HUMANITARIAN DEMINING: EFFICIENCY BY INTELLIGENT PLANNING AND LOW-COST ROBOTICS.

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ABSTRACT

The robot mine clearing, based on cheap and widespread farming contrivances, provides considerably unusual prospects, which aim at enhancing safety, reliability and efficiency, to transform the terrorist anti-personnel mine into almost useless practice. The talk develops along the following lines: • to conceive and implement low-cost robotic equipment, assuring effective, safe and reliable demining: the resources (facilities, functions, fixtures) choice lets devising worthy strategies; • to help out equipment integration, with resort to cheap and widely available (agricultural) fixtures: the on-process adaptive work-cycles lead to better tactical concert; • to provide the modelling and simulation background for the on-duty assessment and training assistance: the alarm (warning, emergency) management brings to efficiency and safety; • to make easier the operators groundwork, involved in self-learning and up-grading duties: the mixed-mode automation grants balanced resources use on the strategic, tactical and execution horizons.

KEY WORDS: MILITARY APPLICATIONS - ROBOTIC MINE-SWEEPING - REMOTE STEERING

INTRODUCTION

The mine reclamation is entangled duty, with demanding socio-economic conditions. Looking at technicalities, we have:

military mine-sweeping: to allow reliable logistics, specific tracks shall be made safe, by locally aimed technologies and real-time efficient work-organisation;

humanitarian clearing: to achieve safe re-appropriation of the ground (for farming, etc.), the all land needs to be overseen and recovered, at acceptable costs.

Indeed, the resort to landmine munitions characterises terrorist-driven warfare theatres, where the local political implications have historical reasons; solutions, on merely technical basis, will not work, unless the implications are also neutralised. The humanitarian demining characterises as necessary activity to assure fit-for-use land operation, where the legal frames bear negligible relevance; the task shall be routine highly effective process, having shared community part at mutual decentralised level (Hemapala, 2006).

The aspects suggest series of assumptions. First, no abstract developments are considered; on the contrary, properly aimed measures are dealt with, deeply rooted on the local historical frames. Second, the factual evidence of useful behaviours is deferred to results, and these are consequence of achieved benefits. Third, the routine business involvement shall comply with current habits, utterly neutralising exogenous or illegal biasing damages. Fourth, techniques and workflow schedules should not superimpose, rather organise on shared know-how.

The challenge is to make the mine clearing becoming standard routine, basically suppressing the terrorist threat, with full resort to local contrivances and personnel. Indeed, the project successfulness would mean to offer a technical solution out of the existing socio-economical obstacles.

The humanitarian clearing was, chiefly, fulfilled by front-end personnel, with resort to the harrow/brush. If accomplished by trained and careful operators, it assures comparatively safe and reliable results, having costs covered within acceptable ranges, directly allowed to local people, which could receive proper wages, independent from the actual land productivity.

The unmanned mine clearance permits safer duty progression, since the work-flow does not include front-end operators. The today state of the art distinguishes two techniques:

• heavy armoured vehicles capable to withstand the mine blast, thereafter eliminating the danger, because not requiring the mine handling;
• sophisticated robotic demining, with resort to three step cycle: detection and localisation; reliable picking, handling and removal; neutralisation and reclamation.

Both have the big hindrance in the cost of the special-purpose outfits. To join safety, low-cost and effectiveness, the mixed-mode processing abilities, incorporating front-end mechanised effectors and back-drop man intelligence, ought to be carefully assessed, by tangible technologies transfer and socio-economic impact as for the Civil Service appropriation. Then:

- the robotic mine sweeping should be privileged, enhancing the productivity by means of front-end automation, and lowering the costs and avoiding undue sophistication;
- the manned contribution is included, properly exploiting the on-process decision-making to widen the process adaptivity and flexibility, without increasing cost and sophistication.

On these ideas, the assembly of mine clearing robotic outfits includes the assessment of each step duty request, followed by the integration of the all system, by bottom-up procedures:

• to select the on-the-field resources, depending on the desired clearing tasks, and satisfying low-cost, leanness and know-how appropriateness (Baskin et al., 1999);
• to integrate widespread resources with task-bend enhanced by co-operative technological inventiveness (Cepolina, 2005), (Schulz, 1999);
• to programme the workflow, adapted to land conditions, mine spreading, effectors type, etc., with remote steering for safe accomplishment (Belotti, Michelini, 2007);
• to help facing un-expected occurrences (break-down, dead-stops, blasts, etc.) by autonomic alarm managing and assisted decision-making (Olling, Kimura, 1992).

The equipment choice quite obviously addresses the area of the agricultural machinery and know-how.

THE LOW-COST ROBOTIC EQUIPMENT

The final robot assembly (Belotti et al., 2008|a) shall include:

- self-powered carriers, say suited vehicles, bulldozers, tractors, power-tillers, etc., to confer the proper mobility;
- task-adapted demining outfits, to fulfil effective, reliable and

safe mine clearing, with robot carrying out.

The carrier choice has to deal with cost, power, thrust, stability and accessibility. The on-field mobility is, in general, provided by means of power-tillers, light tractors, bulldozers, (armoured) cars, etc., the last being typical for military applications. The power tillers are good choice, widely used and commercially available at low cost, also, as second-hand offer. They request clear modifications, (Belotti et al., 2008|b), notably, for steering and stability, through the resort to front trailer, having a further axle. The carrier fitting out shall embed: the special actuation for gear selection and choke setting, to adapt power, thrust and speed; the selective wheels brake, for path tracking; the front and lateral cameras, for visual restitution and course detection; etc., up to the feeding and handling of the front effectors for the mine clearing duties (Cepolina, Hemapala, 2007).

The integrated robotic outfits might each other greatly differ, with the only unifying fact of coming from widely available (agricultural-like) machinery (Havlík, Licko, 1998.). The robot reclaiming duty consists of two tasks (Habib, 2007):

- to detect the mines, by proper contrivances (racks, effectors, etc.) or by front-end sensors;
- to disable (remove/destroy) the mines, so that the incumbent danger is totally eradicated.

The detection is expensive and, by itself, not decisive; the handling and neutralising actuators, complex and scanty. The duty can use whipping flails, to destroy, rather than to remove, the mines. Either, the outfits should inspire to existing fixtures, such as: the potatoes pulling out, or the mine burst once hit by driven strings. Two outfits are, thus, conceived, Fig. 1:

- ground stripe lifting, and mines singling out by gentle sieve descent of the shifted earth;
- land sweeping by (forward displaced) striking flaps and flounders, inducing the mine blast;

the former principally applied on recently laboured pastures or soft sandy lands, the latter commonly used on tough meadows or compact dry areas. The mine lifting device requires design upgrading (by respect to common potatoes risers), to widen the front prospect and to add soil breaking devices. The striking flaps and flounders are derived from existing rigs, and applied to the (added) front axle, with suited forward overhang.

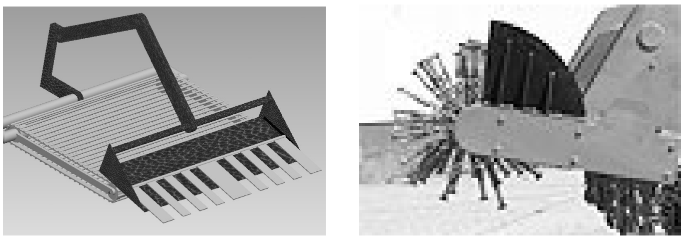

Figure 1: Outfits: mines lifting/singling; soil striking/mine blast

The special purpose mine clearing outfits and procedures are intended to be explanatory options; other fixtures/schedules can be devised on different design concepts and engagement rules; this means that sets of comparable rigs are obtained by resort to the sketched design-and-development approach, as the search just addresses the demands of feasibility and appropriateness, but does not implies the singleness of the outcome. Besides, the frame shows that humanitarian demining is open to lots of issues; technology appropriateness and lean feasibility are only constraints, offering valuable novelty under the methodological points of view, when the clearing process follows, exploiting the intelligent work-organisation paradigms, (Alty, Mikulich, 1992), (Sata, Olling, 1989.), once the pertinent modelling and simulation features are developed, and provided for robot exploitation (Zaremba, Prasad, 1994).

Moreover, the robot duty closing requires software/hardware to place the operator in safe remote location, with data from in-process diagnostics and on-process cameras. The steering task, Fig. 2, presumes mobility control, performed by the operator on the rear. The choice of the hardware fitting privileges the resort to off-the-shelf devices and standard software aids. The search faces two fundamental demands:

- friendliness, to guarantee easy operability to hastily trained operators and leanness to reach simple maintainability and rugged on-the-field equipment;
- low-cost, to make possible fruitful resources assembly from on-the-market offers, and effortless integration of cheap and well assessed technologies.

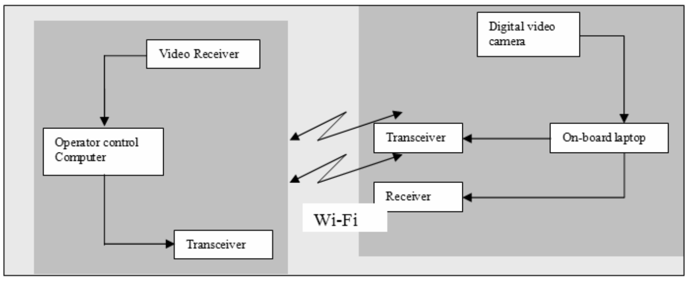

Figure 2: Remote communication hardware/software set-up

The architecture with the duplicated processing, on-site and at the operator location, permits closing control loops, that only need the friendly afterward acknowledgement of the subsidiary recovery/withdrawal manoeuvring. The remote governing of the robotic outfits avoids cables and umbilical, with resort to self-powered carriers and readily transferable overseeing stands. The governing system has two computers: the on board processor; the operator station. The on board processor is in charge of controlling path and ground processing; it provides, also, wireless link to the operator station. The communication cannel uses standard Wi-Fi (IEEE 802.11 b).

EQUIPMENT & COMMANDS INTEGRATION

The robotic equipment integration addresses simple and cheap equipment, privileging leanness, not multi-task machines, so that there is large chance to find out basic devices, readily to transform into helpful outfits, solely adding proper kits. The project requires series of actions, such as:

- to characterise the picked up farming machine, assigning the looked-for work-cycles and specifying the duty-driven rigs to achieve demining capabilities;
- to implement the specified fixtures, preserving technological consistency, so that the resulting outfits are ran, up-kept and maintained by shared know-how;
- to programme the suited work-cycles (with targets, thresholds and timings), to forecast the productivity, on the strategic, tactical and execution horizons;
- to appraise and check the achieved performance (safety, efficiency, reliability, etc.) for steady running, with account of unexpected anomalies (incongruities, failures, etc.).

The all is standard engineering task, and happens to be fulfilled detailing all features, with behavioural issues, covering:

- duty-steered functioning on the strategic horizons, to prove

suitableness (terrorist counter-measure) and appropriateness (shared habits acceptation);
• occurrence-driven efficiency on the tactical horizons, to select optimal off-process plans, to achieve high productivity, on steady running conditions;
• anomaly-coerced progress on the execution horizons, to show adaptivity and flexibility, by on-process decision duties done by the operators.

The equipment and command integration brings to entangled system assessments, (Tzafestas, 1997), leading to the (mobility and clearing) fixtures choice, (off-process) strategic schedules, (on-duty) tactical agendas and (real time) executional resetting, and dressing flow-charts and resource provision details. For explanatory purposes, the example connection of a power tiller and a (specially conceived) mine digger and singler-out, Fig. 3, is addressed. The itemized list in the work-flow incorporates all the diverse branching and recognition agendas incidents; e.g., with the ground stripe lifting, the appearance of a mine-looking body, the stop/go on impasse, the bursting/inert-stuff singling out (and safe removal), the blast and damage evaluation checks, and so on. The task complexity defines the instrumental setting at the detection levels (camera, for the visual recognition, etc.) and at the govern steps (remote control of the forward motion, of the ground stripe depth, of the sieving action, etc.).

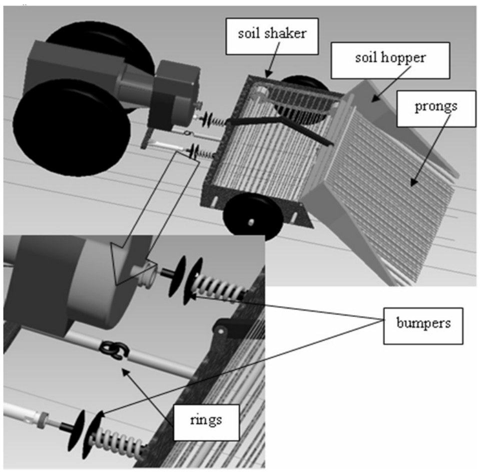

Figure 3: Digital mock-up of the example robotic equipment

The front effectors present with a series of tilting prongs, for gentle soil loosening, Fig. 4. The digging depth is 15-20 cm deep; the lifted ground strip is moved on a shaker, to extract the solid objects, framed by a camera. The power tiller pushes through two couples of bumpers, having a central link fixed by engaged hooks. The bumpers are pneumatically actuated, to assure proper preload, for (damped) negligible carrier/effectors oscillations. The differential biasing of the powered couple of bumpers is, further, exploited to modify the robot trajectory, assuring the requested (rectilinear) path tracking.

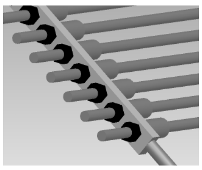

Figure 4: Tilting prongs (easily replaced when damaged)

The analysis of the duty-cycle requirements allows to specify the key functions that the robot has to fulfil. Being followed the ground stripe lifting strategy, the fixture is similar to the potato lifting and retrieval mechanisms (to be modified for the sorting and storing section). Besides, the presetting of the remote control set-up, the location of the detection devices (cameras, etc.) and the management of the shelter and reliability cautions (up to safe picking and mine neutralisation) ought to be watchfully dealt with, in view to lay down effective operation conditions.

The outcome is shown by the block-schema of the expected functional assets, with account of the parallel information flow. To help explaining the procedure, the functional flow, Fig. 4, gives the basic sample choices. The clearing strategy is sort out balancing operation requirements and resources availability. At the tactical level, path planning and ground processing follow, once known the robotic equipment (Fig. 3).

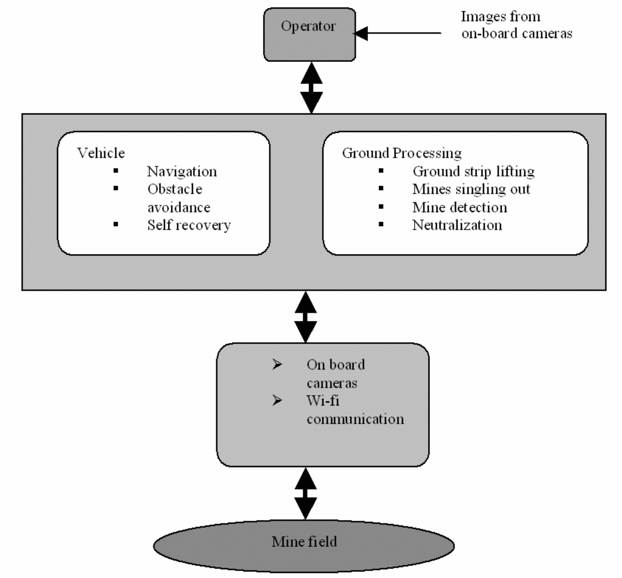

Figure 5: Functional flow of the robot clearing work-cycles

With clearing productivity and technological appropriateness in mind, Fig. **5**, the winning solution shall incorporate:
• the *intelligent* task-driven paradigms of flexible automation, with mixed-mode steering schemes that make use of on-process operators to adapt the on-going work schedules;
• the available agricultural machines to devise implementing mobile *robotic helps*, capable to incorporate the (innovative) task-adapted specially developed demining fixtures;
• the ideation and adjustment of simple front-end effectors, heading to the safe and reliable land reclamation, with high productivity and protected man involvement;
• the (purposely conceived) *remote-control apparatus*, for the direction-steering and navigation of the mobile robotic outfits, governed by the on-line operators;
• the *adaptive process-planning* agendas, to rule/manage the strategic/tactical/execution flexibility opportunities, allowing to achieve enhanced operation performance.

For practical purpose, the overall integration and planning of the on-the-field mine clearing constructs needs to require fast assembly/disassembly and easy maintenance/restoring abilities, suitably achieved by parts modularity and joint standardisation. This means to explore off-process versatility, by, e.g., changing the front-end fixtures. All in all, the availability of alternative carriers and end-effectors is only necessary step, not sufficient to assure good productivity.

The exploration needs forcedly to incorporate advanced checks on the really achieved productivity, at different environmental conditions and competing operation plans. The project looks after suitable simulation aids, based on the modelled dynamical behaviour of material resources and planned decision logics supplied to the human operators. The modelling and simulation permit comparing different resource lay-outs, outfit changes, planning agendas and random alarms, so that the collected data provides reliable anticipations on the on-the-field behaviour of the timely experimented facilities and fixtures. Actually, the counter-measures merit is given by the mine clearing success, and the present examination is forced to devise how the goal can be achieved according to factual measures, directly derived from the locally shared abilities and instrumental aids. The simulated testing is useful, allowing checks on:

- the facility set-ups, by means of the purposely developed digital mock-ups, so that the behaviour of the rigs is duplicated, up to the suited detail accuracy;
- the job agendas, by means of the devised control logics, tactical decision aids and recovery routines, so that the different alternatives are compared.

The transfer of the acquired knowledge into process steps up is greatly enhanced by the modularity of outfits and fixtures, and by the sectional implementation of the govern modes. The latter chance is fostered by resort to virtual instrumentation concept.

MODELLING AND SIMULATION FEATURES

Once detailed demining resources and management policies, the operation planning is obtained with resort to modelling and simulation features, distinguishing three flexibility horizons:

the strategic horizon deals with the off-process versatility, and, for example purpose, the checks aims at maximising the process effectiveness comparing the series of the mobility providers and front-end effectors, actually, implemented; the programmes take into consideration the remote control accomplished by the on-the-field operator, which has the direct visibility of the governed robot, through the connected instrumental data (course, speed, thrust, etc.);

the tactical horizon deals with the on-process adaptivity, and, for example purpose, the mine clearing, done by the power-tiller endowed by the ground stripe lifting, are detailed, defining competing agendas; the pertinent decision aids are developed, with the issues brought to the attention of the operator, who might switch between the agendas, and re-initialise the all duty-sequence;

the execution horizon deals with the unexpected occurrences (equipment failure, mine deflagration, course stop dead, etc.), and, for example purpose, the outlined software/hardware setting is studied on multiple-level (warning and emergency) alarms, depending on the relative risk and frequency, each time showing restoring/healing tracks and occurrence-driven recovery stops of the on-going agenda, and requiring the operator consent for the subsequent steps.

Once the modelling features are assessed, Fig. 6, the equipment behaviour simulation permits to recognise, whether off-the-shelf items (directly or slightly modified) or innovative devices have to be used. The enquiry operates with the resort to locally available pieces, after the throughout understanding of how these might be adapted and exploited. For explanatory purpose, the following alternatives are checked:

- two standard carriers, say: given type of power-tiller or tractor for the open-fields clearing;
- two standard mine clearing techniques: the soil strips lifting, or the flailing and tilling strings.

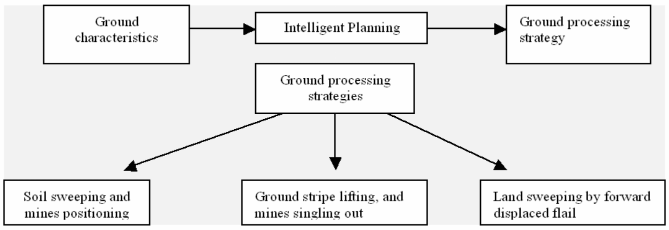

Figure 6: Block-schema of the robotic clearing work-cycles

The strategic setting, thus, permits four (off-process) resource selections, fully retaining the low-cost and leanness requisites, with best allocation and management of facilities, functions and fixtures. Then, the duty-cycle analysis distinguishes:

- the path planning and course acknowledgement, by speed, thrust, direction, etc. adjustment;
- the mine clearing processing, through the detection, singling, neutralisation, etc., tasks.

The top-down analysis is accomplished the find-out the optimal sweeping strategies, depending on the land conditions and on the fixture availability. The bottom-up analysis allows selecting the appropriate operation tactics, once allocated the resources and acknowledged the in-progress operation conditions, with account of the up-surging warnings and emergencies.

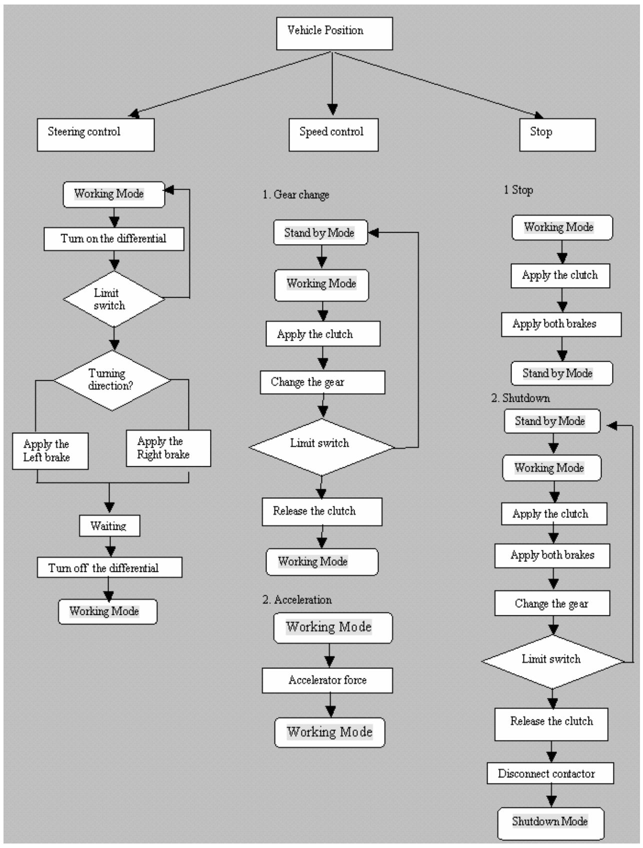

Figure 7: Example steady agenda and course planning

Defined the expected engagement, e.g., with soil lifting rigs, the mine-clearing agendas distinguishes:

- the steady running conditions, to be accomplished in the autonomic mode under operator overseeing, unless special warnings appear on the monitor;
- the emergency running conditions, when the operator selects the single-step mode, or when the front-end sensors switch-

off of the on-going agenda, at unexpected occurrences.

The steady running conditions avail by suited «macros», shown on the monitor by proper keys. The analysis is fulfilled at both ranges. The preliminary attempts run with the remote control. In the hardware selection, the instrumental architecture of the distributed sensing and actuating devices widely profits by off-the-shelf components, to preserve the low-cost final integration. The up-dating, therefore, is easily obtained changing or adding new modules, warranting enhanced visibility on the process or supplying wider versatility and/or dexterity. The next measures address the rethinking of the operation planning.

The information flow during the execution of the standard duty-cycles exploits macros, with coded operation sequencing, to be accessed as single (upper level) command. The idea is to permit the operator to collect data from the surroundings to forecast coming scenarios, leaving the robot in autonomic mode, Fig. 7, dealt with by «macros». The careful and extended checks make possible the detection of local soil or vegetation warning signs, to be associated with the recent laying down of mines, so that the steady agendas are devised and the course planning progresses in the autonomic mode. The path steering, Fig. 8, is forecast off-process, having account of resources and ground features, with the course later adapted by the operators, according to the on-duty rising warning/emergency signals.

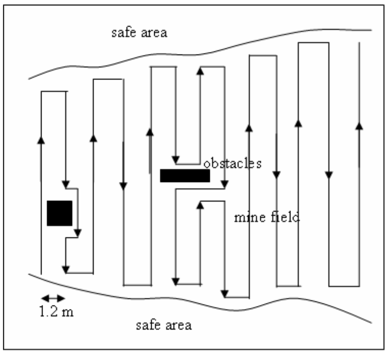

Figure 8: Back-and-forth path steering for full coverage

The careful understanding of the currently enabled functional settings shows that the main constraints, for the project success, distinguish a series of objectives:

- the set-up of the effective management infrastructure, with the bottom-up (cultural) spur of the local society, to establish the promoting, steering and checking Civil Service;
- the setting of the standard work-flow charts, to reach the industrial organisation productivity in the mine clearing, with pre-assigned work-in-progress targets and due times;
- the conception of consistent task-oriented outfits, derived by commonly shared technologies and apparatuses, to warrantee high on-process helpfulness;
- the truthful assessment of the process-agendas, with resort to strategic, tactical and execution flexibility, for the bottom-up mine-clearing programming.

The emergency flow-chart permits the bottom up assessment of the chosen technologies, with discussion of cost, performance and reliability, to acknowledge the productivity decrease by respect to the strategic agendas and, possibly, to revise the resources procurement at the strategic range. The unexpected occurrences represent the typical interrupts in the steady runs, depending on internal or external reasons (hardware/software failures, duty-cycle stops dead, landmine explosion, etc.), and need to be acknowledged and detailed in the flow-chard strategies, so that the alarm management and duty recovery become integral part of the task requirement schedules, at the execution flexibility level. The robot path planner, at the in-progress position, Fig. 7, has to chose direction and speed or to stop, as it is pre-selected by the embedded ruler or established by the remote operator, according to the visual display (e.g., soil aspect) and the sensors feedback (e.g., thrust on the vehicle). In any case, the mixed-mode automation permits the in-progress change and adaptation of the pre-planned path track by the simple switching to alternative «macros».

In fact, the finally rigged robotic equipment is commanded and overseen, with the operator standing into safe location (around 100 m from the robot). The full perception of duty progression is provided by the duplication of the on-board command setting and independent cameras sights. The agendas sequencing can be switched to the autonomic mode: the progression is deferred to «macro», transparently coded in the client-server restitution. Alternatively, can be executed by single-step mode, wanting consent each time; or might turn to the alarm mode, in front at emergencies, enabling bottom-up safety measures. Besides, the three levels hierarchy permits to steadily enhance the operator's attention to the dangerousness of the on-going sequencing, and the switching from one to the other mode is currently shown on the monitor by the pertinent markers.

PERSONNEL GROUNDWORK AND ENRICHMENT

The landmines are weapons developed to be disseminated on the ground, or close beneath the soil, and to explode because of contact or proximity of a person or vehicle. One distinguishes: AP *anti-personnel* and AT *anti-tank* landmines, depending on the disruptive potential (and cost). Both have military purpose to create forbidden zones, where the enemy could not enter. Actually, the AP landmines low-cost transforms them into munitions, spread in the land, making highly risking the further resort to civil (agrarian, etc,) exploitation. On these facts, the (Ottawa Convention, 1997) bans their manufacture, trade, use and stockpile and requests their demolition, because the armed forces objectives cannot justify the falls-off with the human disruption. The Convention promoted by the ONU is ratified by several Nations, but left aside by other ones and ignored by the population where guerrilla-like warfare is going on. The mine risk, then, is typical problem of the under-developed countries.

The humanitarian demining does not possess viable answers, even if long concerns and lots of efforts have been undertaken to solve it. The idea here is to tackle it by bottom up approach, trying to operate with smooth continuity by respect the local technological know-how, so that the overseeing and recovery processes could develop with appropriateness. This will help expanding the people consciousness to become the master of their own safety, by qualifying commonly accepted devices and techniques and turning them towards demining aids.

The study addresses the Sri Lanka situation, assuming facts of the in-progress guerrilla and special details on the on-the-field conditioning peculiarities. The Govern of Sri Lanka, GoSL, has the capability to capture the territory, as shown by the recent east region operations, in spite of mined areas by the Liberation Tigers of Tamil Eelam, LTTE, to stop the Government troops. But the holding proves hard, pushing to new mine spreading, as doable hindrance against the LTTE mobility. The humanitarian demining is done over again, as the land is temporarily seized, but very slowly, because of lack of facilities and of new buried mines at troops withdrawal. The charge transforms into endless business, not even fulfilled, before it needs to be started once more. The business funding, Fig. 9, shows that, in the 2002-2005 period, the mine clearing efficiency decreases and the cost quickly rises. Finally, the cost per mine is higher than the mean household income in Sri Lanka. This is 12 802 Rs (125 $) in 2002. It consumes huge (international and local) money, without efficient return, out of the temporary wages for the (ceaseless) demining. The business cannot reside in the clearing operations, rather in restoring the community conditions for the economical growth. If the political frame cannot give any chance, the problem needs to be tackled by different ways.

	Funds ($ million)	Cleared mines (N)	Cleared Area (m^2)	Cost for mine removal ($)
2002-2003	6,0	45 000	16 356 485	133
2003-2004	15,8	44 000	2 155 364	359
2004-2005	23,6	34 000	3 831 353	694
Total	45,4	123 000	22 343 202	

Figure 9: Funds received for humanitarian demining

The poverty and lack of future prospects are major motivation behind landmine terrorism. The technology-driven solutions are unsuited in 3rd world countries. The clearing cannot be solved by the advanced robotics. Most devices work well for clean and truthful tasks. If the environment downgrades, sophistication and cost rise, while effectiveness and appropriateness decrease. When the price to performance ratio is too high, the robots are academic toys. The demining projects need to involve the local peoples. The operators shall be familiar with the equipment, they are required to use. Then, it is easy to teach them how to use the rigs, and education avoids the necessity to hire foreign specialists. The resort to foreign people is high costly: as a rule, their salary is over 1 000 $, while the local operators work for ten times less. People who live in the north east Sri Lanka are very poor, and any job helps for earn some money, relieving the most urgent necessities.

The local population's technical knowledge is limited, and the access to high technology fixtures is almost nonexistent. Local materials, local manufacturing and local manpower should be used to fulfil the demining operations and to maintain the involved equipment. On one side, low complexity and safe-use machines are highly desirable: an example is the simple tractor or other agricultural machinery. The other side, the operators, instead of endless demining, need to focus on the reclamation effectiveness, to the quickest coming back at their farming duties. God helps those, who help themselves.

The search of solutions, for the landmine problem in the Sri Lanka situation, permits to identify a series of aspects to be taken as characterising lines. Both GoSL and LTTE believe to obtain benefits from landmine giving out, and are confident that, under the current situation, the damages produced to the antagonistic part result into many internally displaced people, with severe effects on the social and economic growth of the spoilt populations, thus, with huge damage due to terrorism.

The idea behind the prospected approach is to change the landmine spreading into basically useless intervention, so that, out of the existing socio-political implications, no real profit is won by terrorist actions. On the contrary, the economical falls-off would be poor, without helpful outcomes: nearly no indirect benefit, leaving clear the responsibility hatefulness.

On the said facts, the engineering approach to the mine clearing business reduces to devising the instrumental process, and the work organisation, to be enabled as routine demining duty, is, each time, crucial. The operators are enrolled on place. The means exploit the local know-how, with resort to the standard agricultural equipment. The efficiency assures high reaching. The process safety and reliability are fit for the required duties. Should these figures be reached, the terrorist effects disappear, and the mine spreading ceases to be winning fact, during the tactical occupation of the enemy lands, as the routine duty minimises threats and fully avoids injuring upshots. The idea is to bring industrial efficiency on-process, assuring high clearing productivity, by the intelligent work-flow programming and high reliability by special-purpose low-cost robotic equipment.

The analysis is standard issue, with the following statements:

- the engaged technologies need to use special purpose outfits, having duty-driven consistency, and to exploit operators adapted uniformity;
- the work-flow pre-setting ought to detail the work-cycles and standard achievements, and to specify the on-going failure protection rules;
- the operators' instruction and training aim at off-process optimised work-flows, notably, to circumvent the emergency of risky engagements;
- the effectiveness comes from organised routine jobs, fulfilled by the work-force diligent activity, in entire conformity to the allotted tasks;
- the local Civil Service is entitled of the authority to promote the mine clearing operations, and the involved community is solidly concerned.

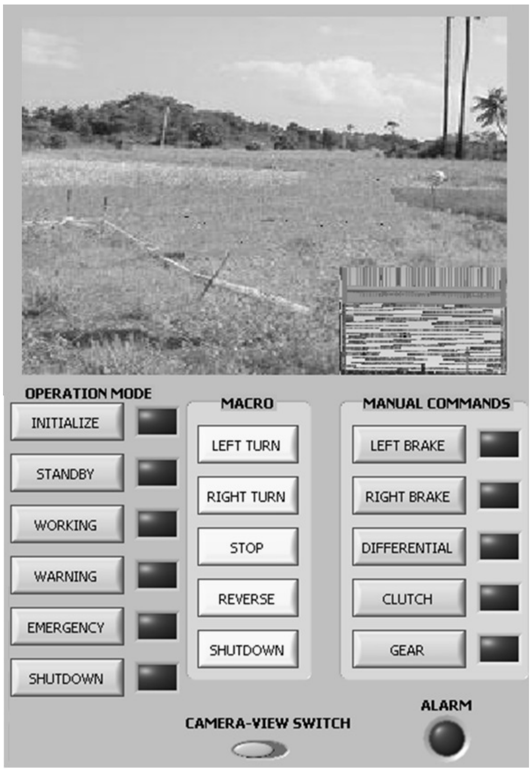

Figure 10: Example man-machine visual interface

The hazardous work conditions absolutely forbid the presence of human personnel in the front effectors neighbourhoods. The remote steering is simple, with today hardware/software tools.

The large availability of personal computers allows preliminary tests on the govern logic (the real-time job allocation is fulfilled by process-computers), having full consistency with the setting. The remote monitoring, steering and governing goals are here chosen, because of:

- the capability of working in hazardous zones, with the operators in safe location;
- the ability for the remote setting and the duty autonomy (at least, to face emergencies);
- the measurements restitution, to provide human perception of the remote operations;
- the experimentation on the faults autonomic management and recovery potentials;
- the exploration of the highest level of reliability, in on-the-field operation contexts.

Explanatory hints add. The duty autonomy allows starting recovery cycles with no time delay. The operator perception is enhanced by client-server request, and remote processor up-dating the on-process parameters. The visual restitution (from the front cameras), Fig. 10, uses graphical interface, where the damage impact is fully understood. The reliability is achieved by the build-up of a state machine, in which the tasks are executed under the real-time processor supervision, and by the command logics, at three levels: macro (decentralised); single step (sequential); and warning (remote steering consent). The three levels, moreover, permits to steadily enhance the attention of operator to the operations dangerousness. The display keys, Fig. 10, exemplify the inter relationship between the defined control modes. The initialize mode applies to the equipment for the manually start. The control mode is in standby; when in start, the equipment is ready to perform the allotted task; when in working mode, the machine is performing the all duty-cycle. The emergency mode is helpful to detect and recover from any urgent situation, occurred while the duty-cycle progresses. In shutdown mode, the machine is in total stop. The all control modes can be by-passed by operator. However, the working and emergency modes have limited autonomous performing abilities, under the operator's overseeing.

The resource integration, as already mentioned, is off-process operation, mainly, depending on the carrier availability. The effectors choice is more related to the ground processing state: flail outfits are successful at lower speeds to carefully sweep every region, and reaches effectiveness, if the mine blast does not affect the on-process equipment; the lifting effectors require more complex agendas, with stop-and-go manoeuvres, resort to soil loosening and watchful picking of the dangerous items, achieving, however, high clearing reliability. The direct involvement of the local front-end operators means, also, their active decision-keeping as for the resource combination and for the work-agendas planning.

CONCLUSION

The personnel landmines are scourge of third world peoples: humanitarian demining quickly turns into ceaseless palliative, without actual issues, if the cost of the engaged techniques are too large, either the efficiency of the current operations are too low, as compared with the mine spreading potentials. The novel approach aims at joining lean and cheap contrivances and workers, with safe, reliable and effective robotic mine clearing, providing unusual *productivity* prospects, with widespread and friendly means and methods. The devised solution develops along four lines:

- to conceive and implement low-cost robotic equipment, assuring effective, safe and reliable demining: the resources (facilities, functions, fixtures) choice permits devising worthy strategies;
- to help out equipment integration, with resort to cheap and widely available (agricultural) fixtures: the on-process adaptive work-cycles lead to better tactical concert;
- to provide the modelling and simulation background for the on-duty assessment and training assistance: the alarm (warning, emergency) management allows joining efficiency recovery and safety;
- to make easier the operators involvement in self-learning and up-grading duties: the resources exploitation at the strategic, tactical and execution horizons exploits the mixed-mode automation.

The background is in reinterpreting some flexible-automation concepts, in keeping with the effectiveness of the dramatic productivity of the industrial organisation. The said lines are, thereafter, moved back to four steps:

to implement effective duty-driven architectures, with the modular build-up of the robotic resources: - the mobility providers, for explanatory purpose identified by light tractors or power tiller; - the front end effectors, assuring safe and reliable mine clearing on properly wide soil extensions; the two, providing effective processing functions, according to related task-oriented proficiency;

to integrate equipment and processes, to assure appropriate operation work-cycle and command logics, say: - ground stripe lifting, and mines singling out by gentle sieve descent of the shifted earth; - land sweeping by forward displaced flail and tiller apparatuses, inducing mines bursts; joining the task orientation with the steady/alarm processing sequences documented evidence;

to manage the resources by suited modelling and simulation features, aiming at intelligent automation: - with the proper versatility, to face all the basic requirements on the strategic horizons; - with high effectiveness to deal with the steady agendas, on the tactical horizons; - with safe reliability, to face warning and emergencies, on the execution horizons;

to motivate the front-end workers, by individual commitment and collaborative rewarding, enhanced by: - technological appropriateness, all the resources being directly provisioned from local equipment; - operation friendliness, all procedures being constantly adapted by the operator loyalty; together promoting the information loops incessant closure, with non-stop engagement of local people.

The paper summarises the main aspects of this challenging bet, starting by the implementation of the robot architectures, the related modularity, permitting the inter-changeability of the effectors, so that, e.g., the same carrier can be differently fitted, depending on the soil conditions. This makes significant the integration step, to be standard practice for the off-process mine clearing strategic setting. The modelling and simulation step is even more important, being the fundamental means to manage the flexibility, by effective switching to the most appropriate engagement conditions. Additional details and comments might usefully better explain the whole project, and will be outlined during the presentation with explanatory example at the four steps: resources choice, robot integration, modelling and simulation features and operator motivation and training.

The focus on the industrial robotics capabilities is deemed the winning weapon, making possible to involve the local people in the *intelligent* work organisation, directly going beyond the old *scientific* work setting, typical of deeply structured societies.

The objective is consistent with the old meaning of "industry", «*diligence*, *assiduous activity at any work*», spurring the really damaged farmers to tireless involvement, and with its classic denotation, namely, the «*structured organisation*, *or systematic work or labour*». The blend leads to modify, in the "trend to innovation", the role of ideas behind the technologies (say, chiefly, the ability to prearrange assiduous labour, the *scientific work* organisation that assures the economic growth), because the diligence of the front-end operators (not the mastery of the individual craftsman or scientist), is winning weapon.

Today, we recognise several "industry" levels, replacing the men, with robots, managed by *intelligent work* organisation of self-governing facilities, each time the business awards yield from fixed assets. Nonetheless, the industrial revolution lies in the aptitude of ruling the work-force totality, by pre-assigned job allocation, once the processing outfits are properly chosen, and the pertinent know-how is duly widespread and accepted. Exclusively in such imperative situation, the technologies reach appropriateness, and lead to effective return to the involved populations. Anyway, it is always true that God helps those, who help themselves.

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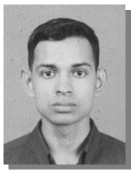

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