

## **Lessons Learned in UXO Range Remediation with Robotic Applique Kits Installed on Leased Heavy Equipment**

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### **Abstract**

Converting vehicles from conventional manned operations to unmanned supervised operations has been slow to adoption in many industries due to cost, complexity (requiring more highly skilled personnel) and perceived lower productivity. Indeed, hazardous operations (military, nuclear cleanup, etc.) have seen the most significant implementations of robotics based solely on personnel safety.

Starting in 2005, the U.S. Army Corps of Engineers (USACE) has assumed a leading role in promoting the use of robotics in unexploded ordnance (UXO) range remediation. Although personnel safety is the primary component of the USACE mission, increasing productivity while reducing overall cost is an extremely important driver behind their program. To achieve this goal demands that robotic range clearance equipment be affordable, easy to install on rental equipment, durable and reliable (to minimize down-time), low or no maintenance, and easy to learn / operate by the same individuals who would normally be performing these operations manually.

This paper concentrates on one of the important developments of this multi-faceted program. The implementation of Applied Research Associates (ARA) Modular-Robotic Applique Kits (M-RAKs) on CAT 521b Tracked Feller Bunchers and their deployment on a USACE range clearance project at Fort Bragg, NC over the past year. The discussion focuses on the challenges and practical lessons learned when remotely operating forestry equipment for extended periods with changing operators, including implementing user feedback to improve the M-RAK technology. Included is a discussion of the challenges encountered when remoting forestry equipment, including the potential for damaging components of the system, the operation of complex jaws, saws, and grinders, and RF communication issues when working behind trees. The paper also considers the impact of robotics on meeting objectives for improved productivity from the perspective of the USACE. Finally, we present future plans for expanding the application of robotics in UXO range clearance and remediation operations.

### **Background**

Live fire exercises are a standard and necessary component of U.S. military training and readiness. Decades of live fire training has, however, created an ever accumulating problem of left-over UXO on training / practice ranges. As the requirements of the ranges change over time, and more on-the-ground training and construction are required to meet the new requirements, the USACE is called in to handle the necessary pre-construction clean-up.

Although range clean-up has been going on successfully for decades, the USACE is working to improve safety, reduce cost, and reduce schedule by piloting Military Munitions Response Program (MMRP) contracts with a requirement to use robotics to the maximum extent possible. Achieving these improvements with robotics is possible because the work of a standard Explosive Ordnance Disposal (EOD) team is so exacting - requiring a significant number of team members with rigorous measures to keep them safe - making *rapid* clean-up nearly impossible.

Under an initial MMRP robotic effort at Ft. Bragg, NC, the USACE and ARA “roboticized” three tracked Feller Bunchers and operated them remotely to clear trees from a heavily used artillery range slated for re-configuration as an Aerial Gunnery Range (AGR). As described in the section that follows, remoting was accomplished rapidly and cost effectively by installing ARA M-RAKs on rental Feller Bunchers.

### **Robotic Applique Kits**

The robotic applique kit is a technology that transforms regular vehicles into remotely controlled or semi-autonomous robots. These kits are typically employed when operators face tasks that are dull (repetitive and “exacting”), dirty, and/or dangerous. Felling trees in an area covered in UXO certainly qualifies as a task meeting all of those criteria, and is therefore an excellent initial application for robotics in range clearance.

The ARA M-RAK used in the USACE MMRP pilot program is an affordable robotics solution that leverages the CANbus technology employed in many modern forestry and earthmoving vehicles, including the CAT 521b Feller Buncher. ARA works with the OEM vehicle manufacturer to create custom firmware that allows motion commands that normally come from the sticks, pedals, or buttons on the platform to instead originate from the robotics kit’s operator interface.

Shown in Figure 1, the latest generation ARA M-RAK comprises a compact Platform Base Controller (PBC), a Tele-op module (which includes a radio transceiver), a vehicle-specific adaptation kit (not shown), as well as up to 8 analog or HD video cameras mounted on the unmanned vehicle. At the remote operator station is a Base Station (radio transceiver), Operator Control Unit (OCU – a laptop computer with an X-box controller), and an independent Emergency-Stop module (E-Stop) that enables the operator to immediately shut down the platform and tools in the event of an emergency. Installation of the M-RAK transitions vehicles to an ‘optionally-manned’ configuration, allowing operators to swap between remote and manual control of the platform with the flick of a switch. The kit cost ranges from \$40k to \$80k, depending on the specific vehicle adaptation kit required and the camera configuration. As discussed below, this is a very affordable price point that can be recouped quickly with even modest improvements in productivity.



**Figure 1. ARA's M-RAK converts any vehicle into a remotely controlled platform. Clockwise from bottom left: Platform Base Controller (PBC); Tele-op module (with a bullet camera on the top right); Operator Control Unit (OCU) computer with X-box controller; two pan-tilt-zoom camera options; Base Station; and E-Stop (two smaller black modules – the one without the red button is mounted on the vehicle).**

For the USACE, M-RAKs were installed on three CAT 521b Tracked Feller Bunchers for the purpose of felling primarily pine trees in the surface clearance area (Figure 2). A critical feature of the 521b is the complete integration of CAN control from the CAT factory. Every motion, from hot saw to the ignition switch creates a CAN signal that is relayed through the onboard engine control unit. Thus, implementation of the M-RAK did not require a vehicle adaptation kit, actuators, or other special hardware to operate the vehicle remotely. This, in turn, represents a lower cost version of the M-RAK (<\$50K).



**Figure 2. M-RAK controlled CAT 521b Tracked Feller Buncher clearing pine trees on a heavy artillery / helicopter range at Ft. Bragg, NC.**

The pilot project at Ft. Bragg has proven highly successful. The most significant time and cost savings attributable to the use of robotics was related to labor. During the hot summer months when much of the work was performed, the field clearance personnel (Feller Buncher operators or individuals with chain saws) would have worked as little as 15 minutes of every hour under OSHA regulations. Operating remotely from an air conditioned trailer, there was no loss of productivity using robotic tele-operation. Improved efficiency was also realized with robotics during inclement weather. Overall, this contract called for the clearance of 1000 acres of trees, and the work was completed in just 9 months. The contractor operating the robotic equipment and performing the EOD field work estimated an additional 6 months would have been required if the robotics were not available.

## Training

Training operators to remotely control heavy equipment involves training them to make effective use of the equipment while working within the constraints of the robotics OCU graphical user interface (GUI, Figure 3).



**Figure 3. The User Interface for all M-RAK applied vehicles is largely the same, minimizing training time.**

The M-RAK GUI provides the operator with all of the data he would normally have available in the cab, but with the added capability of having up to 4 camera views configured any way the operator chooses, as well as a map of the clearance area. The effectiveness of the GUI is really determined by the camera placement on the platform. ARA incorporated feedback from the users early in this project by adding a capability to arbitrarily arrange views, and name both the cameras and the view configurations to improve the efficiency of operations. This also allowed the operators to easily track the cameras as they re-positioned them around the platform to optimize the configuration for their specific tasks.

A majority of integrated platforms, including the 521b, operate with twin sticks. Therefore, these controls are mapped to the twin sticks on the X-Box controller (Figure 1) to ease the transition to remote control for the operators. Similarly, controls that are operated from button presses on the sticks are mapped to the face buttons of the X-Box controller. Finally, functions you would not want to accidentally execute such as the keyswitch, starter, and the throttle are 'protected' by having to hold the right 'cap' button while also selecting the activating button (A for the key switch, B for the starter, or left trigger for throttle). It takes a standard operator about one day to become familiar with the controls and how the vehicle moves with their input. Depending on user skill, the control actuation can be slowed down during the initial training day. For the 521b operators, it took about two weeks for them to achieve 90% of their manned production efficiency as unmanned operators.

### **Challenges**

The M-RAK can typically be installed in a vehicle in 30-60 minutes, depending on the camera layout and cabling runs. This set-up time, which was demonstrated multiple times in the course of this project, is essentially inconsequential as it relates to schedule and cost on typically large, multi-month range clearance jobs. One significant challenge we encountered, however, was related to manufacturing changes that occurred within a model year of the CAT Feller Buncher. As it turned out, in one model year CAT produced three configurations of fuel tank, and two configurations of rear window. Prior to delivery of the three M-RAKs, ARA worked with a local CAT dealer to fit the kit, and design specific brackets and guards to keep the kit safe for a year of forestry work. Specifically, the kit exploited bolt locations from the rear window for mounting. It came as a surprise when we arrived on-site for installation to find three MY15 521b Feller Bunchers that were significantly different from the one to which we had designed. In one case, a mounting location was blocked by a re-located fuel cap, and in another case the rear window and its bolts were completely absent.

This vehicle configuration challenge quickly brought to light two important realities: the 521b's were rental equipment, and the politics of CAT dealer rental agreements are complex. We were able to resolve the mounting issue by getting permission to drill and tap mounting holes in the rental Feller Bunchers, but not before navigating the complexities of the CAT dealer zip-code exclusivity clause of the rental agreement. The 521b's belonged to the New England CAT dealer Milton CAT. However, the NC work site was in the territory of local CAT dealer Gregory Poole CAT. Gregory Poole CAT was uninterested in the robotics job due to the perceived risk, insurance needs, and complexity of the job, and therefore allowed Milton CAT machines in their territory. This is not unusual, but it requires renters to use the service of the local CAT dealer. Thus any call to Milton CAT for service had to first go through Gregory Poole CAT.

A second challenge came when introducing the service needs of the robotics to heavy equipment operators. These operators are very familiar with the issues that may arise during regular

equipment use such as: hydraulic hose leaks, cylinder seal leaks, and damage to the teeth on the hot saw or mulching heads. However, they were not prepared for the challenges associated with diagnosing RF communications issues. The system was designed for about 2 mile line-of-sight radio performance. Taking into account the reality of working behind a row or two of trees, the maximum range was approximately 1.2 miles.

On a nearly weekly basis early in the project, operators wrestled with radio connection issues. Universally, these problems were related to RF components. After ARA fielded numerous calls requesting support due to poor communications it became very clear that the operator training given at the outset of the project did not adequately cover basic troubleshooting of the RF M-RAK components. Consequently, ARA held a special on-site training session for the operations team addressing the following four issues:

1. Undercharged Base Station battery (i.e., did they neglect to charge it overnight?)
2. Bad connection between the OCU laptop and the base station radio (defective or poorly connected Ethernet cable)
3. Damage to the command trailer RF cables and antennas
4. Damage to the RF cables and antennas on the vehicle

The RF equipment used in non-forestry robotics work has typically lasted a year or more without damage. However, in this forestry application where trees frequently crash into the vehicle, the figure is closer to a week or two. The aforementioned RF troubleshooting training, coupled with our lesson learned about the lifetime of the antennas and cables was programmatically codified into a spare parts tracking partnership between ARA and the prime contractor operating the robotic vehicles. Analysis conducted at the end of the project indicated that vulnerable exterior components had a lifetime of about a week at the beginning of the project, and about three weeks by the end of the project. We attribute the increased lifetime to the improved skills of the operators (i.e., not having trees fall on the vehicle as often) as well as implementing a better antenna mount (Figure 4).



**Figure 4. The antenna on the top right of the vehicle cab was mounted on a floppy spring, allowing direct hits from trees to easily deflect the antenna boom without causing antenna or cable damage.**

The last challenge of note was maintaining the depth perception required to successfully operate a complicated machine such as the CAT 521b (e.g., quickly and accurately grabbing a tree trunk). To achieve this, one might first look to employ more advanced sensors or display strategies, such as lidars, stereo cameras and virtual reality headsets. However, with the survivability of externally mounted sensors (cameras) so low, such an approach would prove very costly to implement. The more practical solution was to provide an entirely mobile camera set-up. Our cameras were very low cost, and magnet mounted to allow the operators to experiment with different mounting locations by simply sliding the camera off, and sticking it elsewhere. Most operators eventually gravitated to a camera configuration that provided a “top down” view of the cutting head, along with a more oblique side view of the head, displayed in a split screen at the OCU. This configuration gave the operator a similar view as that from the cab, but also a better view of the “depth” of the cutting head (i.e., distance from a tree trunk).

### **Summary and Conclusions (Lessons Learned)**

This pilot USACE MMRP project made clear the rugged nature of forestry work (tree felling) and the challenges that poses to robotic operations. Forestry equipment tends to be complicated, with highly skilled operators manning the sticks; even so, damage is a common occurrence. Situational awareness for Feller Buncher work is extremely important to avoid down-time and maintain productivity; as such, ARA had to adapt by providing easily movable cameras and supplemental training to the operators. Additionally, a spare part tracking system was

implemented to ensure adequate spare parts were available to minimize down-time. Critical to the success of the effort were the following:

- A simple user interface that closely resembled the in-cab user interface to minimize operator learning time
- Training that included troubleshooting RF issues that were not anticipated prior to the effort
- Maintaining good working relationships with the equipment rental companies, the prime contractor, and the on-site equipment operators
- Soliciting and acting on operator feedback to make modifications that improve user efficiency

The ultimate measure of success for this project was the work being completed many months ahead of schedule, due mainly to the ability of the operators to work more efficiently in remote mode. The relatively low costs for M-RAKs, M-RAK replacement parts, and operator training were minimal when compared to the overall savings realized by the improved operational efficiencies.