A robust, simple, low-cost autonomy enhancement module for LOCOSTRA, a remotely controlled demining machine

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Abstract

The paper gives a short description of LOCOSTRA project and introduces the most recent work done within the project – the robust, simple, low-cost autonomy enhancement module. LOCOSTRA (LOw-COst TRActor for Humanitarian Demining), a remotely controlled, armoured demining machine[5] is the output of an eighteen months project co-funded by the Italian Ministry of Economic Development and the Italian Institute for Foreign Trade and coordinated by the University of Genova. The autonomy enhancement module is part of a recent work undertaken in order to upgrade the LOCOSTRA remote control system. Using easy available components we have created a fully operating system which satisfies the principal requirements of reliability, low cost, and ease of future upgrade. The autonomy enhancement module introduces new important functions to the control system such as the supervision of the safety of the machine's operations and remote control assistance and provides a suitable base for further development of the remote control system.

1. Introduction

Most countries affected by landmines have suffered protracted conflict and Humanitarian Mine Action occurs alongside post conflict reconstruction and development within the constraints of a weak economy. Removing all Explosive Remnants of War (ERW) from a country can take decades and the national economy is often unable to finance such a long-term commitment. The need for the adoption of sustainable demining procedures and tools, and the need to transfer of demining and managing skills to local entities, is now widely acknowledged throughout the HMA community.

In many cases, high purchase and maintenance costs prevent demining organisations from using machines to assist their manual demining endeavours. Sometimes machines are donated by governments but there are many cases of such machines being underutilised because of the lack of spare parts and expertise needed to keep them running. Many were also not designed for practical use in the field.

The use of machines to assist manual demining and make it safer is limited by the following factors:

- High purchase price;
- High running costs (in terms of fuel and fluids);
- High cost of spare parts;
- Limited availability of spare parts;
- High complexity of maintenance and operation.

Exceptions occur when mature agricultural or plant machinery is adapted using locally available materials in a local workshop. In Angola, Sri Lanka, Cambodia and Georgia there are examples of plant and agricultural machinery that has been adapted for use in HMA and that can be both operated and maintained using skills that are available in-country.

As their job is to process the ground, agricultural machines originally conceived to work the soil could be efficiently employed. Agricultural technologies are largely available everywhere and in different sizes. Where they are not already available their presence might be desirable to increase the capability to produce food by farm mechanization. As mine affected countries are traditionally agricultural countries where a great proportion of the gross national product comes from fruits of the land, some agricultural resources are already available [1].

Agricultural technologies are mature and simple, easy repairable in every developing country in local, not specialized workshops. The modularity of agricultural technologies is another advantage; same tools can be mounted on different tractors units and replaced by dedicated agricultural tools when demining operations are over. Moreover, involving local technicians into the re-design of new or improved technology helps reducing dependency of local communities from donor's help as well as facilitating local human development. Empowerment is an integral part of many poverty reduction programs [2]. It is seen as essential to promote human development and

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[5] According to International Mine Action Standards (IMAS) 04.10 Glossary of mine action terms, definitions and abbreviation, the term demining machine refers to a unit of mechanical equipment used in demining operations.

human freedom to help individuals and communities to function as agents for the improvement of their own wellbeing. The handover of all mine action activities to local entities who can perform the majority of the work and can gain skills while participating to the creation and maintenance of new agricultural technology for area reduction is desirable and necessary.

2. LOCOSTRA project

LOCOSTRA, whose name stands for LOw-COst TRActor for Humanitarian Demining, is an agricultural tractor adapted to be used in demining activities (Figure 1). The tractor is armoured and equipped with blast resistant wheels. By employing an industrial transmitter and receiver coupled with electro-hydraulic valves we made it suitable to be controlled remotely as an alternative option to the traditional on board control.

LOCOSTRA has been specifically designed to be used as verification asset for technical survey and can be equipped with many different commercial off the shelf (COTS) tools:

- a mulcher (Figure 2) that allows vegetation to be cut and a visual inspection to be done either by a person on a small tower, by a camera on a balloon, or a video camera on board, or
- with an agricultural derived tool for removing/destroying landmines (Figure 3), or
- with an array of metal detector or a large loop detector to check for the presence of metallic parts of buried mines (Figure 4).

According to the tool with which the tractor is equipped LOCOSTRA machine can be classified as ground preparing machine, ground processing machine or mine protected vehicle (used as a platform for a detection system in a Suspected Hazardous Area (SHA)). LOCOSTRA is an intrusive, semi-autonomous machine. Being the overall weight of the tractor and the blast resistant wheels approximately 3000 kg, the machine can be classified as light.

LOCOSTRA is built around the P796V tractor produced by Pierre Trattori, a small, lightweight, four wheel drive, agricultural mini-tractor with 79hp, designed to be equipped with one or more of a range of proven agricultural tools. Power to the attachments is drawn from a power-take-off (PTO) at the rear of the vehicle. The frame being reversible, i.e. the driving position invertible, the same power-take-off can be used to carry tools such as cutting bars at the front to cut vegetation in front of the machine. The steel frame allows the use of relatively heavy attachments and leaves the potential to add dedicate robotic devices if a need to move ERW is required. A standard, category one three point linkage attachment at the rear allows hydraulic lifting and positioning of many off-the-shelf agricultural tools.

The machine is designed to be easily transported over unimproved terrain without the need for a dedicated transporter. The innovative blast resistant wheels and the relatively high travel speed (20km/h) allow self movement, easy also on uneven terrain, while the overall vehicle weight and dimensions allow it to load into a truck bad, when long distances will have to be covered. When medium long distances have to be covered, the tractor can be equipped with traditional pneumatic wheels, which will be provided together with a set of blast resistant wheels.

The remote control allows the tractor to be driven from a safe distance of up to 100m. No manual controls have been removed, so leaving manual drive with the operator on board possible when the machine is brought to the work place and when it is used in traditional agricultural activities after demining operations are over.

Intended for use in areas where there is a risk from explosive devices, its wheels are designed to withstand the detonation of 500g of TNT without damage that would halt operations. The same blast resistant wheels are mounted at the front and rear.

To maintain a low weight, the minimal armouring required is a composite of ballistic polyamides and polycarbonate with critical areas further protected by steel plate. The armouring can be easily removed for servicing and when working in extreme temperatures (over 40°C).

The machine is too small and light to allow any significant protection against large explosive threats (such as AT mines) and no effort has been made to provide this. The machine is designed for use in areas with an AP mine threat.

The machine has been proven with a vegetation cutting attachment. Other attachments able to prepare the ground surface have been used, but the ground conditions so affect performance that the effectiveness of ground-processing implements in a mined environment must be determined on a case-by-case basis or by reference to a data-pool gained by real field experience. Vegetation cutting is of proven advantage to demining operations from survey to clearance of defined hazardous areas. It allows visual assessment of the ground to be conducted and removes the need for deminers to cautiously remove undergrowth as they advance during clearance procedures. Ground processing can be used for “proving” or confidence building over small or wide areas, but LOCOSTRA is intended to be used as a ground-processor in advance of manual excavation clearance methods widely used in Asia.

According to one of the most important requirements the final purchase price is equal to € 50,000 per unit, with operating costs comparable to that of a road vehicle.

The only components added to the original tractor are:

- Innovative blast resistant wheels, designed to resist several explosions (at least 5) while protecting the tractor from damages caused by the explosions. Wheels are essentially built around a COTS solid rubber wheel embedded in an outer steel structure providing ventilation and protection.
- Remote control system, designed to allow driving the tractor from the safe distance of 100m. It consists of the industrial transmitter/receiver coupled with electro-hydraulic valves. Only essential commands are actuated remotely by electro-hydraulic valves mounted in parallel to hydraulic valves that were on board in the original tractor. Therefore LOCOSTRA can be driven both on board with traditional commands and remotely by the transmitter.
- Autonomy enhancement module, designed to allow an easier remote control of the machine by embedding several more sensors than the basic remote control, an industrial programmable logic controller (PLC), the communication module and a video camera, to help driving the machine remotely in difficult environments such as areas covered by thick vegetation and allowing the machine to be used in more complex agricultural tasks.
- Armouring, designed to be simple and easy to be removed during maintenance. It is constituted by appropriately shaped covers of 3mm thick mild steel mounted to protect delicate parts and easy removable ballistic fabric shields protecting hydraulic hoses and separating the active tool from the machine main chassis.

3. The autonomy enhancement module

The main idea of LOCOSTRA project is to provide a robust, simple, easy to maintain and low-cost solution to ground processing, vegetation cutting and quality control in mine action. On the basis of these assumptions the autonomy enhancement module (AEM) for LOCOSTRA was designed as well.

The AEM for LOCOSTRA was developed to upgrade the already existing remote control system. The autonomy enhancement module introduces new control system functions. It increases the safety of the machine operations during remote control thanks to the presence of additional sensors. Together with the IP (internet protocol) video camera, a video camera using internet protocol to send the captured images to the receiver, additionally mounted on the tractor, the AEM makes the remote driving of the machine easier.

Moreover the autonomy enhancement module can be reprogrammed allowing more features to be added to the control system and is a good base for a further development of the machine autonomy.

The core structure of the AEM and its arrangement on the machine are presented in Figure 5 and Figure 6, respectively. The module has four main components: the main control unit, the sensors, the communication module and the human machine interface (HMI).

The main control unit is basically a programmable logic controller (PLC) together with a block of electrical automotive relays. It is connected with the sensors installed on the tractor. The communication module is composed of wireless network components and is responsible for providing a communication bridge between the main control unit and the human machine interface. In our case the HMI is a notebook equipped with a wireless card.

Additionally to the main parts we installed an IP video camera to expend the functionality of the AEM.

The main control unit core component is a programmable logic controller (PLC). The PLC adds intelligence and some new functions to the control system. Because the PLC is connected to the electro-hydraulic valves in parallel to the remote control system’s receiver, it is able to control most of the machine’s functions. Coupled with additional installed sensors, it makes using the machine safer. The PLC can be remotely programmed trough the communication module using software (free and provided by the producer) installed on the HMI.

The elementary actions enabled by the PLC are: motor ignition, motor switch off, switch between steering axis (front/central), turn ON/OFF the Power Take-Off (PTO) clutch, turn ON/OFF the differential blockage system, and move up/down the three point linkage system.

The PLC is also used to monitor the state of the machine. Having access to the sensors and relays listed below the PLC can supervise operations done by the machine and send information about it to the HMI. Sensors and relays accessible for the PLC are: lack of oil sensor, low pressure of oil sensor, high temperature of oil sensor, double steering system sensors, double steering system relays, ignition relay, PTO clutch relay, differential blockage relay, three point linkage, up/down relays, velocity sensor.

The PLC model we chose provides 36 input and 24 output channels. The inputs and outputs are connected through the relays with sensors and electro-hydraulic valves, respectively. Currently only 20 input and 10 output channels are used, the remaining channels can be employed in future applications. The FATEK PLC was chosen because of its low price and because it is of industrial type, therefore, robust and reliable. Moreover it allows reprogramming and adding features to the control system in case of future upgrades.

The sensors added to the ones already installed onboard (oil pressure sensor, oil temperature sensor, velocity sensor) are inductive sensors used to supervise the driving system.

The communication module includes a RS232-to-IP converter used to convert a serial binary RS232 standard protocol to/from an internet protocol (IP), a wireless router coupled with a Wireless Local Area Network (WLAN) antenna working at the frequency of 2.4GHz, and a human machine interface, which in our case is notebook.

The router, like all the other components of the communication module, is available off the shelf everywhere in the world where Internet in used.
The task of the communication module is to provide a robust and reliable communication bridge between the main control unit (PLC) and other elements installed on the board of the tractor and the human machine interface. Apart from the communication module hardware we developed also the software which is an integral part of the communication module and the human machine interface. The software enables the user to control the PLC and, therefore, to control all the machine functionality provided by the PLC. Moreover, the software provides to the user images transmitted by the IP video camera mounted on board of the machine.
The communication between the PLC unit and the HMI works as follows. The PLC is linked with the wireless router through the RS232-to-IP converter. The notebook used as HMI connects wirelessly with the router which enables to communicate with all the other components linked to it. The network created allows the software installed on the HMI to access the PLC's communication port. All data sent from the PLC are converted (by the RS232-to-IP converter) from RS232 serial binary standard data to IP protocol packets which are readable by the HMI. In the next step, data is converted back to a serial asynchronous data form. This is performed by a virtual serial port driver, which enables to emulate a virtual RS232 serial port on the HMI operating system. Data provided to the virtual RS232 serial port is the data received from the PLC. The communication works in both ways, which means that data sent to the virtual RS232 serial port is delivered to the PLC's communication port. The communication bridge created by the communication module becomes transparent for the PLC and the software user giving an impression of a direct communication between them.
The last main part of the AEM is a standard notebook equipped with a WLAN card, used as Human Machine Interface.
To control the PLC the user handles a human machine interface software run on the notebook. This software consists of two components: graphical user interface (GUI) and OPC server, a software application that acts as a protocol converter. The GUI provides a user a graphical interface constituted by an application window with buttons and indicators and a window presenting images transmitted from the IP video camera. Through the GUI the user can control and supervise the work of the machine. The OPC server works as bidirectional protocol converter, it translates commands to the FACON-PLC communication protocol (a communication protocol used by the PLC) [3] sent from the GUI application to the PLC. By developing our own OPC server we increased the efficiency of the software and enabled a better setup of the communication channel which results in higher communication speed and more stable connection.
The communication module allows introducing some other components such as a global positioning system module and additional sensors, to the wireless communication bridge. The adoption of these new components will enhance the remote control system of the machine and will constitute a forward step toward an increased autonomy.
The autonomy enhancement module is completed by an IP video camera, connected to the communication module. The remote vision system created by connecting the IP video camera to the communication module makes driving the machine remotely easier by providing feedback images from on board the machine to the HMI (Figure 7).

4. Conclusions

Although, the amount of time spent at working on the module so far only allowed us to implement part of the functions foreseen, the current system already satisfies most of our expectations. It is robust, simple and low-cost, embedding only commercial off the shelf components. Moreover, it provides a suitable base for further development of the remote control system, because ready to host new components such as a global positioning system module and additional sensors.
The autonomy enhancement module introduces new important functions to the remote control system and makes LOCOSTRA a semi-autonomous machine suitable also to be used in agricultural activities by disabled people.
LOCOSTRA control system will be further improved within the framework of a European funded project called TIRAMISU (Toolbox Implementation for Removal of Antipersonnel Mines, Submunitions and UXO). LOCOSTRA machine has been included among the technologies for technical survey on which TIRAMISU research will be based.

5. References

[1] Cepolina E.E., Matteo Zoppi: *Sustainable and appropriate Technologies for land release in humanitarian demining*, Woodhead Publishing, 2010, ISBN: 978-1-84569-786-0.

[2] Deepa Narayan: *Empowerment and Poverty Reduction: A Sourcebook*, Poverty Reduction and Economic management (PREM) of The World Bank, May 2002. Accessed from: http://www.handicap-international.fr/bibliographie-handicap/6SocieteCivile/Advocacy/NARAYAN_draft.pdf

[3] *FATEK Communication Protocol*, FATEK documentation, Accessed from: http://www.fatek.com/Download%20Page/English/FBs_Manual/Manual_2/Appendix1.pdf

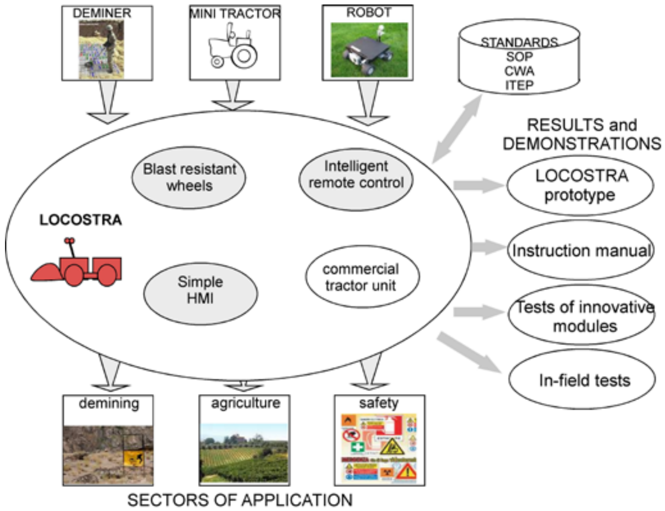

Fig.1. Idea of the LOCOSTRA project

Fig.2. LOCOSTRA machine equipped with COTS mulcher (produced by FAE – Advanced Shredding Technologies).

Fig.3. LOCOSTRA machine equipped with COTS ground processing tool (produced by F.lli Spedo).

Fig.4. LOCOSTRA machine equipped with COTS large loop detector (produced by Ebinger).

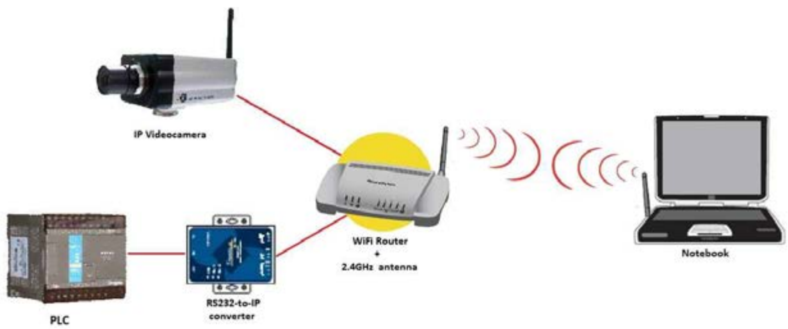

Fig.5. Communication module architecture

Fig.6. PIERRE P796V tractor with hardware installed onboard

Fig.7. Front and rear view from the IP video camera mounted on LOCOSTRA