Autonomy
Robotic Research, LLC

Abstract

Autonomous systems excel at some tasks and are poor at others, especially when compared to humans. Automatically computing line of sight from a-priori data and measuring distances are some tasks in which autonomous systems excel, but doing subtle recognition tasks, like finding humans in a vegetated environment or differentiating between non-combatants and the red team, are not tasks that the state of the art has yet to achieve. Robotic Research is uniquely placed to perform this research.

Robotic Research's software and hardware autonomy kits have autonomously driven large vehicles (with no passengers) for thousands of miles on civilian roadways, with civilian traffic on the unstructured roads of Afghanistan for Special Forces Programs (Figure 1).

RR Proprietary- **Figure 1. Autonomous vehicle driving in civilian roadways with nobody onboard successfully deployed for road clearing.**

These systems – deployed in 2013 – represent the first completely autonomous ground vehicle systems for the DoD, and the government community in general. It was also a first for the DoD's Army Test and Evaluation Center (ATEC) to provide an "acceptable risk" level for autonomous driving with nobody on board. To our knowledge, this has not been repeated by any program since.

Robotic Research is also the prime for two keystone programs for autonomous mobility: AGR and ExL/F. AGR is developing the de facto autonomous mobility kit (A-Kit) for the next generation of army trucks and logistic vehicles. Robotic Research is therefore defining algorithms, interfaces, and architectures that will become the requirements for the next generation of DoD vehicles. But even more relevant to this effort, the ExLF program builds on the progress demonstrated during the Autonomous Mobility Applique Systems (AMAS) Joint Capability Technology Demonstration (JCTD) and AGR programs to develop unmanned prototype systems that address the needs of the Leader Follower Directed Requirement and Program of Record. ExLF will equip existing military ground vehicles and will conduct an Operational Technical Demonstration with scalable autonomy technology showcasing the integration of modular kits, common interfaces, and a scalable open architecture. The AGR architecture is being developed to become the de-facto autonomous architecture for all foreseeable ground robotic vehicles.

Robotic Research has fully demonstrated autonomous mapping and search missions with groups of vehicles. Although the utility functions of those coordination efforts are different from the ones needed for this topic, the underlying structure of the distributed localization and coordination engine is being leveraged for SubT and urban warfare applications.

Robotic Research has a rich history of success in autonomous mobility, as our timeline of autonomy, Figure 2, shows.

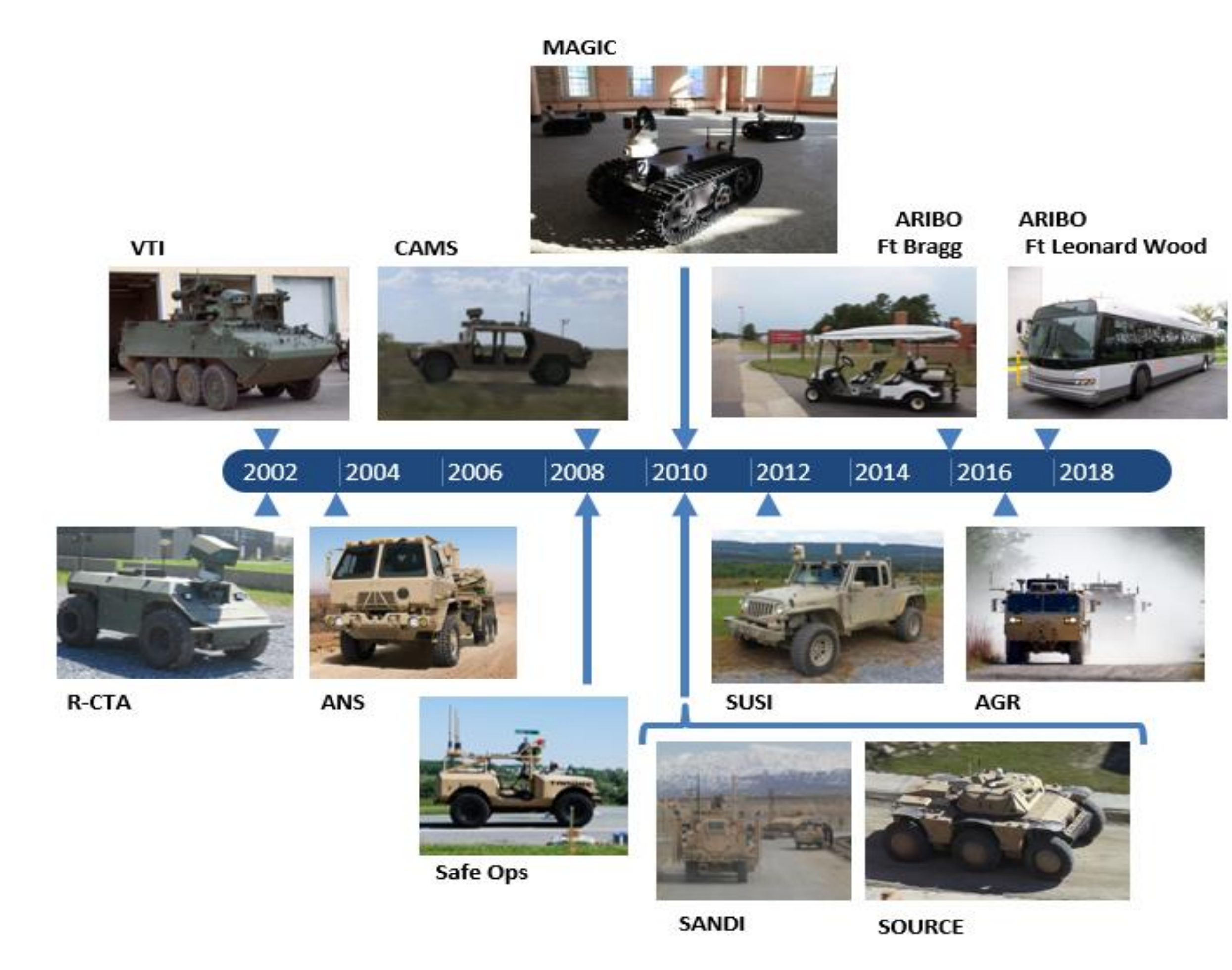

Figure 2. Robotic Research history of autonomous programs.

1 Purpose

Automating the coordination between humans and robots for a variety of missions in both GPS enabled and GPS-denied environments. The autonomous robotic system needs to communicate with humans in a way that does not overwhelm or significantly increases operator/team member loads. A variety of missions with tactical validity can be implemented:

- ***Loose cooperation*** allows to have the operators go about their mission without worrying about mapping or clearing and let the robots clear the areas that have not been covered by the humans. For example, the humans will go through the main tunnel shaft, and the robots will clear all areas surrounding the operator's trajectories.
- ***Autonomous horizon sentry*** will have robots automatically discover the horizons of the explored areas and automatically find locations where to provide persistence surveillance so that the team could is not surprised by enemies coming from the horizon of unexplored areas.
- ***First encounter*** is where the robots automatically explore the operational areas and mark specific areas that have been cleared so that the warfighter can know of, and more safely move into, areas that do not have line of sight to unexplored areas, therefore reducing risk and speeding operation tempo.

- ***Suspicious interrogation.*** Robots can be used to automatically discover movers in the field of view and approach them before the movers get closer to the humans. Non-lethal warnings and deterrents can be used to discourage enemies or noncombatants from approaching the warfighters and the team.
- ***Perimeter sentry*** is a mission where robots are constantly patrolling the perimeter (e.g. opening to a tunnel or a clearing), protecting warfighters while they perform a task. The robots can automatically generate random routes to patrol.
- ***Follow the group*** similar to perimeter sentry, but the group is on the move.

2 Theme

The Robotic Research, LLC research and development addresses autonomous operations of multi-domain robotic systems providing advances in situational awareness, assured robotics communications/control, and human-robot interface for the warfighter.

3 Design/Methodology/Approach

Localization as a Distributed System

Localization is usually thought of as an individual functionality. In other words, navigation units in the market provide localization for a single vehicle or person. Even if all vehicles in a convoy have a navigation unit (they know their own position and a general position of other vehicles), that localization knowledge is not optimally shared and used to create a better localization solution for all unit members. Robotic Research's working during UMAPS (a Phase II and III SBIR supported by ARDEC) turned that common practice upside down. For our approach, localization on a coordinated battlefield became a group functionality, with emphasis on relative positioning between the team members. This relative positioning is the fundamental enabler of coordination. Commands and targeting at the unit level rely on the relative positioning capabilities of its members, especially in GPS denied areas. A warfighter in a building is more likely to say "go to the door to my right" than specifying at Northing and Easting locations of the door. This relative positioning is only possible if the sensors/systems providing the positioning (worn by each unit member) work together to provide this information (Figure 3). Robotic Research has already developed a family of meshing localization products. These devices track friendly forces' positions relative to each other, even in GPS denied environments. This family of systems include the WarLoc™ for dismounts, the RR-N-140 for vehicles, and the SR-Nav, LR-Nav, and RR-140 for small, medium, and large sized UAVs and UGVs. The systems have been tested outdoors, indoors, in subterranean environments, and even perform well under attempts at jamming. The location of each person, vehicle, or unmanned system is shared with all of the other nodes in the mesh.

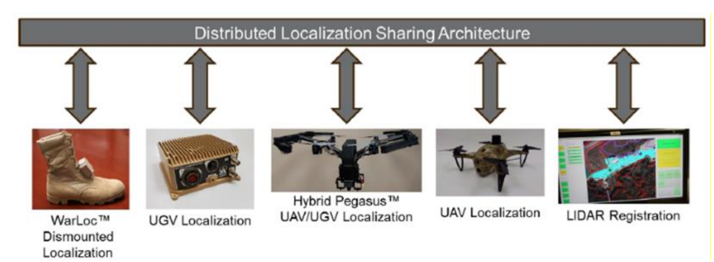

Figure 3. A subset of Robotic Research's family of distributed localization systems.

The ARDEC supported UMAPS SBIR developed the architecture necessary for the distributed filtering of this positioning information. The filtering works across platforms (dismounts and vehicles) to include: inertial measurements, SLAM, ultra-wide band and Bluetooth ranging and GPS when available. The filtering is treated as a distributed filtering network of "springs" (Figure 4). Measurements from odometry, SLAM, ultra-wide band, and GPS are synchronized across platforms and filtered in each node given the communications available to each node. Nodes that lose communications with the rest of the group continue filtering the information that has reached their radios and synchronize the information once they return to communication with the rest of the group. The resulting localization benefits have already been demonstrated in a variety of tests for the Special Forces Community.

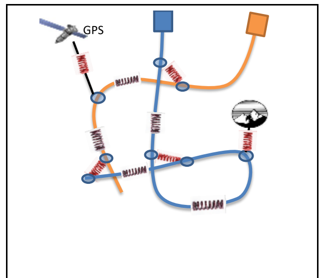

Figure 4. Spring solver.

The advantage of the coordinated localization becomes obvious when we examine the missions/capabilities that it enables. Figure 5, below, shows some examples of mission types Robotic Research has been working on with ARDEC to improve operations through the use of Robotic Research's "Spring Network":

- **Human-Human accurate relative positions** are important for the operational unit. In the figure, as warfighters explore the tunnels, the relative position ("where are my buddies?") is important to coordinate movement, or to help to find a wounded team member. For these cases, the absolute positions are almost irrelevant.

- **Robotic Leader-Follower operations** in GPS denied areas. When GPS is jammed or not available, in order to have groups of robots relay or follow each other, synchronization between their units is necessary.
- **"Follow me" modalities**. Once again, the relative location of the warfighter and the robot are necessary to accurately follow. In this case the LS3 robot (legged) was demonstrated to accurately follow the pedestrian on a complex multipath environment.
- **Multi-robot 2D and 3D map building** can only be accomplished if the maps are registered and "stretched" to fit each vehicle's errors in localization. This registration (SLAM) must be performed to assemble the maps. The coordinated localization synchronization was used to build the maps at the Ft. Hood site.

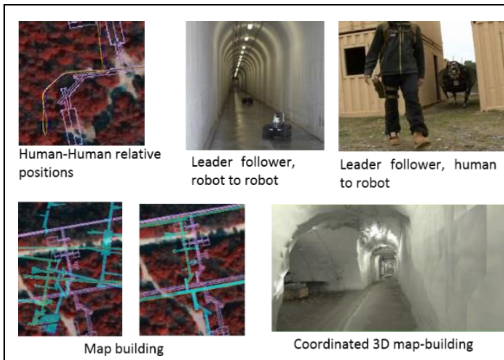

Figure 5. The synchronization and common filtering of the navigation units allow for a number of missions: Accurate relative positions of warfighters in GPS denied areas, robot convoying in tunnels, Human-robot leader followers, coordinated map-building, and 3D map building.

Localization

As mentioned earlier, at the core of every coordination mission, there is always a need for localization. Localization can be absolute or relative. Absolute localization means that the system needs to know where its assets are in the world. Relative means that the systems or individuals know where they are with respect to each other, or with respect to markers left in the field. Of course, if absolute location is known, relative can be derived.

The opposite, of course, is not true. Interestingly, for accurate coordination missions, only accurate relative localization is needed. For example, two humans can coordinate their motion to carry a sofa without knowing their Latitude and Longitude, but they will fail miserably if they cannot determine where they are with respect to each other. The proposed family of systems will work even if the absolute location of the members is not known, as it only requires having relative positions. Moreover, it builds an infrastructure that allows the family to deploy and expand a relative localization infrastructure.

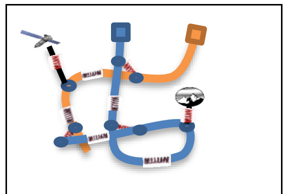

Figure 6. Spring solver depiction of how the filter works.

At the core of this infrastructure is a series of IMU (inertial navigation units) and ranging radios (direct point to point measurement of range) and a distributed filter that allows the system to accurately determine the location of all its members.

Figure 6 shows a depiction on how the distributed localization filter works. The blue vehicle and the orange vehicle are at the beginning of their tracks. The springs in the image show measurements that collaborate towards determining the location of each device. There are springs along the path that represent dead reckoning (encoders, accelerometer, visual odometry, etc.). There are springs shown when vehicles recognize each other and the ranging radios perform a measurement between the two vehicles. There are springs between the orange vehicle and GPS, and there are springs between the position of the blue vehicle and some landmark that it discovered. The stiffness of each spring represents the confidence of the measurement.

For example, the error of the ranging radios is approximately 10cm creating a stiff spring, while the errors accumulated by reckoning could be significantly larger depending on the distance traveled, therefore, creating very soft springs. The same is true with GPS and other measurements. The "spring solver" then solves the overall solution by optimizing the network and finding the position of the family of systems.

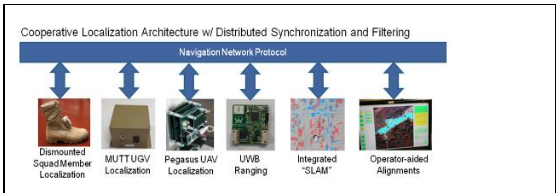

Figure 7. The cooperative localization architecture includes a variety of odometry sources and measurement updates for heterogeneous assets in a distributed framework that is resilient to communication dropouts.

Figure 7 shows some of the devices used for providing these measurements and already incorporated into our localization infrastructure.

4 Findings

Coordination and SA of all systems can create a significant cognitive load on operators as the number of platforms being controlled grows. In particular for search and mapping missions, where the missions for each robot are not easily described by waypoints.

Robotic Research, LLC has developed a SA coordination system that maps and searches areas utilizing large number of assets utilizing different control techniques. In particular, we assign areas to groups of robots and the robots partition these areas to minimize an overall cost function. An outline of this algorithm will be presented in the next section. These techniques were developed for the MAGIC 2010 and were successfully tested to map a variety of locations (see Figure 8) including an exhaustive test at the USG underground testing facility. Figure 9 shows a 2D and 3D map generated by three assets autonomously coordinating and subdividing the space among themselves. The total length of the tunnel is approximately 3 km. This mission was conducted in a GPS denied environment.

Figure 8. Pegasus™ II-e hybrid UAS/UGV first assembled platform flown off a MUTT UGV.

Robotic Research's coordination layer resides on each robotic system and on each OCU. Our overall philosophy embeds coordination capabilities on each robot in the architecture. The communications between robots is kept to a minimum by only propagating bounds of the solutions found in the nodes called "contracts." When communications connect the UGVs and the OCUs; the coordination layer benefits from the larger number of computational units. In those cases, the greater number crunching capabilities of some nodes, such as OCUs, will provide search bounds to the rest of the robot team. When communications are poor and SUGVs are isolated, they can still coordinate in their local communication neighborhood. It has been shown that this system is guaranteed to outperform an auctioning coordination strategy. The Robotic Research MPAC library (MPAC is software and system developed for autonomy of small unmanned surface vehicles) provides the search engine in the Coordination Layer Planner. MPAC is already integrated into Fire Effects software, and it will be migrated into ATAK.

Figure 9. A group of three autonomous robotic systems generated without operator intervention a map of this underground facility. The system autonomously coordinated and merged the resulting map. Both 2D maps and 3D textured maps were generated.

5 Practical Applications

The research and development results demonstrate new and innovative approaches to teamed robotic systems autonomously operating in support of the warfighter in GPS-denied environments enabling the warfighter to focus on critical tasks more effectively. This is accomplished through improved situational awareness and reduced risk to warfighters in SubT and urban warfare. The research results are applicable to a "Family of Systems" of autonomous unmanned ground and air vehicles to include transformable hybrid UAS/UGV that can both fly and drive as needed.

Because these efforts can be leveraged, the full objectives of this program can be more prudently implemented. We expect that the Family of Systems will be able to perform a variety of missions very relevant to the Army. In particular: Cooperative SA, Coordinated effects, and counter UAV.

Figure 20, below, shows a Multi-Utility Tactical Transport (MUTT) autonomous ground vehicle and Robotic Research's Pegasus IIe, a transformable UAV/UGV vehicle. These two autonomous vehicles are part of the current Family of Systems.

Figure 20. An autonomous MUTT (behind the fence) deploys a Pegasus vehicle that "hops" over the fence. Pegasus transforms from its aerial modality to its ground modality.

6 Original Value

This generalized formulation allows other types of missions to be performed in addition to search-only missions. The ability to plan for multiple types of sensory capabilities is made possible by abstracting the tasks into the starting conditions, ending conditions and resources required for completion. Through this basic formulation, a wide variety of pertinent missions can be managed on-the-fly by a group of human robot teams. A new algorithm was developed by Robotic Research and tested with robotic only teams to perform this same mission. This algorithm is called K-means Line-of-sight (KML) and computes the countries and capitals given initial information about the building layout.

Robotic Research has developed a situational awareness tool that provides SA during the mission and stores data for use in detecting changes in the environment, called Flashback™. Flashback™ is an intelligence and reconnaissance tool that captures, time tags, geo-references, and stores data (such as camera imagery) for use in mission planning, intelligence analysis, and aids warfighters to detect changes in the environment. Flashback™ achieves this by storing data to a spatiotemporal database, and provides and intuitive user interface to query, display, annotate, and compare data over time, thus providing superior target detection of existing and emerging threats. Robotic Research has also integrated Flashback with ATAK, providing the government with time-tagged panoramic imagery and navigation data. Flashback™ provides the warfighter a superior advanced real-time analysis framework (Figure 11).

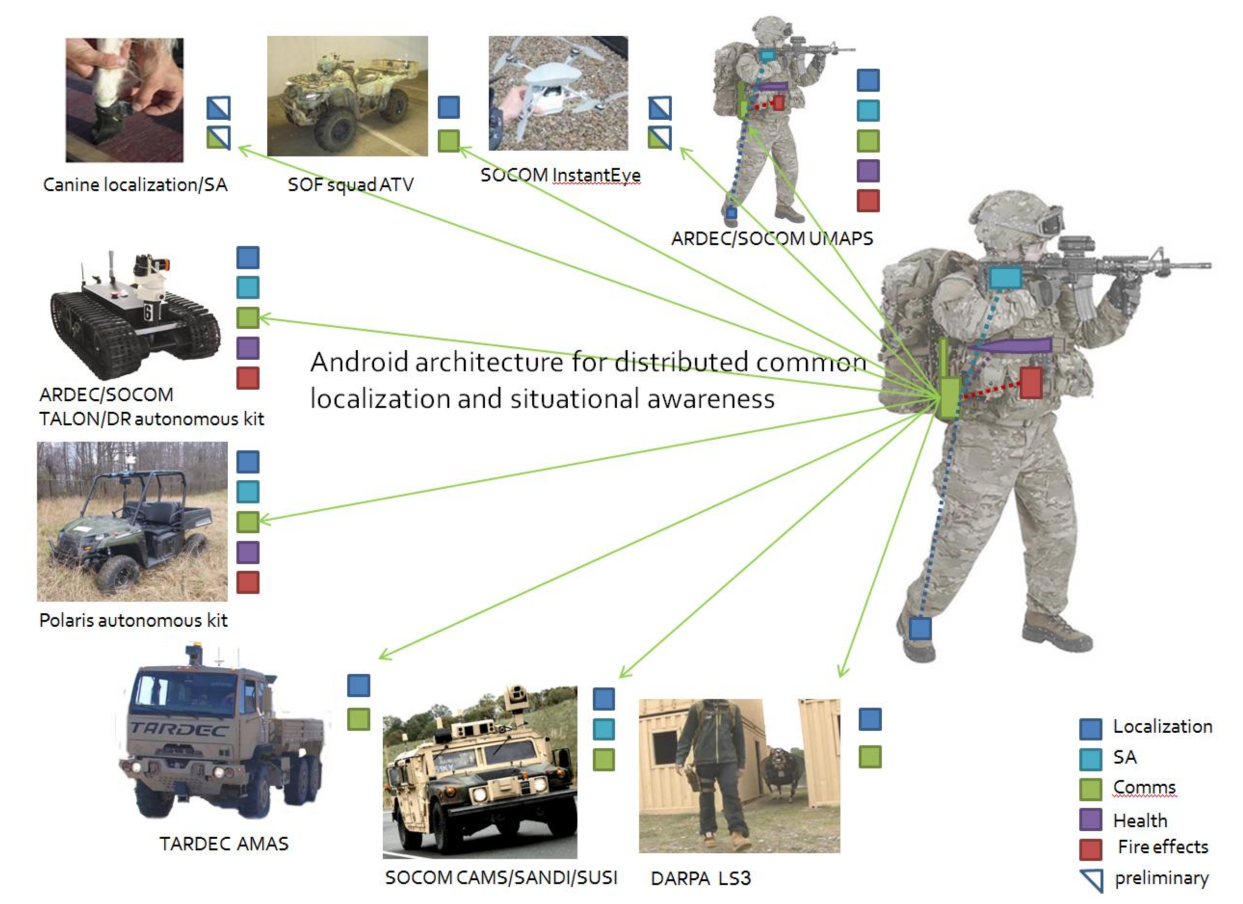

Figure 11. The connected battlespace starts by having common localization, situational awareness and fire-effects tools. Family of Systems in development and testing.