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LARGE PLATFORM AUTONOMY IN URBAN ENVIRONMENTS

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ABSTRACT

This paper describes aspects of the Safe Operations of Unmanned Systems for Reconnaissance in Complex Environments (SOURCE) Army Technology Objective (ATO) that affect urban terrain autonomous mobility R&D programs. The SOURCE ATO provides essential large platform autonomous capabilities for executing unmanned reconnaissance missions, such as leader-follower, move-on-route, tele-operation, and remote situational awareness. The system includes multi-modal, high resolution, all-digital sensors which support nighttime and daytime operations. The SOURCE ATO development includes different classes of UGV vehicles as well as different classes of perception sensor technology. To date, the SOURCE ATO has successfully completed two out of three scheduled field experiments. The paper presents the latest SOURCE ATO results.

INTRODUCTION

The U.S military is presently extending its concept of MOUT (Military Operations on Urban Terrain) for robotic systems by taking advantage of new unmanned ground vehicle (UGV) technology and focusing on mission capabilities in populated cities and towns. Autonomous systems have the potential to increase Warfighter safety by mitigating the risk of unnecessary enemy exposure during routine urban missions, such as logistics and reconnaissance, by removing the Warfighter from direct contact with potential enemies.

The objective of the SOURCE ATO is to advance existing UGV technology development specifically in the area of MOUT missions. MOUT sites and missions generally contain complex and technically challenging variables for UGV operation, such as close operation with Warfighters and vehicles as well as potential interaction with civilian populations and enemy combatants. The environmental surroundings are geometrically and visually complex as well, and may include: man-made, structured elements; natural, unstructured elements; static structures and dynamic elements. In addition, maneuverability may be constrained in close quarters operation.

The three major experiments of the SOURCE ATO provide opportunities to advance the development and assessment methodologies for UGV's in more complex environments. To date, the SOURCE ATO has successfully completed two out of three scheduled field experiments: Baseline (January / February 2011) and Enhanced (November 2011). The third experiment, the Capstone Experiment is scheduled October 2012. The Capstone Experiment is planned as a joint event with the Improved Mobility and Operational Performance through Autonomous Technologies (IMOPAT) ATO program, which will include Warfighters as operators.

PLATFORM AND AUTONOMY SYSTEM

SOURCE Platform

SOURCE UGVs are built on capable, base vehicles of different classes. A suite of multiple sensors and an advanced SOURCE Autonomy System (that leveraged technology from multiple DOD programs) are added to the platforms to provide autonomous operation.

Figure 1 shows the system based on one class of base platforms - the TARDEC Advanced Platform Demonstrator

(APD). The APD was the primary UGV vehicle used in the Enhanced Experiment, but for the Capstone Experiment, commercial Jeep-based T2 platforms equipped with the SOURCE Autonomy System will be used.

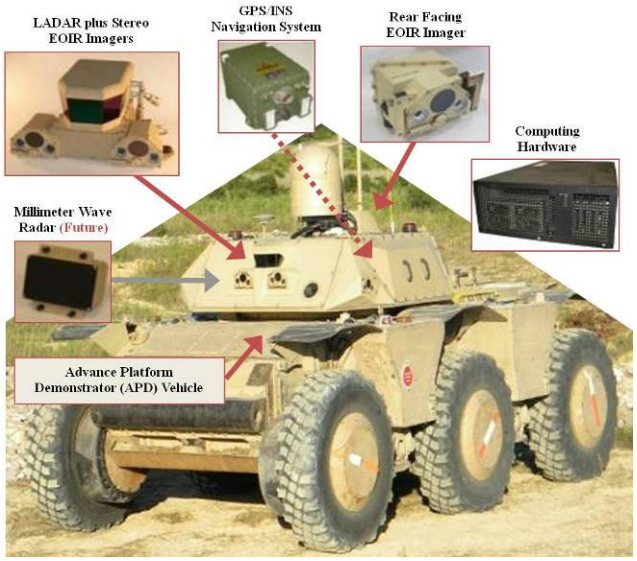

Figure 1 - SOURCE Testbed UGV - Advanced Platform Demonstrator APD

SOURCE Sensors

The SOURCE Autonomy System sensor suite includes a scanning LADAR, stereo vision Electro Optic Infra Red (EOIR) imagers, a precision GPS/INS navigation unit and COTS computing hardware. The sensor suite collects data about the immediate environments and uses advanced algorithms to build a model of the surroundings. In order to ensure robust UGV operation in a broad range of environments, the system uses of a range of sensors that depend on different physical modalities for detection, including LADAR using laser ranging, visible light imagers, long wave infrared (LWIR) imagers, stereo vision processing and RADAR.

The core sensor suite used in the first two SOURCE experiments was based on technology leveraged from the Autonomous Navigation System (ANS) program – an advanced sensor suite capable of supporting high levels of autonomy in challenging environments and conditions. However, not all applications require the most advanced and costly technology. Systems based on smaller UGV platforms at lower speeds or lower levels of autonomy could benefit from lower cost sensors. For example, the TARDEC Lighten the Load (LTL) Tech-D is developing technology for smaller platforms to assist in offloading support equipment for Warfighters. So to support this effort as well as a broader range of target applications, the SOURCE ATO is integrating and evaluating a suite of lower-cost sensors on a T2 platform.

The lower-cost sensor suite will be evaluated at the Capstone Experiment using two T2 platforms.. One T2 will use the core SOURCE sensor suite used in the prior experiments. The second T2 will use a suite of lower cost sensors, including a Very Low Cost LADAR (VLCL), a low cost GPS/IRU Navigation Module, a low cost ESO Stereo Video module and a commercially available automotive Millimeter Wave RADAR (MMWR) module. These sensors are shown in Figure 2 below.

Figure 2 - -SOURCE Low Cost Sensor Suite Configuration for Capstone Experiment

Other integrated sensors provide information about the vehicle's state, including wheel encoders, various engine/motor monitoring sensors, steering angle sensors, and driver shifter, throttle and brake sensors. The system can also use a variety of databases, including topographical and road maps, sensor data from prior runs through the environment, and rules of the road.

SOURCE Autonomy System

The autonomous capabilities of the SOURCE system are provided by the SOURCE Autonomy System. In addition to the sensor suite, the Autonomy System includes all of the software and algorithms necessary to autonomously operate the UGV to accomplish a mission based on operator objectives.

Key technology includes the automated extraction and intelligent interpretation of relevant(and often, subtle) information from multiple sources of data. The SOURCE Autonomy System fuses data from various sources to create an internal model of its surroundings. This internal model represents everything the UGV "knows" about the world around it. The UGV uses this knowledge to plan its immediate actions given the higher-level mission planning and goals. The quality of the UGV's model depends on both the performance and complement of sensors available and the UGV's ability to interpret the sensor data with respect to its mission and capabilities.

In a complex environment, there are a number of dynamic variables to consider, such as different atmospheric and environmental conditions, different lighting conditions and various objects of different sizes with a wide range of material properties, both natural and manmade. As such, it is important to have diverse set of sensing technologies as well as the advanced autonomy system to interpret the sensor data. No single sensor technology works well in all situations. Figure 3 shows the types of sensor data available from the SOURCE sensor suite.

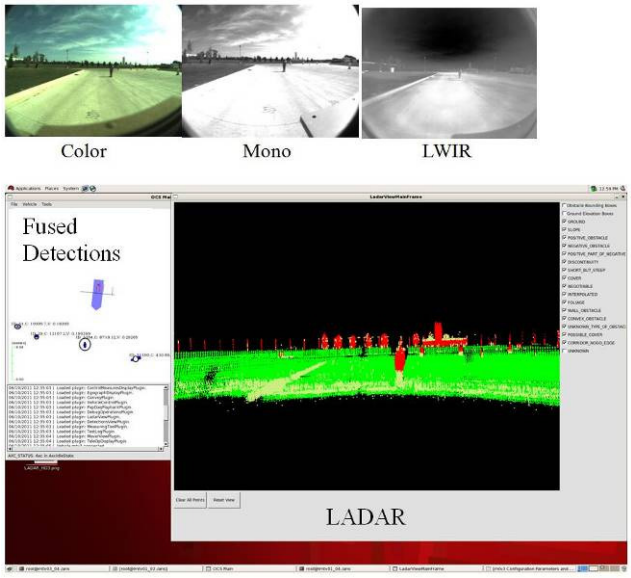

Figure 3 - SOURCE Data from Multiple Sensors Is Used To Interpret Its Surroundings

Data from all of the sensors is used to develop the SOURCE UGV's model of its surroundings. This model is used to plan it actions to achieve the mission objectives. Figure 4 shows an example of part of the internal model developed by the SOURCE UGV.

Figure 4 – Internal Model Developed From Sensor Data

SYSTEM CAPABILITIES

This section provides details about particular SOURCE technologies that could provide significant control capabilities to future DOD UGV programs.

Move On Route

The SOURCE Autonomy System provides autonomous Move-On-Route capability. This capability provides the core autonomous driving operation and behavior in support of robotic operation for a wide variety of missions.

The UGV follows waypoint plans specified by the Warfighter through the systems Warfighter Machine Interface (WMI) System. Within the waypoint plan, the Warfighter designates multiple waypoint goals, speed limits, and corridor limits or keep out zones along the planned route. The Warfighter also designates specific high level driving behavior between waypoint segments of the plan, specifically on road or off road behavior. SOURCE on road behavior includes operation on known roads while following standard rules of the road, including proper understanding of roads, lanes, intersections, lane directionality, traffic and pedestrian motion. For current phases, on road behavior depends on prior data defining the surrounding road network.

While executing the user-provided route plan, the SOURCE Autonomy System maintains safe operation of the UGV by detecting and avoiding both moving and static obstacles within its environment as well as other terrain hazards. The Autonomy System detects and predicts the movement of pedestrians and vehicles near the UGV and determines the appropriate action to avoid colliding with them.

The latitude the UGV has in selecting obstacle avoidance maneuvers depends on the constraints the operator provided in the route plan as well as knowledge of the surrounding road network.

Once under way, the UGV autonomously performs the Move-On-Route with little or no intervention by the operator unless the UGV cannot find a route to achieve the specified goals.

Each of the SOURCE Experiments includes Move-On-Route operation under complex urban settings with a variety of obstacle types and conditions.

Leader-Follower

The SOURCE Autonomy System provides autonomous Leader-Follower capability. Like Move-On-Route, this is a high level autonomous capability. However, instead of driving based on a waypoint plan, the UGV follows a lead vehicle or dismounted Warfighter.

When following a lead vehicle, the Autonomy System primarily attempts to closely match the route taken by the lead vehicle as reported by the lead vehicle's navigation unit. That is "Put your wheels where the leader put his wheels." This supports autonomous convoy operations such as those in resupply missions. The operator can specify the following parameters including speed limits, separation distance as well as lateral offset to support multi-vehicle formations.

As with the Move-On-Route capability, the SOURCE Autonomy System maintains safe operation of the UGV by detecting and avoiding both moving and static obstacles within its environment as well as other terrain hazards. In particular, the UGV detects and avoids obstacles even if they were not present when the leader passed that location.

To optimize vehicle following accuracy, if the lead vehicle is equipped with an Autonomy System, the lead vehicle shares geometric information regarding its surroundings. The following UGV will use this information to more precisely determine the exact route taken by the leader and thereby improve its following accuracy.

In addition to vehicle following, the SOURCE Autonomy System supports following a dismounted Warfighter. This is a key capability for the LTL objectives.

Similar to following a lead vehicle, when following a dismounted Warfighter, the UGV follows the dismount's route rather than a waypoint plan. On the SOURCE ATO, the dismounted leader's path points may be determined in one of several ways. The dismounted leader's path may be provided by sensing equipment the Warfighter has; or the path may be determined by directly tracking the dismount using UGV sensors (under the right conditions); or the path may be determined by a combination of the two techniques.

To support urban operation, the follow-dismounted-leader capability includes a smart following mode where the UGV does not attempt to follow the dismounted leader's path precisely. Instead, the UGV follows the leader by following the road network. In this way, if the leader is walking down a side walk, the UGV follows by staying on the road and does not drive up on the sidewalk to follow the Warfighter's precise path.

To support a wider variety of missions, the SOURCE leader-follower capability supports leader switching for the follower UGVs, even between vehicle or Warfighter leaders. The capability also supports following a dismounted Warfighter switching from movement on foot to boarding a vehicle and later dismounting again.

A SOURCE dismount controller unit allows the Warfighter to communicate basic follower directions to the UGV, including changing leaders and transitions between traveling on foot and riding a vehicle.

The SOURCE Autonomy System capability to follow a lead vehicle is based on mature technology leveraged from earlier programs. The follow dismounted leader capability is being integrated as part of the SOURCE ATO and will be evaluated as part of the Capstone Experiment.

Teleoperation and Supervised Autonomy

Being able to assist the autonomy system when the vehicle finds itself in undesirable situation is yet another SOURCE feature. This feature provides close interaction between operator or vehicle driver and autonomy system. During teleoperation, vehicle information such as video, speed, heading, and absolute position are presented to the operator as with most teleoperation systems. The SOURCE system takes it a step further by providing additional information which allows the operator to make more informed decisions. These are called Driving Aids.

Using Driving Aids, the SOURCE system presents the operator with autonomy data. The data can be objects detected with the LADAR, stereo vision or Millimeter Wave RADAR. These tools give the operator greater certainty when tele-operating or under Supervised Autonomy mode. For instance, a UGV may be traveling on a dirt road and its visual data may be degraded due to dust. With Driving Aids, the Millimeter Wave RADAR penetrates through the dust and returns any objects that are found in the path. This is especially helpful in convoy situations. Under normal driving conditions the sensor data and analysis results

support situation awareness. This can be in the form of highlighting potential hazards or obstacles to the operator.

TESTING

The SOURCE ATO program is build around three major experiments, each evaluating and demonstrating progressive capabilities and more challenging test conditions associated with complex urban environments. The Baseline Experiment occurred in Jan/Feb 2011 at the Maryland State Police Training Facility in Sykesville MD. It focused on initial integration of the Autonomy System from the Autonomous Navigation System (ANS) and the TARDEC Robotic Vehicle Control Architecture (RVCA) programs onto TARDEC platform vehicles. The Enhanced Experiment occurred in Oct/Nov 2011 at the Camp Lejeune, NC MOUT site. It was a key technology demonstration event focusing on autonomous operation in a complex urban setting with moving vehicles and pedestrians (mannequins). The Capstone Experiment is planned for Oct 2012 at the Camp Lejeune, NC MOUT site. The Capstone Experiment will be the final performance event for the SOURCE ATO.

Baseline and Enhanced Experiments

For both the Baseline and Enhanced Experiments, a large collection of data was gathered and recorded. This included logged sensor data, resulting vehicle behavior, logged internal software data, , independent ground truth data for moving and static obstacles, and test personnel observations and comments.

The SOURCE Baseline Data Collection Experiment included basic autonomous Move-On-Route operation on a road network as well as initial moving obstacle avoidance using the off road behaviors using the T2 platform vehicle. Figure 5 below shows portions of the Sykesville test site used for the Baseline Experiment.

Figure 5 - SOURCE Baseline Experiment at Sykesville MD State Police Training Facility

The SOURCE Autonomy System supports different behaviors for On Road operation and Off Road operation, in much the same way as human drivers drive differently when on road versus off road.

A brief summary of the Baseline Data Collection is shown below. The On-Road Behavior portion occurred on the Highway Loop at the Sykesville Police Training site. The Off Road Moving Obstacle Avoidance occurred at the GDRS Westminster, MD property (due to scheduling conflicts with the Sykesville facility).

On Road Behavior

- 6 Highway Course Runs
- 2 Different Test Scenarios
- 10 obstacle encounters per Run
- Some obstacles were in vehicle's path, requiring avoidance maneuver
- Some obstacles near vehicle path and did not require an avoidance maneuver
- Obstacles included
    - Mannequin(s)
    - Barrel(s)
    - Small Animal Model
    - Rubble

Off Road Moving Obstacle Avoidance

- 13 Moving Obstacle Runs
- 2 Different Test Scenarios

- 1 Mover Per Run
- Mannequin on computer controlled pulley system
- Avoided mover on each scenario by more than 6 meter

The SOURCE Enhanced Experiment demonstrated key autonomous operation capabilities in a complex urban MOUT site commonly used for training Warfighters for urban operations. The APD platform vehicle was used for this experiment.

Figure 6 below shows portions of the Camp Lejeune MOUT site used for the Enhanced Experiment. The MOUT site included narrow roads, paved and unpaved road surfaces, curbs, sidewalks and an underpass (shown in Figure 4).

Table 1 below shows a summary of the test runs executing during the Enhanced Experiment.

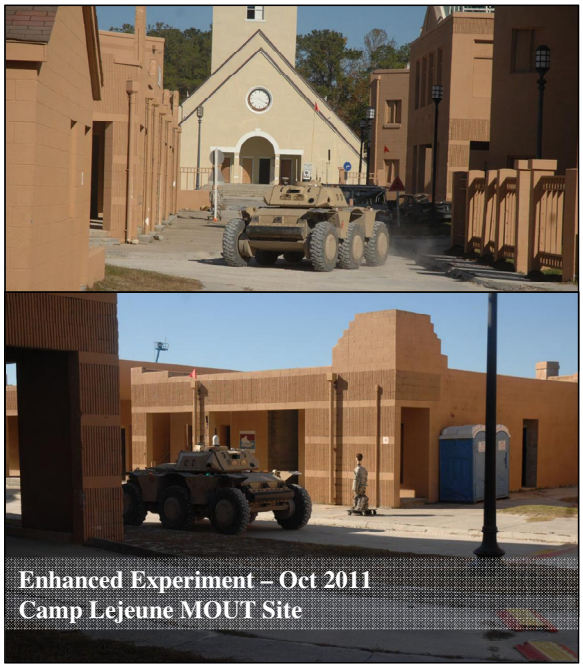

Figure 6 - SOURCE Enhanced Experiment at Camp Lejeune, NC MOUT Site

Table 1 - Summary of test runs during the SOURCE Enhanced Experiment

Test Run	Nominal Distance	05 Nov	06 Nov	07 Nov	08 Nov	Total Runs
Movers Off	1.5 km per run	3	2	2	2	9
Complete Course	1.5 km per run	10	1	-	15*	26
Blue Course	0.5 km per run	-	11	5	-	16
Red Course	0.4 km per run	-	11	5,5*	-	21
Black Course	0.6 km per run	-	11	5,5*	6#	27
Raw Data Collection	1.5 km per run	-	2	1	-	3
Other	1.5 km per run	-	-	2°,3&	2@	7
Total	**98.2 km**	**13**	**38**	**33**	**25**	**109**

** Executed run at increased speed, except in safe zone closest to base camp*
° Tele-op runs of the entire course
& Vehicle maneuvering runs at higher speeds with mover detection disabled
 # Different sensor algorithms turned on or off
@ MapReg used for entire test run

Capstone Experiment

The Capstone Experiment will be the last testing event for the SOURCE ATO. It will be conducted at Camp Lejeune North Carolina between September 19th 2012 and October 25 2012.

Figure 7 - SOURCE Capstone Experiment at Camp Lejeune, NC MOUT Site Oct 2012

In executing the Capstone Experiment, we will take a close look at the performance differences between the full-up ANS system and the Low Cost system. There are 2 T2 vehicles on the SOURCE ATO. One will be outfitted with the ANS system and the other with the Low Cost system. Also, for the first time, the SOURCE program will be officially testing the Dismount System. The Dismount System consists of a human mounted pedometery, localization and OCU interface. On the vehicle side we developed perceptive technologies allowing us to track the Dismount Operator via vision. This is valuable in multiple cases, such as during communication outages or in urban environments. The dismount system doesn't blindly follow the Dismount Operator. It takes in to account environmental factors such as roads. For instance if the T2 is autonomously following the Dismount Operator on a city street, it will take into consideration the rules of the road. If the Dismount Operator is walking on the sidewalk the vehicle won't try to position itself directly behind the Dismount Operator, rather it will stay on the road.

SUMMARY

In summary the SOURCE ATO has helped pave the way for lower cost autonomy systems that can benefit the Warfighter now. Continued Technology Advancement from earlier phases of SOURCE Program and leveraging technologies developed under other programs. SOURCE has added new capabilities and cheaper sensors which align with future TARDEC efforts. and utilized multiple, different vehicle classes with both high-end and low-cost sensor suites. Also, SOURCE integrated different levels of autonomy and user interaction through Driving Aids and theLow-Cost sensors and Dismount technologies set the stage for supporting the LTL Tech-D. The system will be operated by Warfighters in joint demo with the IMOPAT ATO at the end of October.

REFERENCES

No external references used.