# Power tillers for demining in Sri Lanka: vegetation cutting module

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***Abstract* –According to the Study on Global Operational Needs of the Geneva International Centre for Humanitarian Demining (GICHD), "mechanical systems can achieve a major impact particularly if designed by the users and based on simple, agricultural and commercial earth-moving machines adapted to meet the local needs of humanitarian demining"[1].**

**Here, a simple, low-cost machine based upon commercially available power tillers, for helping removing landmines in Sri Lanka is introduced. In particular, the paper discusses the complete design, virtual prototyping and testing of its vegetation cutting module. The module can be placed on the front of the machine when vegetation is too thick for the system to get through. It is powered by the tractor unit engine and is supported by the same frame supporting the ground processing tool. The tractor unit is remotely controlled from the safe distance of 20m.**

## I. INTRODUCTION

There is increasing consensus on the fact that landmines heavily affect the development of contaminated countries and that mine action activities need to be integrated into general development initiatives.

There is also general acknowledgment that machines have fallen short of expectations: only few are actually employed in the field and are often down for maintenance waiting for spare parts or experienced technicians able to fix them coming from abroad [2].

These reasons are at the base of the idea of adapting commercially available power tillers to demining applications by designing different modules attachable to the main tractor unit in a participatory way together with deminers.

In fact we believe that involving deminers into the whole design process would allow them to get familiar with the innovation process, which is a key component of the development process, and would help realizing a machine nearer to real needs, sustainable because made of materials available locally and therefore more efficient.

The project presented here therefore regards the participatory design and development of a new small machine for helping removing landmines in the Vanni region in Sri Lanka, where landmines are of the small plastic type containing approximately 50g of TNT. The whole work encompasses the realization of three modules:

- tractor unit
- ground processing tool
- vegetation cutting tool
-

and the control unit to drive the machine from the safe distance of 20m, set by local authorities.

The tractor unit is the power tiller, opportunely modified to resist possible explosions of landmines underneath and adapted to the remote control [3], while the ground processing tool is the means by which landmines are lift up on soil surface to facilitate later hand removal by deminers. The ground processing tool is placed on the front of the machine, to allow landmines to be removed before the tractor unit passes over them.

This paper focuses on the vegetation cutting module, which can be attached on the front of the machine when vegetation is too thick for the machine to pass through. It is powered by the power tiller engine and is supported by the same supporting frame of the ground processing tool.

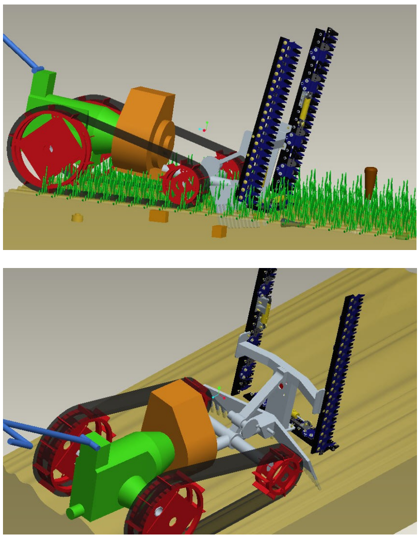


Fig.1. Digital mock up of robot composed by three modules: tractor unit, ground processing tool and vegetation cutting tool.

## II. DEFINITION OF REQUIREMENTS

Before starting the project, end-users have been asked to indicate in which operations they would have liked to be helped by a new small machine. Between standard operational procedures currently in use by Norwegian People's Aid, the NGO partner of the project in the field, they indicated as more boring and difficult the operations of hard ground processing and vegetation cutting, specially palm leafs [4].

In fact, no metal detectors are employed as soil is ferrous and mines have very low metal content; instead, ground is excavated at the depth of 100mm, specified by local authorities, to expose to eye sight buried landmines. Two simple rakes with handler extended to 2m are used: light rakes to remove loose soil and hard rakes to process more compact and deep soil. Vegetation is manually cut with simple gardening tools like saw, sickle and shears.

The task of the vegetation cutting module is to cut the vegetation obstructing the passage of the machine. When vegetation is present and the module needs to be employed, deminers, following the machine to locate and pick up mines lifted up on soil surface by the ground processing tool, will firstly proceed to remove the vegetation cut by the machine with the light rake.

Vegetation of the Vanni region can be classified into three types: light, if only grass is present, medium if there is also bush and heavy, if there are palm trees.

Fig.2. Vanni region, vegetation types: light, medium and heavy.

We would need to use the vegetation cutting module only in case of medium and high level vegetation. When palm trees are present, the task of the module is only to cut leafs, as palm tree is protected by Sri Lankan law.

The power tiller we are employing as tractor unit has 7.5kW engine; due its limited capacity, energy consumed by the vegetation cutting module should be as low as possible. The other requirements the module has to meet are the general ones valid for the whole machine: it should be low-cost, easy to use and maintain, robust, made of few simple parts, easy to find on the local market, able to work in dusty and dirty environment at high temperatures. Moreover, as it is supported by a frame on the front of the machine it should also be as light as possible.

## III. STATE OF THE ART

Generally, large machines using flails, tiller units or brush cutters [5] are employed for cutting vegetation in minefields.

According to the general philosophy of the project and due to the small size of the power tiller, instead of analysing dedicated systems we looked into existing technologies for cutting vegetation available on the agricultural market. Those are of four types:

- String trimmers (Fig.3.a.): using plastic strings rotating among a vertical axis. They can cut grass and small bushes. Approximately, the power absorbed is 1kW, the cost is 100€, the cutting width is 300mm and the weight is 5kg. They can cut near to obstacles as the string is flexible, but the string has short life and needs to be changed often.
- Lawnmowers (Fig.3.b.): using blades spinning on a horizontal axis. Vegetation is cut by scissor like action between spinning blades and fixed ones. They are mainly used to cut grass. Approximately, the power absorbed is 3kW, the cost is 300€, the cutting width is 500mm and the weight is 30kg. They achieve a clean cut.
- Hammer knife mowers (Fig.3.c.): using hammer knifes spinning among a horizontal axis. Vegetation is chopped by knives rotating at high speed. They are used to cut grass and small bushes. Approximately, the power absorbed is 4kW, the cost is 1000€, the cutting width is 500mm and the weight is 100kg.
- Cutter bars (Fig.3.d.): using two-knife bar sections; the upper one reciprocates over the stationary bottom one. Vegetation is cut by scissor like action between the bars sliding horizontally. They are used to cut grass and small bushes. Approximately, the power absorbed is 1.5kW, the cost is 100€, the cutting width is 1000mm and the weight is 40kg.


Fig.3. Cutting vegetation technologies on agricultural market.

## IV. CHOICE OF CUTTING SYSTEM AND ARCHITECTURE

Because of its ability to cut small bushes as well as grass, its large cutting width, low cost and low power absorbed, we have decided to employ cutter bars as cutting system. Moreover cutter bars present a high level of modularity. In fact, they are constituted by two identical knife bar sections mounted on two frames, one fixed and one moving. In the version available on the market, rotary movement of the power take off (pto) is transformed into linear sinusoidal movement of the upper moving bar thanks to an eccentric and a sliding joint.

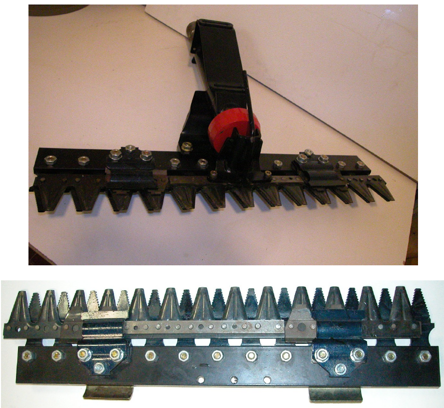


Fig.4. Cutter bar.

A simple model shown in Fig.5 has been implemented to study the kinematics of the cutting bar.

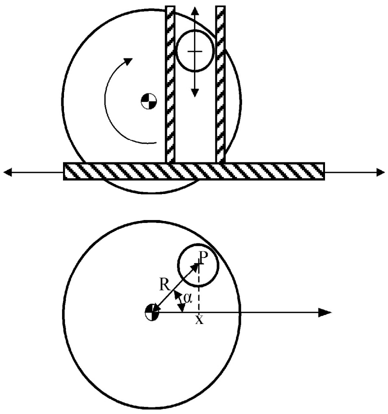



Fig.5. Cutter bar model for kinematics analysis.

The position and speed of the moving blade is given by Eqs.(1,2).

$$x = R \cdot \cos\alpha \qquad (1)$$

$$V = \frac{dx}{dt} = -R \cdot \sin\alpha \cdot \frac{d\alpha}{dt} = -R \cdot \omega \cdot \sin\alpha \qquad (2)$$

The maximum translational speed of the moving bar is 2.83m/s, when the pto rotates at 900rev/min. As for every revolution two cuts occur, the cutting frequency is 1800Hz. Therefore, when the machine proceeds at 0.1m/s, there are 300 cuts per meter.

Fig.6. Cutter bar teeth.

The fixed bar presents segmented teeth to grasp vegetation before it is cut. This allows also to cut tripwires when fragmentation landmines are present. Clamps are used to push the moving bar over the fixed one. Their height must be set according to different vegetation types.

Fig.7. Cutter bar clamps.

Experiments conducted in the lab have shown that cutter bars are suitable also for palm leafs cutting. In order to create the space necessary for the machine to proceed when vegetation is thick, we have decided to employ three bars at the same time: one horizontal and two vertical. Vertical ones allow the machine to proceed in the bush and near to palm trees; they also cut tripwires if present.

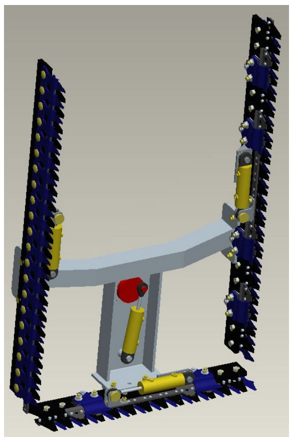


Fig.8. Vegetation cutting module architecture.

Different cutter bars with different lengths are available: they only differ for the number of teeth, the length of frames supporting the two knife bar sections and the number of components fixing bar sections to frames.
The overall number of components types is therefore limited, allowing simple maintenance even in the field. To repair the cutter few items per type of components are

necessary to the operator, who can assembly and disassembly the whole system using only one wrench 17mm size for nuts and a small hammer for pins fixing the mobile bar to its frame.
Commercially available 650 mm and 1050mm long bars are suitable to be mounted horizontally and vertically respectively.

## V. ACTUATION SYSTEM

The actuation system provides bars with the sliding movement needed to cut vegetation.
The same considerations for the choice of the vegetation cutting tool apply also to the choice of the actuation system. It has to be robust, low cost, low weight, simple and modular. Moreover, it has to be suitable to work in dusty environment and as compact as possible to fit between the cutter bars.
Between possible actuating systems, a hydraulic one was preferred. In fact, it can produce high forces while occupying a reasonable compact space; it allows for flexible placement of components, is cheap, robust and easy to repair and maintain.
Electric actuation was abandoned because too delicate for working in unstructured dusty environment, even if allowing for flexible placement of components. Moreover, electric motors are expensive and difficult to maintain; in case of blockage they can fuse. Instead, mechanical actuation needs complex gears. Pneumatic actuation presents the same advantages of the hydraulic one but due to air compressibility, the control of movements is more difficult.
To actuate the three cutter bars, double acting cylinders were chosen, providing both forward and backward stroke with the same force. To generate hydraulic power the idea to employ a pump actuated by the pto and three valves controlling the three cylinders was encompassed. This option was abandoned because both pump and valves are easy to break and difficult to repair in the field. Instead, it was chosen to employ another double acting cylinder actuated by an eccentric connected to the pto. This solution presents the advantage of being simpler, more robust and cheaper; moreover, it allows avoiding the use any type of control as the eccentric determines the correct motion law of the cylinder connected to it. Motion is transferred to cutting bars with no other components needed.
After choosing the actuation type, the architecture of the actuation system was chosen. Three main solutions were considered.
In the first one three cylinders were powered by the pto through the eccentric, each one connected to the cylinder actuating a cutter bar. This solution presents the advantage of high modularity as each cutter bar has a separate hydraulic circuit and bars can be removed if not necessary without having to modify the whole system. But, a large space is required to fit three cylinder to the eccentric.
The second solution foresaw the use of only one cylinder actuated by the eccentric and three cylinders on the cutter bars connected in parallel. Space required is less, but the system is intrinsically unstable as pressure waves due to the blockage of one bar travel along the whole circuit, changing the motion law.
In the third solution, that was chosen, only one cylinder is actuated by the eccentric and three cylinders on the cutter bars are connected in series. For the system to work properly, facing chambers need to have the same volume. The layout of cylinders is shown in Fig.9, where eccentric, cylinders and the forces acting on them are shown.
The sum of forces acting on the cylinders moving the cutter bars is smaller than the force acting on the cylinder powered by the eccentric.
The third solution is simpler and more compact than the previous two. All cylinders are identical: only one type needs to be bought and stockpiled for maintenance. Repair in the field is also easier because operators need only few components. Moreover it is modular, if two cylinders are disconnected the volume of the two remaining facing chambers is equal. This is particularly useful when palm trees are not present in the minefield and only grass is present. Detaching the two vertical cutter bars allows saving power and fuel.

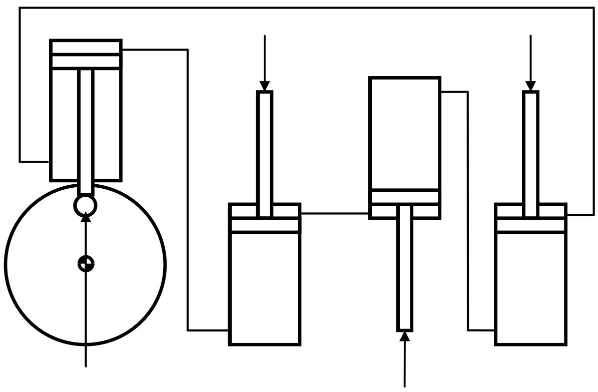


Fig.9. Layout of cylinders in solution three.

For dimensioning reasons, the maximum pressure of the hydraulic system was calculated from Eqs. (3,4,5).

$$P_{\max} = P_w + \Delta P_{oh} \quad (3)$$

$$P_w = P_c + \Delta P_p + P_o \quad (4)$$

$$\Delta P_{oh} = \frac{c \cdot V_c}{g} \quad (5)$$

Where,

| | |
|---|---|
| $P_w$ | Working pressure |
| $\Delta P_{oh}$ | Overpressure due to object hitting |
| $P_c$ | Circuit pressure |
| $\Delta P_p$ | Pressure drop in tubes |
| $P_o$ | Pressure necessary to accelerate oil |
| c | Circuit speed rate |
| $V_c$ | Maximum speed of oil |

Resulting maximum pressure $P_{max}$=232bar was used to choose cylinders and oil. Agip OSO 15 type of oil and double acting cylinders with 15mm bore diameter and 80mm stroke, not cushioned, with pin joint attachments were chosen.
This type of cylinder has to be built on purpose but because not presenting cushions, as all other types available on the market, is lighter and smaller. Moreover, although it has to be manufactured ad hoc, is simpler and cheaper as less internal components are necessary.

## VI. FRAME DESIGN

After choosing the cutting methodology, the architecture and having dimensioned the actuation system, it was possible to design the frame of the cutting tool.
The maximum stress on the frame occurs when one of the cutter bars encounters an obstacle, particularly when the obstacle is hit at one of the two ends of the bar. In this case, in fact, a high momentum is applied to the connection between the bar and the frame. Therefore, in the design of the frame attention has been posed at keeping connections as near as possible to the centre of cutting bars in order to reduce the moment arm.
Attention has been posed also at reducing as much as possible the weight of the frame, in order to reduce the load on the power tiller. Two materials have been investigated: aluminium for its low weight and steel for its strength and possibility to be welded and repaired easily.

The frame has been designed and virtually prototyped using a 3D CAD software: different solutions have been investigated and analysed with finite element static approach. Analysis has been conducted both for aluminium and for steel. The frame chosen is shown in Fig.10.
While applying loads to the structure the assumption of having only one vertical bar engaged at time was made. This is reasonable in the case of palm leafs cutting as palm trees grow up spontaneously and it is difficult to have two on both side of the machine at the same time.

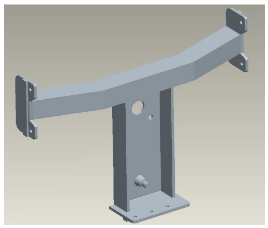
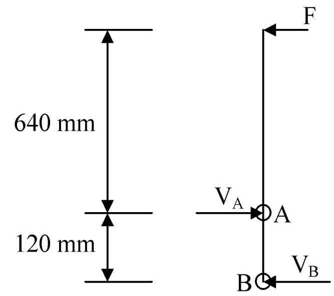


Fig.10. Frame of the vegetation cutting module.

Loads applied to the frame in the worst case are:

- horizontal force at the top of one vertical bar




From equilibrium Eqs(6,7):

$$\sum \overrightarrow{M}_{F_{ext_A}} = \vec{0} \tag{6}$$

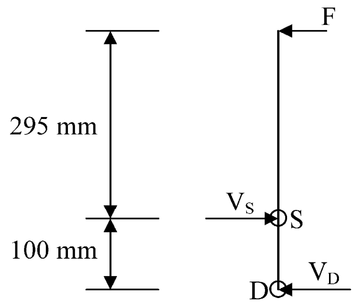
$$\sum \overrightarrow{F}_{ext_H} = \vec{0} \tag{7}$$

For an applied force of 2000N, we have:

$$V_A = 13000N$$

$$V_B = 11000N$$

- horizontal force at the top of thee horizontal bar




From equilibrium Eqs(8,9):

$$\sum \overrightarrow{M}_{F_{ext_D}} = \vec{0} \tag{8}$$

$$\sum \overrightarrow{F}_{ext_H} = \vec{0} \tag{9}$$

For an applied force of 2000N, we have:

$$V_D = 5900N$$

$$V_S = 7900N$$

- Force generated by the driving cylinder connected to the p.t.o. on its pin

$$F = P_{max} \cdot A = 4100N \tag{10}$$

where, A is the cross section area of the cylinder.

Loads applied to the steel frame within the finite element static analysis are shown in Fig.11 together with corresponding deformations, the maximum being of 1.3mm at the upper corner of the vertical connection.

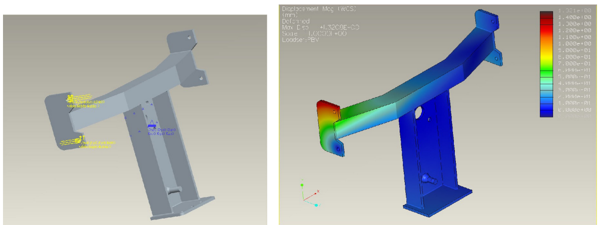


Fig.11. Loads and resulting deformations of the frame.

Calculated loads applied were:
13000N force applied on the upper part of the connection of the vertical bar, 11000N force applied on the lower part of the connection of the vertical bar, 7900N force applied on the right part of the connection of the horizontal bar, 5900N force applied on the left part of the connection of the horizontal bar.
Therefore, a steel frame was preferred. It is mainly constituted by a C draw piece with connections welded on it.

## VII. CYLINDER CNNECTIONS DESIGN

Two connections have been designed to attach cylinders to cutter bars: one for the fixed knife bar section and one to the moving knife bar section. They are shown in Fig.12.

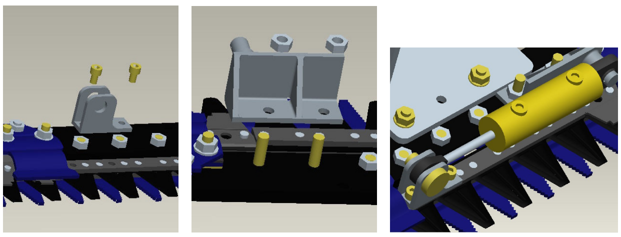


Fig.12. Cylinder connections to cutter bars.

The connection to the moving knife bar section uses set screws. Pin joints are used to attach cylinders to connections in order not to add constraints.

## VIII. CONCLUSIONS AND FURTHER WORK

The vegetation cutting module of a small cheap robot to help demining operations in the Vanni region of Sri Lanka has been presented. The overall work to finish the project encompasses the design and development of other two modules plus the control unit. The vegetation cutting module will be realised only when the work on the tractor and the ground processing tool module will be completed. At that time more details on the interface between tractor unit and other modules will be available and a supporting frame to the vegetation cutting module could be designed.
The vegetation cutting tool designed can cut grass, bushes and palm leafs and accomplishes the requirements of cost-effectiveness, capability to work in unstructured dusty environments, simplicity and modularity. Only few components have been used and the whole module can be disassembled and assembled using a wrench 17mm size, a set screw key 6mm size and a small hammer for the pins. A single tool including the ones just mentioned, has been designed and reported in Fig.13.

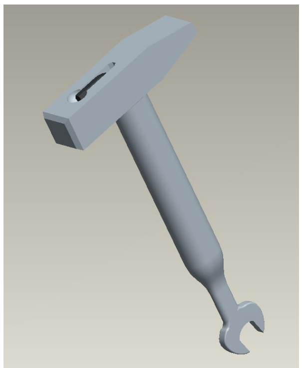


Fig.13. Tool allowing complete assembly and disassembly of the vegetation cutting module.

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