THE BUGS "Basic UXO Gathering System" PROJECT FOR UXO CLEARANCE & MINE COUNTERMEASURES

Christopher DeBolt, Chris O'Donnell, Craig Freed, Tuan Nguyen
Naval EOD Technology Division (NAVEODTECHDIV)
2008 Stump Neck Road
Indian Head, MD, 20640-5070

ABSTRACT:
The objective of the Basic UXO Gathering System (BUGS) is to test, evaluate and demonstrate the use of distributed robotics in clearing unexploded submunitions and minefield neutralization. A team consisting of industry, universities, and the government is working together on the BUGS program. We are concentrating on control methodologies required for multiple, autonomous robots working together to perform a practical and useful mission. The choice of architecture is important in selecting a system that is flexible enough to operate reliably and robustly in an unknown environment. This paper also addresses the current team efforts on the BUGS project.

INTRODUCTION:
The tasks of removing Unexploded Ordnance (UXO) by the Explosive Ordnance Disposal (EOD) technicians put personnel at great risk. The risks are associated with the new technologies used in the submunitions or mines and that these objects have been subject to weather and environment that could trigger detonation at any time. However, practice ranges and other lands that are contaminated by ordnance or mines must be cleared so they can be converted back to more beneficial use. Not only is the cost of training personnel in locating, gathering or disposing the unexploded ordnance enormous but this activity puts the EOD technician in great physical danger.

The main force behind building most robotics systems is to reduce the human presence in dangerous task areas such as UXO clean up and de-mining. The difficulties of performing complex tasks in the real world environment present a challenge for engineers in designing a fully autonomous system. Furthermore, the cost of building a single intelligent robot fully equipped with complex sensor capabilities is too high for use in UXO gathering or mine detection because of the risk associated with equipment destruction. Under the leadership of NAVEODTECHDIV, a team of industry, academia, and the government has been formed to explore the possibility of developing a low cost, easy to use, and simple to maintain system to perform the Explosive Ordnance Disposal (EOD) mission.

The BUGS concept consists of a reconnaissance platform with suitable sensors to detect and locate the submunition or mine from a safe distance, and then a low cost, simple Basic UXO Gatherer (BUG) to perform the Pick Up and Carry Away (PUCA) or Blow In Place (BIP) function. Once the desirable behavior of a single simple robot is obtained, the same architecture can then be distributed to all other similar platforms to create a group of robots to accomplish a practical and vital mission. It is believed the BUG system of cheap, simple robots, operating collectively to accomplish a mission, will be faster, cheaper, and easier to build than a single high cost intelligent robot.

EOD/MCM MISSIONS:
The primary mission considered for the BUGS system is the clearance of scatterable submunitions. The goal is to have a system which can gather a large number of unexploded submunitions to one location that can be disposed of at one time. This is the PUCA procedure that is currently employed in some cases by EOD technicians. The act of disposing (with an explosive charge) a stockpile of UXO items is much quicker than disposing of numerous individual items that are spread out over a large area. The EOD technician will be safer since he will not have to traverse an area littered with UXO to place numerous individual charges, and will not have to handle the UXO's himself. Proximity sensors, tripwires, and the like
are being used more frequently in submunitions, making the EOD technicians task more hazardous. Also, submunitions are cheap to manufacture, large numbers are used at one time, and the low cost is indicative of low reliability, leading to many duds that must be cleared. Small gatherer robots of the BUGS system will perform the most hazardous tasks.

Another important mission that is considered for BUGS is mine countermeasures. For breaching a minefield, the practice of deploying large nets filled with explosives works well, but is not efficient nor does it take advantage of the knowledge of the location of individual mines. This knowledge of locations is being developed by several mine detection technology projects currently underway. The individual BUG vehicles can covertly place neutralization charges over mine targets, and at the appropriate time, a single command from a remote operator can initiate the charges, rendering safe a required portion of a minefield.

**SYSTEM CONCEPT / TECHNICAL APPROACH:**

The BUGS system concept consists of a three phased approach. The first phase is to detect and locate targets to be collected or neutralized. The second phase consists of either reacquiring and gathering the targets, or placing neutralization charges on the targets. The final phase consists of actually neutralizing the targets. The approach of using these three phases, using different assets, will accomplish the desired missions.

The detect and locate target phase is first. A sophisticated sensor platform can be used to perform this task, such as the USMC's COBRA or the Army's ASTAMIDS landmine detection and location systems that are being developed. For targets that are not buried, such as submunitions in the UXO scenarios, a human can perform this task. He can visually detect the targets and record locations with a GPS receiver, or some other local positioning system. NAVEODTECHDIV has recently developed the Remote Controlled Reconnaissance Monitor (RECORD), which is a teleoperated robot with a camera used by an EOD technician to remotely survey a hazardous area for ordnance targets. For the UXO scenarios, RECORD is being automated to autonomously perform an extensive area search, recognize targets optically, and record the target locations.

The second phase is the reacquiring and collecting targets, or placing neutralization charges on the targets. For the UXO mission, the approach is to gather the small submunition targets in a central location. This collection of UXO's can then be neutralized at one time, providing a savings of time and explosives for the EOD technician as opposed to neutralizing each of numerous targets individually. For the MCM mission, the approach is to place an anti-mine munition over each mine target for later simultaneous detonation. The individual BUGs will be loaded with target location information gathered in the first phase. They will then go to the proximity of the targets, individually, and reacquire the targets using low cost sensors. These low cost sensors are being developed under a number of other programs, and the technologies being developed will be inserted into this program. The vehicles to perform the gathering function or placing munition function have to be autonomous and cheap. They must be autonomous to allow the use of numerous vehicles by one operator, to realize time efficiencies. They must be cheap so that numerous vehicles can be afforded, and a few can be replaced in the event that one may be inadvertently destroyed. Small vehicles operating in an area littered with UXO's or mines, and handling explosives, have a probability of being destroyed.

The final phase is the neutralization of the targets. For the UXO mission, this would typically consist of an EOD technician placing an explosive charge on the collection of submunitions, and neutralizing the collection at one time. For the MCM mission, with the anti-mine munitions in place over the mine targets, a command from a standard military transmitter, such as the MK186, can simultaneously initiate the munitions to neutralize all of the mines.

**BUGS PROJECT TEAM:**

The BUGS project is managed by NAVEODTECHDIV, with other government, industry, and academic entities on the team. Several BUG vehicles and a reconnaissance platform are being developed, and computer modeling and simulation is being performed.
Individual BUG Vehicles

For the individual BUG vehicles, several industry contractors have been developing initial concept robots. For this initial phase of the project, the emphasis is on the control system that will lead to expansion into a successful multiple vehicle system.

Draper Laboratory is using an evolution of their MITy-series of vehicles, which is a 6-wheel drive flexible frame micro-rover driven by battery powered motors. Draper's local positioning system is an optical-electrical one, with two tripod-mounted beacons that emit a rotating laser beam. Dead-reckoning is used as a backup navigation and positioning system. Draper also employs an operator station which serves as an automated mission management host. A wide scoop on the front of the vehicle is used for a manipulator.

![Draper Lab's Vehicle](image)

The hierarchical control strategy for the Draper Lab concept is dependent on sensor inputs, too. Sensors are used to detect obstacles and collect information about the world. This requires constant communication of sensor data and vehicle location with a operator station to create a map. The vehicle has two speeds. In the slow mode, it is collecting information from the sensors, which are fully active, and the operator station is creating a map, melding the sensor information with any other map information that may be known a priori. In the fast mode, the vehicle is traveling along paths that have been identified by the operator station as being clear of obstacles. The three critical activities of the operator station are mission management and mission planning, maintenance of target and path maps, and human operator intervention as needed. The operator station performs autonomous mission management and mission planning, and sends four types of commands to the individual vehicles; waypoint-slow, waypoint-fast, collect UXO, and deposit UXO.

The autonomous planning performed by the operator station consists of hierarchical planning, route planning, and road-building. The hierarchical planning decomposes tasks in steps, or levels. At each level, a set of tasks is decomposed into subtasks. The top level controller deals with mission goals, the middle level deals with subgoals derived from the mission goals, and the low level deals with commands to the vehicle. At each level of planning hierarchy, the value of accomplishing tasks is traded off against the cost of consuming resources. An initial plan is repeatedly modified using heuristics in an attempt to generate a plan of maximum expected utility. This simulation procedure is an iterative improvement scheme wherein, for each iteration cycle, the heuristic search attempts to improve on the current solution. The steps of the mission planning cycle are repeated over and over, until the time allotted to the planner for planning has been exhausted, or a point of diminishing returns has been reached. Each level of the planning monitors the performance of the plan and compares it to the performance expected when the plan was created to determine the plan's fitness. When the value of the plan being executed falls below its potential value, the planning process begins anew, and uses the results to modify the plan during execution. An outcome of this process is the identification of "roads", which are used over and over again as the vehicles traverse the field, gathering UXO targets or placing anti-mine munitions.

Foster-Miller is using a vehicle similar to their Lemmings, which is a battery powered, tracked vehicle capable of traversing a wide variety of terrain. It is symmetrical, and is designed to flip over and continue traveling if necessary. It is taller than the Lemmings, since an array of antennae is located on the top and bottom for receiving homing signals. For the initial concept, beacons will be placed on the targets to guide this vehicle. Beacons may also be used to identify waypoints. Radio
frequency transmitted from the beacon is used for the vehicle’s homing from long distances in to approximately six feet. The vehicle recalculates the desired angle of travel, and turns to this angle, every six to ten seconds. Closer than six feet, an array of light emitting diodes on the beacon is used for homing directly, without any time delay in changing direction. A magnet is used to pick-up the metallic targets and carry the anti-mine munition.

**Figure 2. Foster-Miller’s Vehicle**

The Foster-Miller control strategy is quite simple. It is designed to operate in an unstructured environment, and maximizes the mobility potential of the vehicle. Sensors are not used to detect obstacles, and the vehicle is expected to traverse obstacles, or if it gets stuck, it will back up and turn, and continue traveling. If the vehicle flips over, this is acceptable, since the vehicle concept is to operate even if it is upside down, like the Lemmings vehicle. The vehicle’s goal is to reach a beacon. A heading towards the beacon is recalculated every six to ten seconds, and the vehicle makes a turn to that heading and continues forward. In the final configuration, once the beacon is reached, the vehicle will either perform a pick-up function or a drop/place function, depending on the beacon and the mission (either PUCA or BIP). The vehicle would then know which beacon should be approached next. The beacon homing navigation scheme could be replaced in the future with some other type of navigation / location system.

**IS Robotics** is using a variant of their Pebbles III vehicle, which is a small, battery powered, tracked vehicle. A DGPS system is used for location and navigation information. An operator control unit, being developed by ISX, is used to interact with the vehicle. This control unit will serve as a central data collection for the vehicle, a vehicle activity coordinator, and a control interface between vehicle and the operator. A mission for the gatherer vehicle is communicated from the control unit to the vehicle. A joystick at the control unit can be used to tele-operate the vehicle when needed, and a series of “go to” commands can be entered for the vehicle to communicate the target locations. An electro-magnet mounted to an arm is used for a manipulator.

**Figure 3. ISX / IS Robotics’ Vehicle**

The ISX / IS Robotics control strategy is a supervised autonomy, dependent on sensor inputs. Infrared sensors are used to detect obstacles, bumpers detect collisions, and inclinometers measure the slope and roughness of terrain. The individual robots are programmed with a behavior control paradigm. Behavior control facilitates rapid reaction to environmental hazards and robust response to system failures. Multiple independent behaviors compute commands for the robot’s actuators, based on sensor inputs, and an arbitration module resolves conflicts. The robots monitor their own progress and alert an operator if there is an anomaly. As mentioned above, the operator control unit will serve as a central data collection for the vehicle, a vehicle activity coordinator, and a control interface between vehicle and the operator. Constant communication is required between the individual robot and the control unit, transmitting location and status information. A map is maintained of detected obstacles, clear areas, and targets. Constant
communication is also required between the robot and the DGPS base station for precise navigation. Dead reckoning is used as a secondary navigation system, and can be used exclusively, if the DGPS system is unavailable or inoperable.

Ultimately, the operator control unit will plan paths for the robots, based on known obstacles, or locations of obstacles as they become known by other robots in the field and mapped. If an individual robot gets itself stuck, and calls for help from the operator, the operator can tele-operate the robot with a joystick, watching a video display from a camera mounted on the robot.

K²T has designing a new legged, walking vehicle that is being investigated for the BUGS program. This vehicle has eight legs, and is biologically inspired, applying concepts found in the mechanisms of locomotion, manipulation, and neural control in biological creatures. K²T has teamed with Case Western Reserve University for the control system. The first vehicle has just been built, and is now becoming operational. This concept is of particular interest for situations where difficult terrain is encountered. Walking vehicles are expected to have much better mobility than wheeled or tracked vehicles.

NAVEODTECHDIV designed and built a new vehicle for this program. After building legged, tracked, and wheeled vehicles, we decided to develop our control system using a small, battery powered, wheeled vehicle, and uses a DGPS system for navigation, with dead reckoning as a backup system. As an autonomous system, it does not employ an operator’s control station.

The control methodology for this concept is a layered subsumption approach. There are three levels of controllers used. The highest level controller maintains the overall mission goals, and receives and sends data externally, such as DGPS data and remote operator commands, such as initial mission goals, including target locations. The lowest level contains the subsumptive control modules in the sensor controller that generate behaviors in response to real-time sensor inputs, and a motion controller that controls the motors on the vehicle. The middle level controller acts primarily as a data handler, channeling data between the other controllers. Since the vehicle’s response is based on various asynchronous external stimuli, such as navigation, communication, or environmental data, specific modular programs can operate independently. In this way, the specific coordination of the overall behavior is still performed by its central coordinator to achieve this objective. The centralized coordinator is flexible and doesn’t control the robot’s actuators directly or manage tracking and navigating by itself. Instead, the coordinator provides indirect control by selecting among alternate functional modules. Therefore, a combination of simple subsumptive modules with some hierarchical control to prioritize its decisions is used to achieve the vehicle’s mission objective.

A demonstration of the single robot approaches in UXO clearance and/or mine field
neutralization was performed in July 1996 at NAVEODTECHDIV.

Each of these individual proof-of-concept BUG vehicles were put through a test series to collect data that will assist in the evaluation of candidate control systems which will lead to follow-on development of a multiple vehicle system concept. The test series consisted of individual subtask tests, and culminates in a field test with multiple targets which simulates a complete mission for one vehicle. The subtask tests include transit to a location (with and without obstacles), local area search for target, dealing with signal loss (RF and GPS), and picking up target submunitions or placing anti-mine munitions on landmines.

**Reconnaissance Platform**

For the reconnaissance platform, Lockheed is developing an autonomous version RECORM. RECORM is an EOD robot recently developed by NAVEODTECHDIV for initial site survey of hazardous environments. Lockheed is incorporating autonomous search and target classification and location functions to the RECORM for use as a reconnaissance platform for BUGS.

**Simulation**

For hazardous missions or big projects, simulation is important both for safety and financial reasons. In the case of BUGS, simulation is used as a rapid prototype statistical analysis tool and a demonstration tool. The Naval Postgraduate School is performing required computer modeling and simulation of the different BUGS concepts being proposed. Both UXO and MCM scenarios have been developed and are being used to evaluate expected system performance.

The Artificial Intelligence Laboratory at MIT is performing a series of tests to assess different strategies for UXO and mine detection and clearance. In these tests, the amount of central control and communication among individual robots is varied to determine their affect on search and retrieval tasks. These tests are being performed using mobile microrobots which have a suite of sensors, a microprocessor, and a manipulator, and run a version of subsumption architecture.

**SUMMARY:**

This paper discussed the early efforts being taken to develop a multiple robot system to perform a very important task. We believe the subsumptive behavior control is simple and robust enough in its hardware and software structure, that these simple robots can interact in a complex and unpredictable world. The future work area of group behavior in performing a mission is interesting and challenging. While no promise can be made, we believe that if we implement a system that is adaptive and robust in hardware and software, then the cooperative behavior of robot groups will allow us to perform practical missions in real world environments.

**REFERENCES**


