Portable mechatronic system for demining applications: control unit design and development

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Abstract: A new participatory approach that makes use of and improves local end-users knowledge has been used to design a new portable mechatronic system for humanitarian demining applications in Sri Lanka, using power tillers as core module. They are very simple and versatile machines with large scale diffusion in developing countries, where they are commonly used for agriculture and transportation purposes.
The system, composed by a tractor unit, a ground processing tool and a vegetation cutting tool is firstly introduced. The paper then focuses on the portable control unit allowing to control the machine from remote distance, in case unexploded ordnance or other fragmentation weapons are known to be present. The module allows forward motion by acting on the clutch, differential and acceleration of the power tiller; steering is controlled by additional brakes, mounted on the driving axle. Two wheels supporting the ground processing tool on the front of the machine are connected to the rear driving ones through tracks. The module can be fit to every kind of power tiller actuated by levers, using differential gear, after only little adjustments. The control is pneumatic and it is powered by the engine of the power tiller itself. The unit, like the others modules, responds to the requirements of safety, low-cost and *simpleffectiveness*.

Keywords: mechatronic demining system, modularity, remote control, pneumatic actuation, low-cost design.

1. 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 [1].
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.
This paper focuses on the control unit, which allows forward motion and steering, leaving gear change to be done manually, at the beginning of the working lane.

2. Requirements and system design

A one-month trip to northeast Sri Lanka was organized, at the beginning of the project. Deminers asked for their preferences during group interviews, expressed a strong desire for new small, light and cheap machines. They want machines to help in the most boring/difficult parts of their job, particularly cutting vegetation and processing the ground, specially the hardest one, currently scarified using a simple rake called heavy rake, to remove the soil hiding mines [2].
Therefore, the target of the project is to develop a modular system using as core module a power tiller and equipping it with modules specialised for ground processing and vegetation cutting. A special end-effector to process the soil and bring mines up to the soil surface is being designed. Each machine can be considered a semi-autonomous system, helping a single deminer in his work, and a certain number of machines can be controlled automatically to perform area-reduction operations, working as a multi-agent system.
Deminers will always assist machines: once a mine is found and lifted up on the soil surface by the special end-effector, a deminer can remove the mine manually. Manual mine removal has been introduced in order

to lower the complexity and cost of the machines, as well as to allow a quicker integration of machines in operational procedures.
A modular top-down design approach was chosen. Starting from the task, defined by deminers, the mechanical modules able to accomplish the work were conceived. The machine exhibits modular structure, as two end-effectors compatible one to each other can be attached to the tractor unit: one is dedicated to ground processing and the other to vegetation cutting.
Therefore, the project involves the mechanical design of three modules: tractor unit, ground processing tool and vegetation cutting tool. The project includes also the implementation of the remote control that needs to be used when Unexploded Ordnance (UXO) and fragmentation Anti Personnel (AP) mines are known to be present.

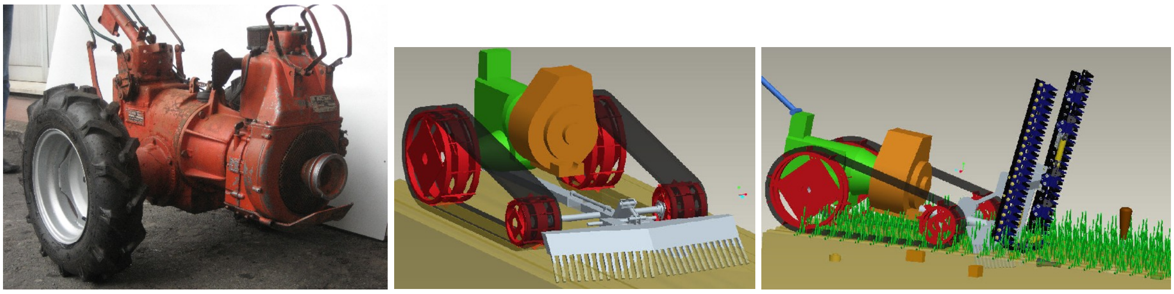

Fig 1. Power tiller and digital mock ups of the system designed, composed by three modules: tractor unit, ground processing tool and vegetation cutting tool.

The tractor unit is the power tiller, opportunely modified to be adapted to remote control and equipped with tracks to provide sufficient traction [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. The vegetation cutting module 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.
The overall essential requirements the machine has to satisfy are:

- reliability: 100% clearance
- safety of operator: 100%
- depth of demining: 100 mm
- width of clearance: 1200 mm
- speed of clearance: higher than manual
- types of mines: small plastic blast-type AP mines
- cost: 20.000 €
- remote control distance: 20 m

Considered mines are small because they are between the less harmful existing ones, containing up to 50g of explosive only. UXO and fragmentation mines are also present, especially Claymore types, but only in certain known minefields. The machine is specifically designed to be proof against AP blast mines and to resist damages caused by fragmentation devices.
Cost is one of the main points of the project. The cheapest machine for humanitarian demining applications available on the international market, the Tempest which is classified as mini-flail, is used for cutting vegetation and costs US$120,000 [4]. Although entirely produced in Cambodia, it is entirely specifically designed for demining purposes and therefore is inherently expensive.
Cost has to be contained as much as possible being one of the major causes of poor adoption of machines into demining programmes. The price of €20.000 does not include the research and developing cost and is equally divided between the modules and the control.
Attention is being paid to keep the machine extremely simple, avoiding adding complex modifications or tools to a very simple basic unit such as the power tiller. Therefore, parameters have been identified that contribute to achieve extreme simplicity and effectiveness, referred to as *Simpleffectiveness*.
The features the machine has to present in order to be *Simpleffective* are shown in the box beside.

SIMPLEFFECTIVENESS

forward/backward motion (traction)
steering: 1m curve radius
energy supply to end-effectors
stability
assessment of ground processing depth
mine disposal
safety of operator
shock wave protection for machine (and operator, in manual use)

3. Control unit

The control system has to allow to operate the tractor unit remotely in forward motion with steering acting on the semi-axles. In fact, even most basic power tillers, with no differential gear, present two semi axles and turning can be achieved by acting on them separately.

Generally power tillers are controlled manually by an operator walking behind them. Speed and direction of movement are influenced by using:

- gearbox – to choose one of the gears defining speed and reduction (torque on wheels),
- forward/backward lever – to choose between forward and backward movement; neutral position is also allowed,
- differential – mechanism allowing for coupling and decoupling synchronous movement of wheels,
- clutch – coupling/decoupling actuation on wheels,
- acceleration – angular speed of engine.

After having started the machine manually, while keeping clutch pressed, the gear is shifted and forward/backward motion selected. After this, the clutch can be released causing wheel to decouple and motion starts. The operator follows the machine adjusting the acceleration according to working needs. When direction needs to be changed, firstly the differential is actuated to allow non-synchronized movement of the wheels. Direction is manually changed acting on handles. When the power tiller is moving in proper direction the differential can be switched off to preserve the direction.

After having analysed manual operations, the features to be actuated by the control system need to be selected. All existing levers can be automated but changing direction, which is usually performed by the operator, rises up a problem. As a solution, external braking system was considered. The system consists of two disk brakes attached to each wheels and works in the following way. When direction is not relevant the differential firstly is actuated. Then, when wheels can be moved in not coordinated way, one of the brakes can be applied decreasing the speed of the wheel. This causes the direction to change proportionally to the difference in wheels speed. After reaching the proper direction, the brake should be released and differential switched off forcing synchronous motion.

According to previous considerations, the features selected for actuation are shown in table 1. Motion type analysis indicates that linear motion is needed mainly. In some cases actuation is needed in both movement directions in others one direction is passive. Deadlocks possibility should be regarded as source of further possible actuation problems.

Control system actuation can be realized in three ways: electrically, hydraulically and pneumatically. Advantages of the electric control system are:

• all parts of electric system i.e. DC motors, relays, sensors etc. are easy available,
• accurate position control (with usage of external sensors),
• easy to assembly, small and shock resistant wiring system,
• low cost of most commonly used parts.

Electric system drawbacks are mainly:

• difficult (in case of this project timing) remote control — microchip circuit board is needed,
• difficult and not resistant to deadlocks realisation of linear motion,
• actuators are not resistant to vibrations and contamination.

Instead, advantages of hydraulic system are:

• slow motions and big forces,
• angular and linear motion,
• is resistant for vibrations and contamination,
• has biggest available power/mass ratio.

Feature	Motion type	Actuator type
Differential	Angular and linear; linear easier to apply; deadlocks during switching the differential on	Single-acting cylinder, return stroke by spring
Clutch	Linear motion, big force, no deadlocks, one-side force needed	Single-acting cylinder, return stroke by spring
Acceleration	Linear motion, low force, position holding	Double-acting cylinder
L / R brake	Linear motion, one-side force, no deadlocks	Single-acting cylinder, return stroke by spring

Tab. 1. Power tiller actuated features

And drawbacks are:

- pumps, valves and actuators are expensive,
- additional equipment i.e. oil sump and oil accumulator is needed,
- wiring system is very extended and can be easily damaged.

Pneumatic system was chosen having the following significant advantages in this application:

- natural linear motion,
- resistance to deadlocks,
- resistance to vibrations and contamination,
- very big variety of actuators available,
- can be integrated with hydraulic system (brakes) with usage of pneumo–hydraulic amplifiers.

While electric system needs power generator and hydraulic one needs a pump the pneumatic system needs an air-compressor.

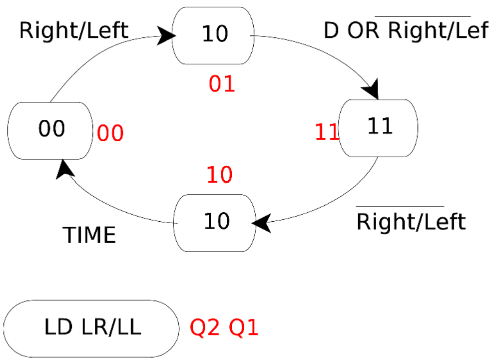

Fig. 1. State flow diagram for logics design

Control system was designed accordingly to digital control system design Moore approach. The state flow diagram is shown on figure 1. Corresponding to this and concerning Karnough tables as a result the following control laws can be obtained:

- State equations:

  $S_1 = \overline{Q_2} \cap \text{Right/Left}$

  $R_1 = Q_2 \cap \overline{\text{Right/Left}}$

  $S_2 = Q_1 \cap \square\overline{\text{Right/Left}}\square D \square$

  $R_2 = \overline{Q_1} \cap \text{TIME}$

- Output equations:

  $\text{LD} = Q_1 \square Q_2$

  $\text{LR/LL} = Q_1 \cap Q_2$

  $\text{LL} = \text{Left} \cap \overline{\text{Right}}$

  $\text{LR} = \text{Right} \cap \overline{\text{Left}}$

The logic equations presented before can be implemented in different ways: as relay circuit (ladder diagram), digital logic circuit (using available electronic stuff), microchip program and predefined controller available in stock. For this application we have chosen Siemens Logo controller which is cheap and robust, allows for software based programming, conventional switches are not needed and extended communication features can be used. This selection fulfils requirements as well as provides some additional advantages which can be useful in the future.

4. Conclusions and further work

The control unit of a small cheap machine to help demining operations in the Vanni region of Sri Lanka has been presented. The overall work to finish the project encompasses the finalization of ground processing and vegetation cutting modules design, the manufacturing of parts and the general assembly. The control unit design is complete, only fixtures need to be finalised and sent to the workshop for manufacturing.

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