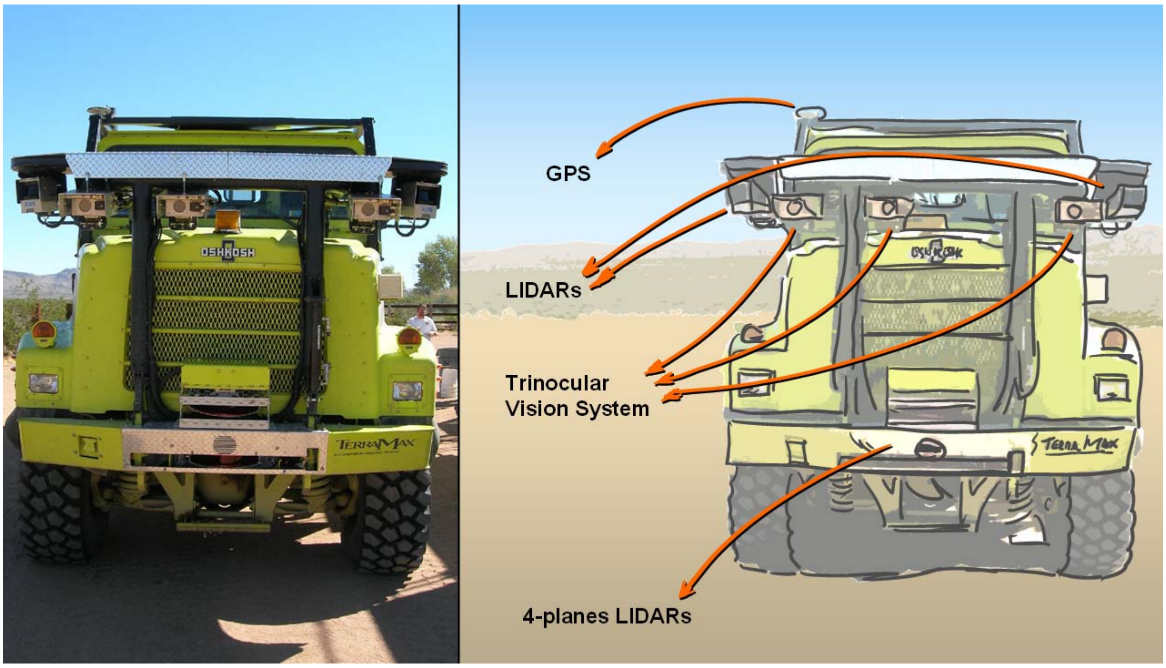


Figure 5: The TerraMax™ sensor suite: the picture shows the GPS position, the three forward looking cameras, the two SICKs, and the multi-plane laserscanners.

Trinocular Vision System

The vision system is based on multi-stereoscopic vision (forward looking trinocular system). Figure 5 shows the trinocular vision sensors: three identical cameras mounted on a rigid bar above the front edge of the hood. The asymmetrical location of the central camera divides the 1.5m between the left and right cameras into two distinct camera to camera separation distances (0.5m from right to center and 1.0m from center to left). A graduated grid allows precise calibration and alignment of the cameras. Holding the roll and yaw angles to zero degrees simplifies the calculations, reducing processing time. The desired pitch angle minimizes camera exposure to direct sunlight (framing just a small portion above the horizon) and brings the terrain into camera frame about 4 meters from the vehicle.

The trinocular system sends three video streams at 10 Hz (640x480, color with Bayer pattern) to the vision PC via a firewire connection. The PC selects which stereo pair to use depending on the speed of the vehicle. Since the baseline of the stereo vision system influences the depth of view, the large baseline is used at high vehicle speeds so that a deeper field of view is obtained, the medium one at medium speeds, and the short baseline is used at low speeds. This is one of the very few examples of very large baseline stereo systems (1.5 m) used on rough off-road terrain and delivering a robust environmental perception at more than 50 m, regardless of terrain slope.

Design efforts stressed the need for a reliable solution: three non-moving cameras provide a more mechanically robust system than pan-tilt solutions seen on some other vehicles. Additional considerations reinforced the selection of three fixed cameras. Vision must be able to sense obstacles at large distances (exceeding 50 m on rough terrain), requiring use of a stereo vision system. Furthermore, the baseline had to be large enough to guarantee depth perception at the large distances. Systems based on moving cameras using stereo vision with large baselines face a number of mechanical problems, including non-negligible vibrations for which processing must compensate. Using multiple cameras and selectively choosing the video streams for the appropriate stereo pair provided a very successful system.

Vision provides sensing for both obstacle detection and path detection (see Figure 6 and Figure 7).

1. Image disparity is first used to estimate the average terrain slope in front of the vehicle [7]. Slope information is then used for both obstacle detection and path detection. Any significant deviation from the average smooth slope detected previously is identified as an obstacle. The exact location of obstacles is then obtained via stereo triangulation between the two views of the object. A fairly precise localization is obtained, but it can be further refined via sensor fusion with raw data coming from the multi-plane laserscanner. This system can detect thin vertical posts and fence poles. It can also detect small obstacles [8], but—due to both the size and capabilities of the vehicle and to the team strategy—it was tuned with very high thresholds, reducing the number of false positives to a minimum. In other words, the capability of detecting small obstacle was traded for increased detection robustness. Even with this trade, the system could detect small construction cones used during both the tests and the qualification runs. Since the vehicle can negotiate 60cm steps, obstacles smaller than 60 cm need to be detected primarily for speed management issues.

2. Image disparity is also used to compute the area in front of the vehicle which features a smooth slope, the so-called free-space. The free-space is one of several features that are collectively used by the path detection algorithms. Path detection generates the free-space along with information about shape, similarity in texture and similarity in color and then fuses all the data together to deliver the location of any paths to the motion-planning supervisory controller. Free space is obtained using a standard image warping [9] in order to localize deviations from a smooth road surface: Figure 7 shows the right image (a), the warped left image (b), and –in green- the matching cluster representing free space (c). Figure 7(d) shows the final result of path detection. This algorithm also signals the presence of a straight segment of road, in order to increase vehicle speed. When a curved path is present (the red dot in Figure 7 shows the presence of a non-straight road), vehicle speed is reduced.

Figure 6: Images showing left and right images of different situations; on the right images, colors show the presence of detected obstacle: different colors indicate different distances. Posts—including even fence posts—and thin poles are correctly detected.

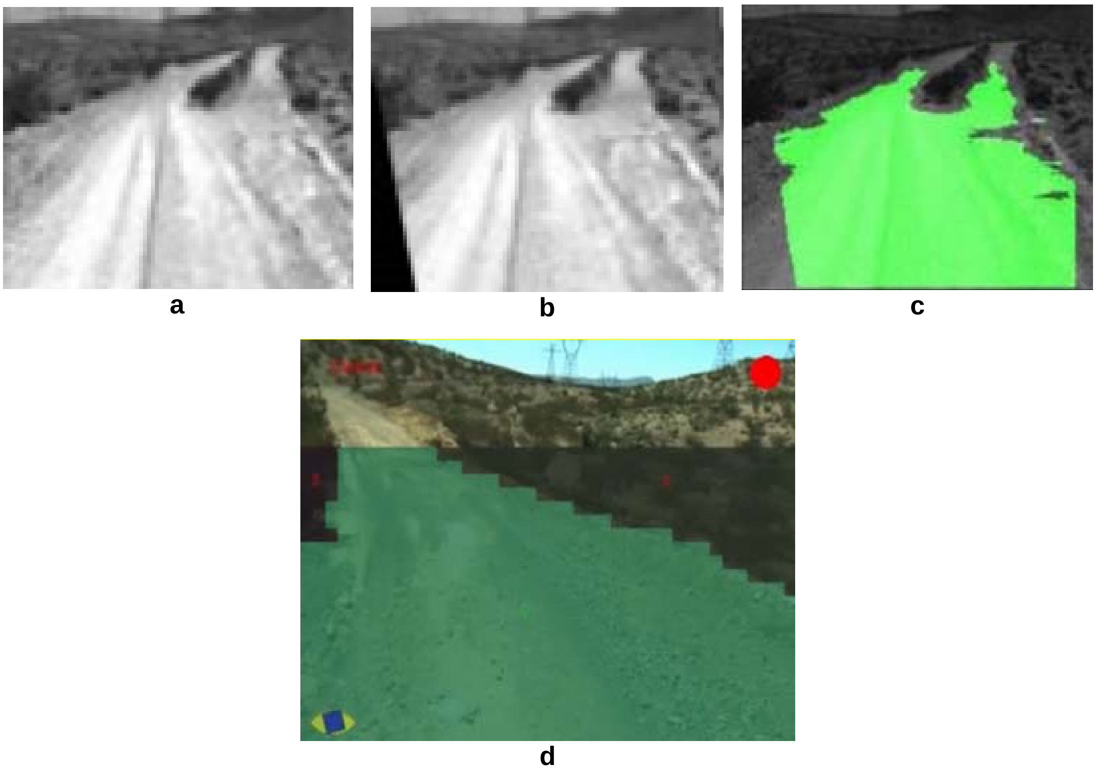


Figure 7: Image showing different steps of path detection: first the free-space is determined then the path is localized. Right image (a), warped left image (b), free space in green (c), the final result of path detection (d).

4.0 TERRAMAX™ PERFORMANCE

DARPA Grand Challenge I and II have provided an important measuring stick against which Oshkosh and VisLab (and 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 the technical community and mobilize them 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 completed 10% of the course. Over the next 18 months, Oshkosh, VisLab and the rest of Team TerraMax™ continued their development efforts. The period saw many redesigns or design enhancements, several of which have been described in this report. In October of 2005 TerraMax™ returned with a much stronger entry. To the left of Figure 8 one can see TerraMax™ during a portion of the National Qualifying Event (NQE), which it successfully passed to qualify for another Grand Challenge Event (GCE). Of course, Team TerraMax™ was not the only team hard at work between challenges I and II. Twenty-three teams qualified for the GCE in 2005 and nearly 20 of them completed at least 10% of the course. However, while many improved, ultimately only five vehicles were able to complete the entire course. On the right side of Figure 8 one can see TerraMax™ joining the winning circle after completing the full course. Along the way to the finish line, TerraMax™ reached a top speed of 42 mph—an impressive feat for a 16-ton vehicle and one which required the full range of its sensing suite. The vehicle even spent a full night in the desert; waiting patiently during the DARPA imposed evening curfew and restarting to successfully complete its mission the following day.

Figure 8: TerraMax™ at Grand Challenge II (2005): successfully qualifying and finishing

5.0 CONTINUED DEVELOPMENT

Shortly after the DARPA Grand Challenge ended, Oshkosh, VisLab and their partners demonstrated the autonomous navigation system "kit" on a much larger vehicle, using the Palletized Loading System (PLS) as the target platform. The PLS is a 10x10 vehicle with a gross vehicle weight of 44 tons and the capability of delivering 16.5 tons of payload. This heavy hauler serves as one of the US Army's premier logistical workhorses. Figure 9 shows the autonomous PLS operating off-road with full load. The project took approximately 75 days to complete. In January of 2006 (literally on the heels of the October 2005 Darpa Grand Challenge) the vehicle was successfully demonstrated at the US Army's Yuma test center.

Figure 9: Autonomous PLS operating off-road with full load

Even with the aggressive timeline, attention was paid to the details of integration. On the right side of Figure 10 one can see improvements in sensor integration on the autonomous PLS. Cameras for the vision system have now been discretely placed inside the cab, instead of on a heavy external support at the front of the hood. Installation of an upgraded computing center did not sacrifice cargo space or passenger space. The left of Figure 11 shows the passenger seat mounted computed center in TerraMax™. The right side of the figure shows the installation on the PLS, with the computers tucked neatly behind the passenger seat. Attention to details such as this and efforts to minimize the intrusion into either the cargo space, or the passenger space follow from one of Oshkosh's guiding principles in autonomous system development: vehicle functionality should not be sacrificed for autonomy. Ground military vehicles are working vehicles. Autonomous systems that cannot provide full functionality do not give armed forces the tools they need.

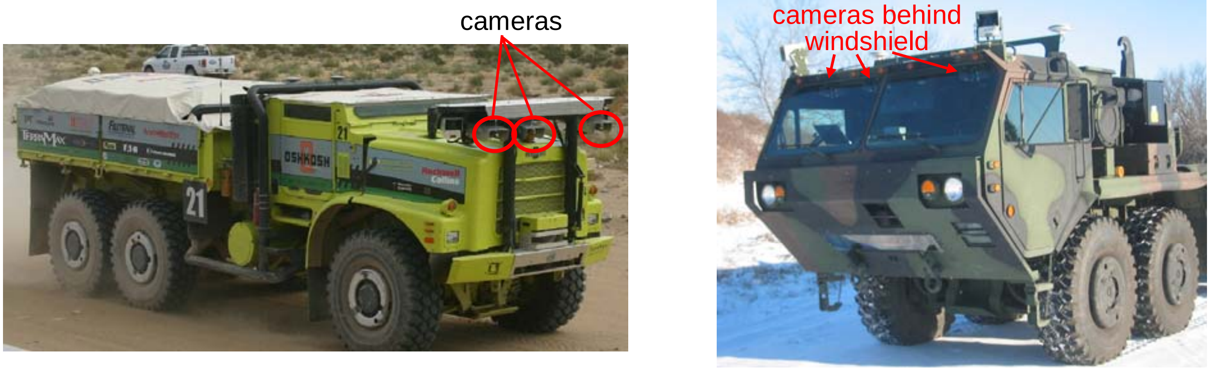
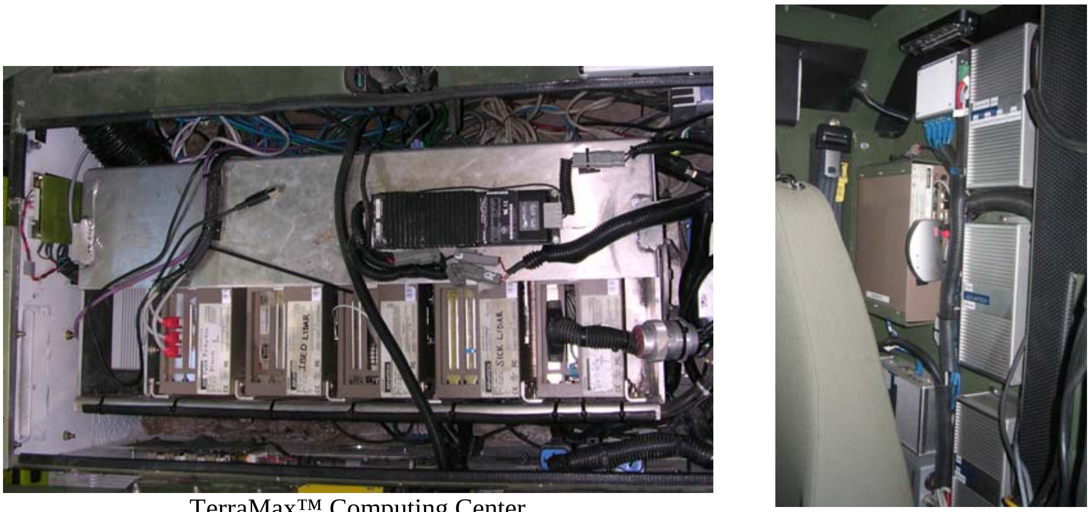


Figure 10: Oshkosh Truck unmanned vehicles: TerraMax™, based on MTVR, (left) and autonomous PLS (right)


TerraMax™ Computing Center

Autonomous PLS Computing Center

Figure 11: Integration of computing center in seat of TerraMax™ (left) and upgraded computing center in Autonomous PLS (right)

6.0 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 laserscanning 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/laserscanner fusion. Using multiple camera sets, each specialized for perception in a given direction, combined with laserscanner 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.

7.0 REFERENCES

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