Work in progress: Robotics mapping of landmine and UXO contaminated areas

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Abstract—Explosive remnants of war like landmines and unexploded ordnance (UXO) are a serious threat in post conflict environments around the World. Aside from the killing and injury of many people the landmines and UXO have a significant impact on the local economy due to inaccessible roads and loss of fertile agricultural areas.

The Biosystems Engineering Groups at the University of Southern Denmark and Aarhus University, Denmark, have developed several autonomous terrain robots for use in semi structured and unstructured dynamical environments. This article presents a work in progress applying the knowledge and experience from the agricultural plant nursing robotics domain to demining applications.

The aim is to have a reliable, efficient and user-friendly autonomous robot capable of mapping as well as visually marking detected landmines and UXO within a bounded area. The operator specifies the area boundary by steering the robot along the perimeter using a simple and intuitive remote control, and the robot will then perform a complete coverage of the bounded area. The robot is considered a tool carrier and as such it may utilize various mine detection implements like for instance the Wide Area Detection System (WADS) developed by the organization Danish Church Aid.

Current status of the project is that the first autonomous area coverage tests have been performed successfully using Casmobot, a tracked mower platform capable of working in rough terrain including steep slopes. An improved modular platform design with ample room for a mine detection implement is almost finished and will form the base for further experiments.

The area coverage algorithm is being improved to handle static and dynamical obstacles as well as slopes. Detection of obstacles will be performed using a 3D laser range scanner and possibly stereo vision. Current pose estimation is based on a dual RTK-GPS unit, but a gyro will be added to improve the driving precision. Software components will be released as open-source for others to build upon.

Index Terms—humanitarian demining, mobile robotics, WADS

I. INTRODUCTION

ANTI-PERSONNEL landmines and explosive remnants of war (ERW) are a threat to the life and livelihood of many thousands of people in many parts of the world. ERW include unexploded ordnances (UXO), which are explosives like grenades, mortars, cluster munition etc. that have failed to detonate as intended. Aside from the killing and injury of people, the landmines and UXO have a significant impact on the local economy due to hindered access to water points, schools etc. and loss of fertile agricultural areas.

No one knows how many landmines and UXO remain uncleared, however The Landmine Monitor[1] recorded 3956 casualties from mines, victim activated improvised explosive devices (IED) and other ERW in the year 2009. Civilians made up 70% of all casualties for which the civilian/military status was known, and children made up 32% of all casualties for whom the age was known. 66 states and 7 areas not internationally recognized are confirmed or suspected to have contaminated areas.

Humanitarian demining are activities leading to clearance of landmine and UXO hazards that poses a threat after the conflict has ended. The aim is the identification and removal or destruction of all hazards, from a specified area to a specified depth to ensure the land is safe for land users[2]. The removal or destruction of a landmine or UXO hazard is a relatively simple process once the location is known, however the critical problem is detecting the precise location of a hazard and ensuring that all hazards within the area have been identified.

Mine clearing is typically performed by a deminer segmenting the area into marked lanes. He is then working his way along the lanes using a metal detector or prod-der. When a possible target is detected, he excavates it and in case of a landmine or UXO it is either removed or destructed on site. The mine clearance speed appears to be 3 to 20 square meters per deminer per day depending on the terrain and level of metal contamination[3]. Newer mine types contains little metal and hence require a much more sensitive metal detector. This leads to a lot of false positives which slows down the speed significantly as all potential targets need to be inspected carefully[4].

The idea of using a mobile robot fitted with a mine detection sensor to achieve a faster and more reliable coverage of the area is not new, and a number of robots have been developed and tested the past years. While none of them seem to have reached production on a larger scale, many lessons may be learned from the projects.

[5] describes the problems and challenges of robotics applied to demining and gives a number of recommendations based on lessons learned. [6] analyses some most important characteristics that should be taken into consideration in building the robotic demining vehicle. [7] gives a state of the art overview of mobile robotics for humanitarian demining as well as recommendations on sensor technology, robot control, navigation etc. [8] surveyed the robots and search methods for landmine detection over the last decade and describes the problems involved, some of the issues
that have been overlooked, and stresses certain guidelines for future robot design. [9] gives a review and status summary of detection technologies that could be applied to humanitarian demining operations. [10] made a performance comparison between manual sweeping and a teleoperated robotic system and concluded that remotely operating a mine detector is technically very feasible, and does not affect the detection rate negatively. [11][12] explore the idea of using common agricultural machines as demining robots.

It is hypothesized that using an autonomous robot for mapping detected landmines and UXO within a bounded area is more efficient and more reliable than manual detection methods using the same sensor technology. At the same time it does not put the operator to the risk of harm.

The aim of this project is to have a reliable, efficient and user-friendly autonomous robot capable of mapping as well as visually marking detected landmines and UXO within a bounded area. The robot is considered a tool carrier and as such it may utilize various mine detection implements.

A. Background

The landmine and UXO contaminated areas vary from reasonable flat open areas to quite rough terrain with slopes, rocks, trees, bushes and other obstacles. The surface vary between soil, various types of sand, gravel and stones which depending on the climate may be either dry and dusty, muddy or even partially covered with water. This terrain puts high demands on any vehicle operating in the area, and some areas will be almost impassable by a vehicle.

Many of the areas are located in countries having a poor infrastructure with respect to logistics, availability of materials, machine shops etc. Therefore challenges such as transportation of the vehicle to the area of operation and availability of fuel and spare parts needs to be taken into account. It is also of great importance that any technology introduced is accepted by both the authorities and the local residents. The people and hence available labor often have only minimal formal education, and skilled technicians may be quite difficult to find.

B. Robotic platform

Considering the challenges mentioned above it makes little sense to base a humanitarian demining robot project on one of the traditional robotic research platforms usually available at the universities. A better solution is to look at the agricultural and forestry industry, where the development of tool carriers have evolved for decades enabling some of them to work under these tough conditions. Potential candidates seems to be remote controlled slope mowers like the Spider ILDs from DVOŘÁK Machine Division [13] or similar systems on tracks from Lynex [14]. McMurtry Ltd. has developed a high capacity autonomous mower, MAS05, for relatively flat grass areas. The operator drives the machine to the field or area to be maintained and guides it around the perimeter in installation mode. Permanent obstacles such as power poles or irrigation points within the working area are marked in the same manner to identify their positions. Once the mower has this information it is capable of cutting the grass within the perimeter autonomously. This approach seems applicable to detection of landmines and UXO.

C. Mine detection implement

Wide Area Detection System (WADS) is developed by the organization Danish Church Aid (DCA), who became involved in humanitarian mine action in the mid 1980s and started running operational demining projects in 1999. Today DCA has carried out demining projects in Albania, Angola, Burundi, DR Congo, Sudan and Denmark (Skallingen). In 2010 WADS was accredited as compliant with IMAS 03.40 Test and Evaluation of Mine Action Equipment by The United Nations Mine Action Office (UNMAO) in Sudan and can thus be used to mark an area as free of landmines and UXO [15].

WADS has been used as a portable setup (Fig.1) as well as mounted on a vehicle (Fig.2) and uses one or more commercially available field tested metal detectors as the mine detection sensor. Output from the metal detectors are continuously sampled and saved on a laptop along with the current position measured using Differential Global Positioning System (DGPS). Fig.3 shows a diagram of a typical WADS setup.

The sensor used in WADS is the Ebinger UPEX 740M Large Loop UXO Detector which uses the pulse induction principle to detect the metal components in UXO. Pulse induction metal detection in general allows detection of deeper targets but less discrimination between different types of metal. The discrimination problem may be remedied by adding magnetometers which only detect magnetic metals. The UPEX 740M is intended for fast search of large areas, it allows an adjustable search head diameter,
it is rugged and waterproof and it has been used in humanitarian demining projects in a number of countries. The UPEX 740M outputs an analog voltage corresponding to the amount of metal detected.

After performing an area survey the saved data is post processed as listed in Fig.4. The output is a color contour map of the area as shown in Fig.5 and a list of target coordinates. A deminer then visits all target coordinates and performs a manual sweep in a radius of 1.5 meter from the target center.

II. Suggested Humanitarian Demining Robot

A promising solution is a relatively small and lightweight vehicle on tracks which may be transported on a 4wd pickup truck or a regular sized trailer. A very simple mechanical design and a modularized setup allows easy repair or replacement of defective parts. Making the mine detection module dismountable from the robotic tool carrier will allow the module to be utilized for hand carried operation at locations inoperable by the robot. It is important that the robot operation is very simple and intuitive allowing local deminers to perform the operation with a minimum of training.

The field robot is considered a tool carrier and as such it may utilize various landmine and UXO detection implements using different detection technologies like metal detection, magnetometers, ground penetrating radar, explosive vapour detection [4], mine raking [16] etc. Due to the ability to carry multiple implements the robot is also capable of utilizing multi-sensor technologies [9][17]. The theory of UXO detection methods and principles is outside the scope of this project however, instead the existing WADS designed for portable and vehicle use has been chosen for testing the robotics mapping system.

Adaptation of WADS for use as a mine detection implement on a robotic tool carrier requires only a few modifications, Fig.6 shows an overview of the system. The robot acquires data from WADS and dynamically updates a map based on WADS data and the estimated robot position and orientation. The map contains information about mine detection coverage, detected targets and impassable obstacles.

A visual marking implement allows optional spray paint marking of the surface where a target has been detected. The spray paint is similar to what is used for marking football fields. The visual marking serves as additional safety to the deminer who performs manual sweeps based on the list of target coordinates.

III. Operator Interface

Using a remote control the operator controls all operation modes and settings of the robot. For this project a Nintendo Wiimote has been selected as remote control unit. While the Wiimote may not be considered reliable, safe or even suitable for the harsh environment, it serves as a good demonstration of how simple and intuitive remote
controlling a humanitarian demining robot can be. Field test have shown that the robot can easily be Wiimote controlled at a distance of more than 50 meters.

The robot has been programmed with three operation modes viewed in Fig. 7. Start up time is less than one minute allowing the robot computers to boot and the GPS to obtain a satellite fix. The operator switches cyclic between operation modes by pressing a button. The current mode is visually indicated on the remote control.

**Manual driving** is used for driving the robot to and from the area. The operator controls the robot speed by tilting the remote control forward and backward. Turning is controlled by tilting the remote control to the sides. A button under the remote control serves as a dead-man’s button, unless pressed the robot will not move. A button on top of the remote control activates “precision driving” causing the robot to drive slowly which is ideal for e.g. parking the robot on a trailer.

**Assisted Mapping** works like manual driving from the operators point of view. However the robot actively acquires data from WADS and updates the map with information about area covered and detected targets and obstacles. Attempts to remote control the robot to drive fast over rough terrain causing the robot to vibrate, drive backwards over terrain not previously covered by the WADS, drive close to obstacles or drive across detected targets are prevented.

**Autonomous Mapping** allows the operator to specify boundaries of the area to be mapped by driving the robot along the perimeter using Assisted Mapping mode. He then places the robot at the desired start location and turns the robot to the desired direction of driving. The robot will now autonomously cover the entire area within the perimeter as shown in Fig. 8 and map all targets. When the robot detects a target, it will replan the route to avoid overpassing the target area.

The operator has access to an updated list of target waypoints and a map showing coverage and detected targets. The information can be accessed through a built-in web server by connecting to the robot wifi network using a laptop, a tablet or a smartphone. The map is formatted as an image and the list of target waypoints is formatted as text (CSV), GPS Exchange Format (GPX) and Keyhole Markup Language (KML). Another way to access the information is to insert a USB memory stick into the robot Autonomous Task Computer. Updated versions of the files will then be written to a directory on the USB memory stick.

The robot has a set of advanced settings which should only be modified by a technician. They may be updated by inserting a USB memory stick with an updated configuration file. The settings include:

- Maximum driving speed
- Minimum sensor overlap between two lanes
- Allow the robot to overpass detected targets
- Visual marking on/off
- Audible signals on/off
- Robotic Tool Carrier parameters
- Mine Detection Implement parameters
- Visual Marking Implement parameters

**IV. ROUTE PLANNING**

Area coverage route planning for the autonomous mapping operation mode is based on the algorithm described in [18].

Fig. 9 illustrates the main steps of the algorithm. The waypoints recorded during the drive along the perimeter of the area are considered vertexes in a polygon describing the area boundaries. Linear segmentation is applied to the list of waypoints to reduce the number of vertexes, this smoothens the data and reduces computational load. Using the coverage map generated during the drive along the perimeter of the area and the robot geometry the configu-
ration space of the polygon is then calculated. If necessary
the configuration space polygon is decomposed into locally
convex polygons before generating a single route plan. The
route plan is then checked for complete coverage.

V. ROBOTIC TOOL CARRIER

For this project it was chosen to base the field experiments on a slope mower vehicle, Casmobot (Fig. 10), used
in previous research. Casmobot is an acronym for Com-
puter Assisted Slope Mowing Robot. It was developed by
the University of Southern Denmark as part of a plant
nursing robotics project with the purpose of automating
mowing of large sloped grass fields. The goal was to im-
prove efficiency as well as labor ergonomics for the opera-
tor.

Casmobot is based on the commercially produced
tracked mower platform Lynex which due to its center of
gravity only 26 cm above ground is capable of working in
rough terrain including steep slopes up to 75 degrees incli-
ation. The transmission is hydraulic driven by a 22 hp
gasoline engine. The width of the vehicle is 153 cm and
it weighs 295 kg [14]. It can easily be transported on a
standard trailer or pickup.

Within the plant nursing robotics project a robotic
mower module was developed. It enables the operator to
perform the mowing semi-autonomous as opposed to man-
ually remote control. A simple and intuitive user interface
and two mowing operation modes similar to autonomous
mapping were implemented. Based on the knowledge and
experience obtained in this project an evolved version of
the Casmobot vehicle, named Armadillo, has been devel-
oped.

The mechanical platform for the Armadillo robotic tool
carrier vehicle (Fig.12) has emphasis on modularity, im-
proved ground clearance and better efficiency in the pow-
ertrain motor and transmission. Each of the Armadillo’s
two track modules, seen in Fig.11, can be regarded as self
contained propulsion modules, with on-board electric mo-
tor, motor controller and gearbox.

This gives rise to a flexible vehicle platform where track
modules, and the supporting hardware such as battery
pack’s and robot computer, can be mounted in different
configurations favouring e.g. weight distribution or other
requirements of the implement that must be carried.

Each track module is powered by a 3.5kW brushless DC
motor. With a 1/25 gear ratio, which gives a top speed of
7.4 km/h and an expected 25% loss in the powertrain, one
track module can deliver 1kN continuous thrust and up to
1.7kN thrust in 30 second bursts.

Currently the Armadillo carries two exchangable 48V
100Ah battery weighing 150kg each. The battery packs are
based on deep-cycle lead-acid batteries supporting a 50%
discharge. This gives the Armadillo 40 minutes of worst
case operating time at maximum continuous power. In nor-
mal operating conditions, where a vehicle with two track
modules have to overcome a dynamic friction of 500N, an
effective operating time of 2.6 hours can be expected. With
additional battery packs ready and charged, the vehicle
can be operational as long as desired. Each battery pack
can be recharged in 4.5 hours. More advanced and ex-
pensive battery technologies, such as Lithium-ion, will im-
prove performance in terms of weight and operating time
per charge.

Mechanical adaptation of WADS for use as implement
on the Armadillo requires only a few modifications. A
metal-free frame supporting the sensor loops constructed
with brackets for mounting in front of the robot is needed
(Fig.12). As the detector loops are very sensitive to
nearby metal and electromagnetic disturbances they must
be placed away from the robot. The exact distance needs
to be determined experimentally. Important mechanical
design considerations are the ability to drive in uneven
terrain with the frame mounted, and optional dismount-
ing of the frame allowing manual hand carried operation
of WADS.

VI. ROBOT COMPUTER

FroboBox (Fig.13) is a ruggedized and waterproof com-
puter that has been developed for use as field robotic ve-
Fig. 13. FroboBox robot computer

Fig. 14. FroboMind conceptual architecture fitted for Armadillo and WADS

The FroboBox provides commonly used interfaces such as CANbus, USB, RS232 and Ethernet. It is based on a PC/104 motherboard with an Intel Core 2 Duo processor and 2 GB RAM, and runs the Debian GNU/Linux operating system. The FroboBox can be powered directly from an unregulated battery power source, and can provide regulated voltages of 5V and 12V to the attached sensors. It contains a WiFi hotspot with optional internet connection via 3G wireless broadband, which enables wireless local and remote monitoring and programming.

VII. AUTONOMOUS ROBOT ARCHITECTURE

The robotic tool carrier system architecture for the armadillo demining robot is based on the Field Robot Cognitive System Architecture (FroboMind) [19] (Fig. 14). An open source implementation of the FroboMind architecture is currently being developed utilising the open-source cross language robotic framework Robot Operating System (ROS) [20].

By utilising the ROS method of structuring the software, each level of abstraction listed in the conceptual architecture of FroboMind is created as a ROS package which is the main unit for organising software in ROS. Each package contains ROS processes (nodes) as well as source code and ROS specific files. Besides the packages defined by the architecture, two packages containing ROS core functionalities and one package containing lowlevel interface drivers (CANbus and serial communication) are implemented. These packages are collected in a ROS stack named FroboMind. ROS stacks are collections of packages that provide aggregate functionality, in this case the abstraction levels of the FroboMind architecture as well as lowlevel interface drivers.

The implementation of the lowlevel interface drivers ensures a reliable communication link between the FroboBox and the sensors used by the WADS carrying Armadillo demining robot. Furthermore the modularized setup, with the well defined relations between the different components, does make sure that it is possible to reuse components in other applications.

VIII. DISCUSSION

Below is a list of some of the advantages and disadvantages of using an autonomous robot for mapping detected landmines and UXO within a bounded area:

Advantages
- Robotic mapping based on position estimation of the mine detection implement allows accurate identification of the location of potential targets to the extent of the accuracy of the mine detection implement. The implications of human errors are kept to a minimum.
- A robotic tool carrier allows simultaneous use of different mine detection sensor technologies which has a great potential of increasing the accuracy and reliability of the detection of targets.
- When using a robot the operator is able to keep the required safety distance to the area of operation and is not in danger in case of an uncontrolled explosion.
- The robot allows visual marking of detected targets. This lowers the risk of the deminer accidentally triggering an identified target when entering the area to perform manual sweeps.

Disadvantages
- Robotic mapping is costly compared to manual operation of the mine detection sensor. Additional costs are the price of the robotic vehicle, fuel, spare parts, logistic transport of extra equipment etc. These additional costs needs to be balanced with the higher efficiency, reliability and safety of the operator.
- Some of the areas contaminated with landmines and UXO are practically inaccessible by robotic vehicles and definitely inoperable when using a mine detection implement. This problem can to some extent be mitigated by the vehicle design, actuation of the mine detection implement so it stays clear of the ground when driving and designing for optional dismount of the equipment for manual detection.
- A robotic vehicle suitable for driving in rough terrain carrying a mine detection sensor by far exceeds the maximum ground pressure allowed for safe target overpass. This requires modification of the route plan each time a new target is identified.
IX. CONCLUSION

This article has presented a work in progress applying the knowledge and experience from the agricultural plant nursing robotics domain to build a reliable, efficient and user-friendly autonomous humanitarian demining robot. The existing slope mower platform Casmobot was used to perform the initial experiments. The vehicle design fits the application well, but the platform has limited options for mounting mine detection equipment, and due to the engine mounting the chassis also vibrates rather much.

The robotic tool carrier Armadillo is currently being built and is expected to be ready during the summer 2011. It is highly modularized and can easily be applied to this project. Still some of the design solutions concerning driving abilities and weight could be optimized if targeted directly towards demining applications.

The next project milestone is to perform a successful autonomous trial resembling the one used for the WADS IMAS 03.40 accreditation as close as practically feasible. This first trial assumes that obstacles have been removed from the area and that target overpass is safe.

Steps further ahead are to include obstacle detection using a 3D laser range scanner and possibly stereo vision, dynamical route replanning based on detected obstacles and targets, active leveling of the WADS frame with respect to the ground when driving in uneven terrain and visual marking of detected targets.

Design documents and source code available from the project will be released as open source for others to build upon.

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