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Title: YUMA PROVING GROUNDS AUTOMATIC UXO DETECTION USING BIOMORPHIC ROBOTS

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June 1996

Los Alamos
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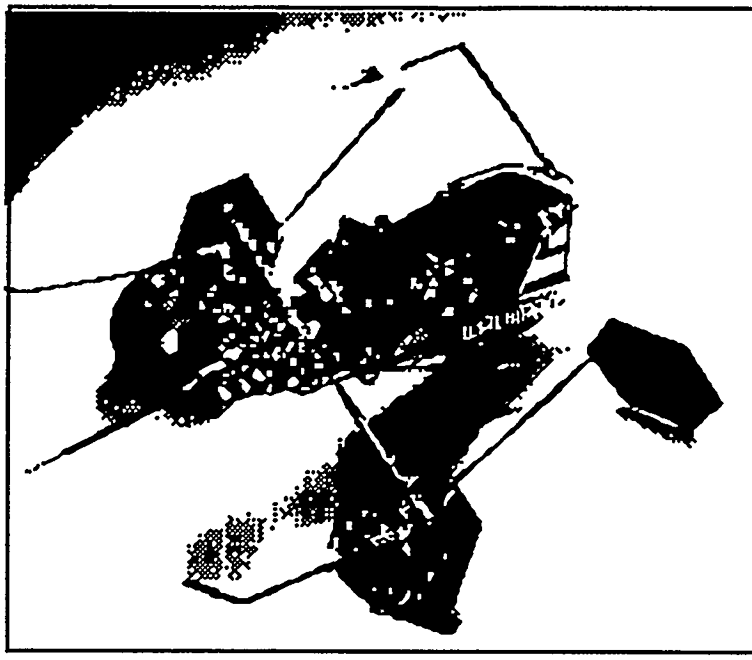
Yuma Proving Grounds Automatic UXO Detection using Biomorphic Robots.



Walkman Solar 1.1:

12 Nv neuron, high temperature, high power walker designed for desert environments. Self starting, self regulating, WS 1.1 runs continuously on 20mA currents provided by several redundant solar cells. A first generation prototype for long term, autonomous UXO detection.

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White Paper: Yuma Proving Grounds Automatic UXO Detection using Biomorphic Robots.

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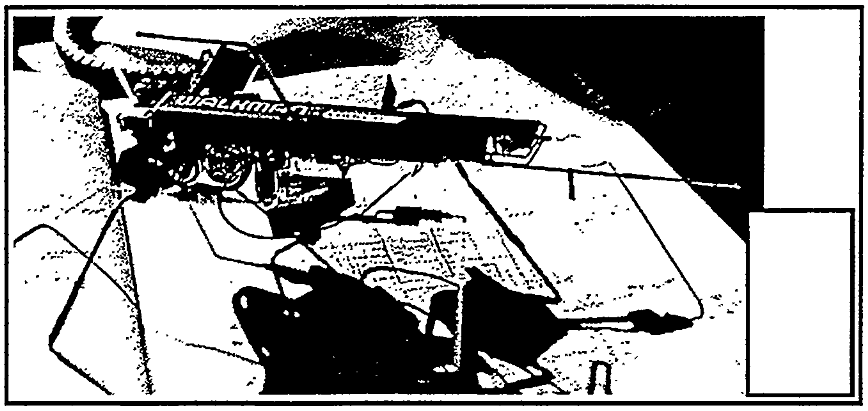
Abstract:

The current variety and dispersion of Unexploded Ordnance (UXO) is a daunting technological problem for current sensory and extraction techniques. The bottom line is that the only way to insure a live UXO has been found and removed is to step on it. As this is an upsetting proposition for biological organisms like animals, farmers, or Yuma field personnel, this paper details a non-biological approach to developing inexpensive, automatic machines that will find, tag, and may eventually remove UXO from a variety of terrains by several proposed methods.

The Yuma proving grounds (Arizona) has been pelted with bombs, mines, missiles, and shells since the 1940s. The idea of automatic machines that can clean up after such testing is an old one but as yet unrealized because of the daunting cost, power and complexity requirements of capable robot mechanisms. It has been very difficult to give machines "skills" that can encompass the day-to-day problems of working in unstructured environments such as a field or forest. However a researcher at Los Alamos National Laboratory has invented and developed a new variety of "living" robots that are solar powered, legged, autonomous, adaptive to massive damage, and very inexpensive. This technology, called Nervous Networks (Nv), allows for the creation of capable walking mechanisms (known as "Biomorphic Robots", or "Biomechs" for short) that rather than work from "task" principles use instead a "survival-based" design philosophy. This allows Nv based machines to continue doing work even after multiple limbs and sensors have been removed or damaged, and to dynamically negotiate complex terrains as an emergent property of their operation ("fighting to proceed" as it were). They are not programmed, and indeed, the twelve transistor Nv controller keeps their electronic cost well below that of most pocket radios. It is suspected that advanced forms of these machines in huge numbers may be an interesting, capable solution to the problem of general and specific UXO identification, tagging, and removal.



"Walkman 1.0", the first experimental twelve transistor Nv design.

The application concept is simple. These devices move towards whatever stimulus they are hard-wired to perceive. If this stimulus is UXO (as provided by any of a range of possible detectors), then these machines will fight to acquire to them despite obstacles and danger. They have no memory and as such will continue their task for as long as they have sufficient power, ability, and remaining legs. If they are solar powered, careful and methodical cleaning tasks can potentially go on for years (Some lab based solar prototypes have been in continuous operation for over five years now). If the devices are made from sufficiently cheap materials, they could be left in-field to provide cleanup services until they fail, at which time their proposed "biodegradable" bodies will decay with minimal environmental cost. A long term goal is to make these devices cheap and widespread enough so that they can continue to remediate UXO long after an area is officially "clear". Machines which will continue to do an unpleasant task in unpleasant areas to assure human operatives that remediation continues.

The Yuma problem for such machines was looked at for several reasons. The problem is real, the need immediate, and the terrain so hostile that many other computer based approaches have generally failed. The Yuma terrain is excessively hot during the day (140 degrees F. nominal ground temperature, 165 degrees max.) and freezing at night, excessively alkaline soils and fine sands, over fourteen types of complex desert terrain including cliffs and rock mesas, high airborne humidity (80% nominal), dust-laden winds, harsh vegetation (Barrel cactus to Spineweed), and occupied by rattlesnakes, scorpions, wild horses, and fifty years worth of military scrap metal. Even careful mapping has not been able to keep adequate track of all UXO because of both the variability of terrain characteristics and the unpredictable behavior of UXO deployments. The result is a vast hostile terrain littered with shifting military metal, some of which can still explode.

Yuma (AZ.)Terrain. All this and scattered UXO.

On the other hand, Yuma does get over three-hundred days a year of unobscured sunlight, and less than two inches of rain, which means that for adequately designed solar-powered Biomechs, there's enough power to go around, and little rain to obscure sensors and rust robot structures. For the right kind of robo-organism, it could be ideal.

The Yuma problem statement is map it, clean it up, thoroughly and cheaply, with as little human endangerment as possible. How fast is not so much an issue as some UXO has been sitting around for over forty years. The Yuma mission statement can be broken down into three parts by priority:

1 - Identification, monitoring, and tagging.
2 - Neutralization.
3 - Remediation.

This breakdown also matches the development of UXO Biomech development with a 0-th statement; make something with sufficient ability just to survive the terrain. After that, "domesticate" the devices into performing the tasks above, the goal to produce an array of cheap, disposable robots that will systematically tag, stomp, or pound UXO areas blowing up all they encounter, or collect debris and small ordnance for remote disposal. As ordnance is designed to inflict damage to humans and vehicles, these robots will be designed to withstand (accidental) blasts with the greatest chance of continued survival.

The goal is to make machines which are terrain capable, solar powered, easily repaired (or salvageable with interchangeable components), long lasting, and simple enough to use effectively in a variety of UXO clearance operations.

Biomech Design Advantages:

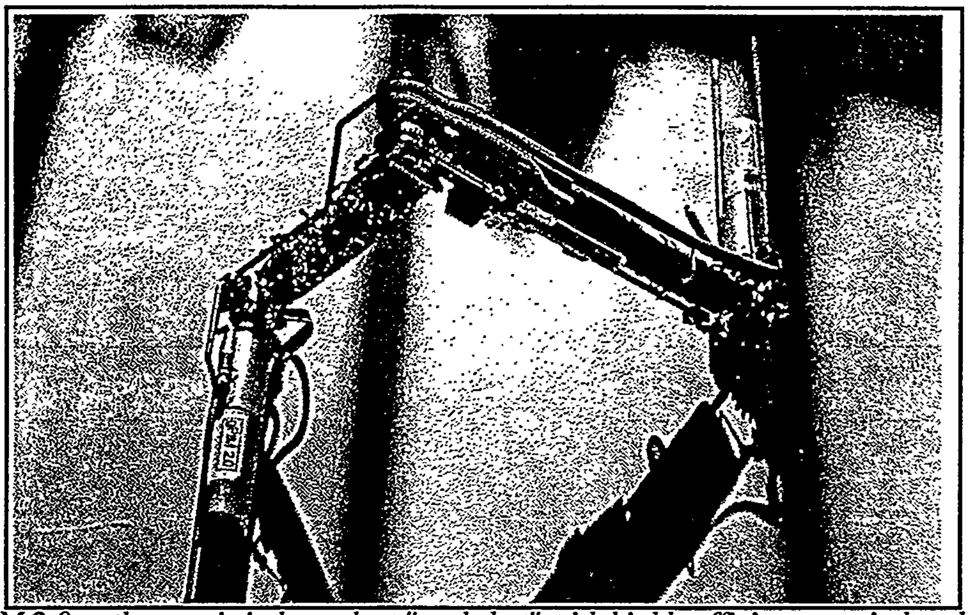
The primary advantage of legged UXO sweepers compared to wheeled machines is that legged machines can survive under-foot explosions much better than wheeled or tracked designs. For example, if a robots legs are made from slim carbon steel or similar tough alloys, then if/when an explosion occurs under foot, the blast then has only a very small surface area to react upon directing the blast up rather than out. This serves to minimize damage to both the immediate area and the robot itself. If the robots legs are suspended and if the robot is of a certain size, only one of four things can happen:

1 - the robot will flex its leg to the blast and carry on.
2 - the robot will flip over and carry on walking on its knees.
3 - the robot will loose a bit of leg, but still carry on.
4 - the robot will be shattered by the force of the blast.

If one, two, or three, the machine will continue to hunt for more UXO (albeit slower. Prototypes which exhibit these behaviors do exist). If four, then robots must be designed that are cheaper to produce than the average cost of the UXO they remove (nominally $27 per anti-personnel mine). Recent work shows that this may be feasible given the discounts possible with mass-production and an adequate industrial partner, and the more machines deployed, the more thorough the coverage.

As well, if a robot is deployed to deliberately trigger live UXO, there is an advantage in that a legged machine puts over twice its weight on each leg every forward step it takes. This means that a forty pound robot (for example, prototypes under development) can put down better than eighty pound steps, more than enough to trigger an average sub-surface anti-personnel mine (as an example of the most prevalent form of international UXO). The advantage is that when the UXO explodes, the robot being only forty pounds will not suffer the inertial damage otherwise delivered to a larger, heavier body. The robot can be designed so it could "roll" with the blast. This damage can be further reduced with flexible materials and suspensive designs, and the placing of the main motor/control/payload/power components a reasonable distance from the blast (as in the "High-Stepper" or "Turbot" designs detailed later in this paper).

Legged designs are also, as nature has shown, capable of negotiating much more varied terrains than wheeled devices. Where walking is not practical, slithering is (robot snake mechanisms are proposed for mined jungle environments. As yet, the current prototypes await further study).



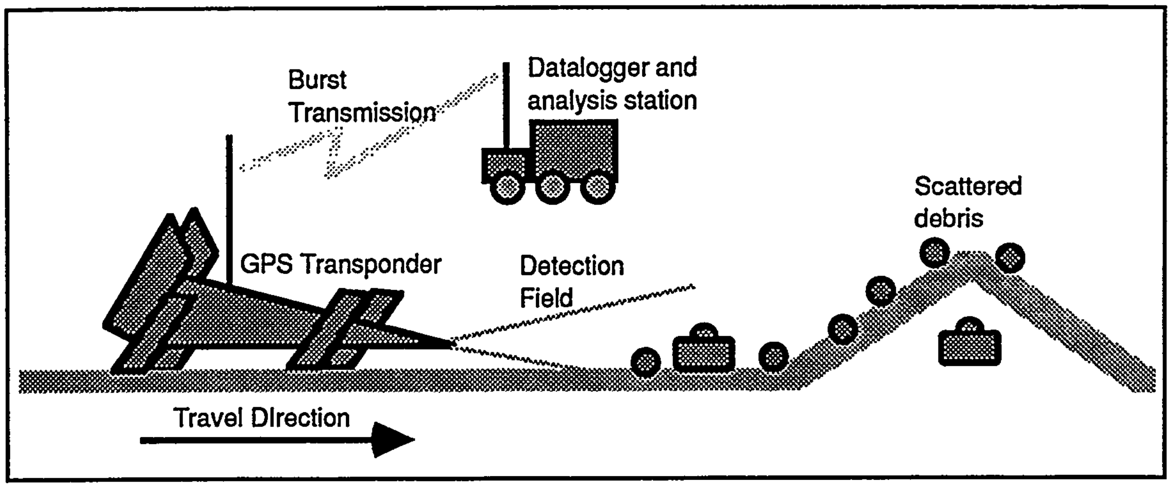
gPIM 2.0, a three-axis independent "snakebot" with highly efficient terrain handling potential.

As in nature, there is no one universal machine that can negotiate all terrains, but as these devices have a broad reconfiguration space they can be customized easily to everything from desert to snow-tundra environments. Design of these machines is directly related to the limit complexity of the environment to be traversed. Eventually, a robots design will be as simple as getting detailed environment specifications about the afflicted area. For Yuma, the initial research devices will be designed to cover level, vegetation stripped areas of loose rock and sand strewn with UXO and mark their positions. These are the standard "target" fields used in bombing tests, and are the first order problem for cleanup at the Yuma site. A simple problem, but an important first step in proving and refining the technology.

Implementation:

Given the current level of Biomech research and application possibilities, the best method of machine development involves specializing various classes of Biomechs for particular UXO remediation tasks. This section details the potential of Biomech designs to handle a range of perceived UXO clean up problems.

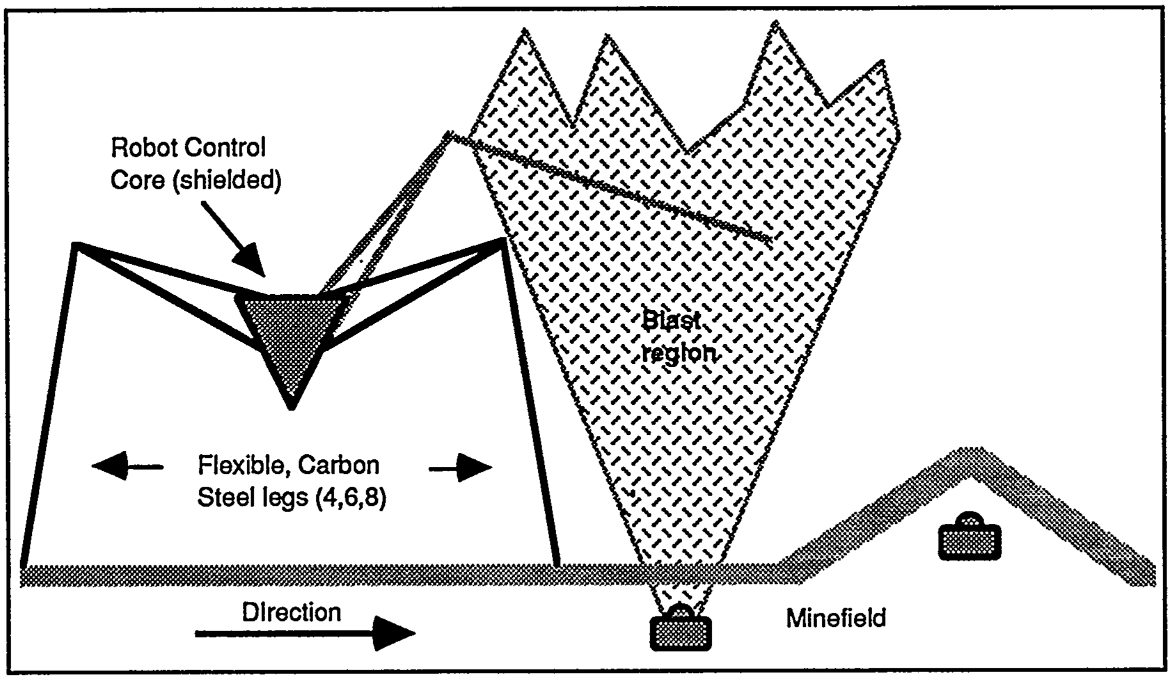
The most likely option for the first generation of Yuma application focused robots would be the "GPS Tagger"; a machine that can systematically scan an area for perceptible UXO and report back the exact position of same to a remote data logger. This data can then be analyzed later or interactively by specialists or automatic programs. Furthermore the data will give efficiency profiles on the robots operation that will be invaluable to the development of next-generation machines. The power of this technique is that the inexpensive Tagger robots will not contain any costly components (minus the initial cost of telemetry equipment), be close to the ground for best sensing resolution, and be untethered so as to cover the largest possible areas without restriction.



A "Walkman" Tagger robot. Objects are identified with a variety of UXO sensors and those that exceed certain criteria are reported back to the datalogger station. With adequate sensors (to be determined), Biomechs can be made to not mistake debris for ordnance.

Once this simple task can be handled by solar-Biomechs at a speed and sufficiency adequate to Yuma personnel, the technology will be sufficiently advanced enough for subsequent research into more advanced applications as follows.

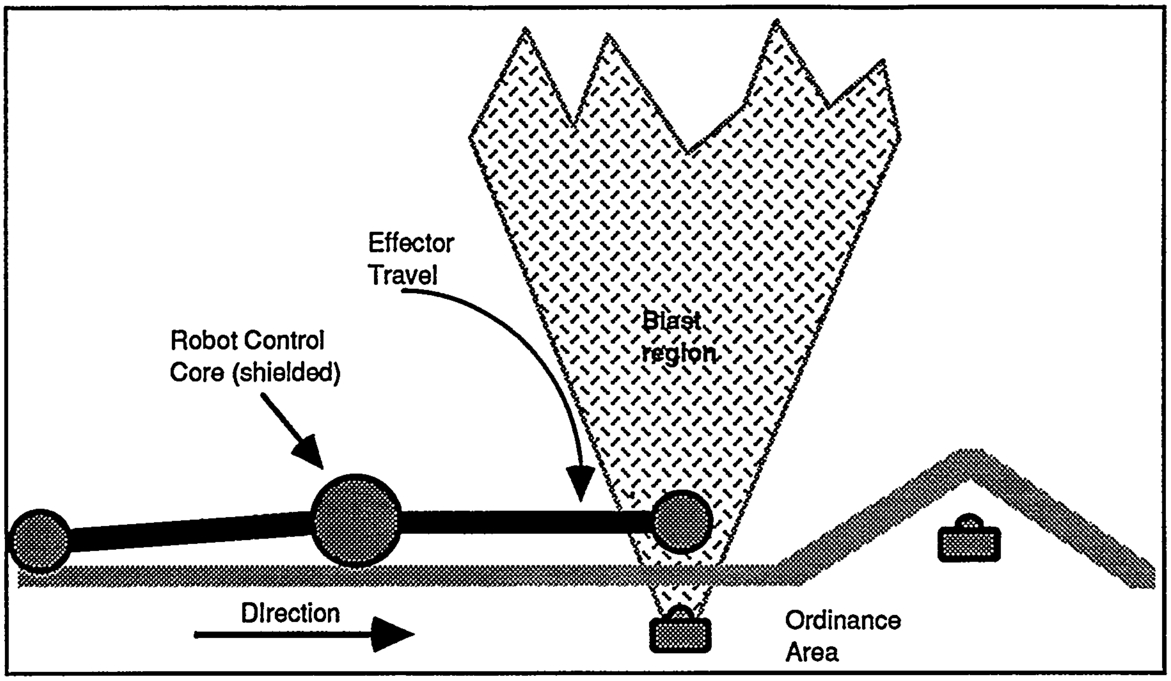
The "High-Stepper" design takes into account that some "smart" UXO may be listening for the sound of biologic footsteps, and that sub-surface UXO detectors may need a broad view area and be well protected. It also has the advantage of being able to negotiate very rocky or plant strewn terrains because of it's high under-carriage clearance.



A biomorphic "High-Stepper" robot with its control apparatus, sensors, and solar cells in a contained, blast-resistant cone, responding to an explosion underfoot.

The previous figure shows a High-Stepper design that would be necessary for environments where bushes, rocks or grasses may hinder progress. At Yuma it also has the advantage of keeping the main control and motor housing above the eleven inch "hot zone" that lies above the desert surface. This could be important if larger versions of the device are to carry computers, transponders, and other instruments that may be temperature sensitive.

The second potential remediation design is the "Turbot Ground-Pounder", best described as a self-mobile barbell. Based upon the diffusing motions of lichen, anemones, and cells, the "Turbot" (from "Turing Machine Robot") is a device that lifts and drops heavy end effectors on the ground as it travels. The idea is that the shock of pounding will detonate ordinance within an area, while the low profile of the device serves to protect the single robot motor and control core from explosion.

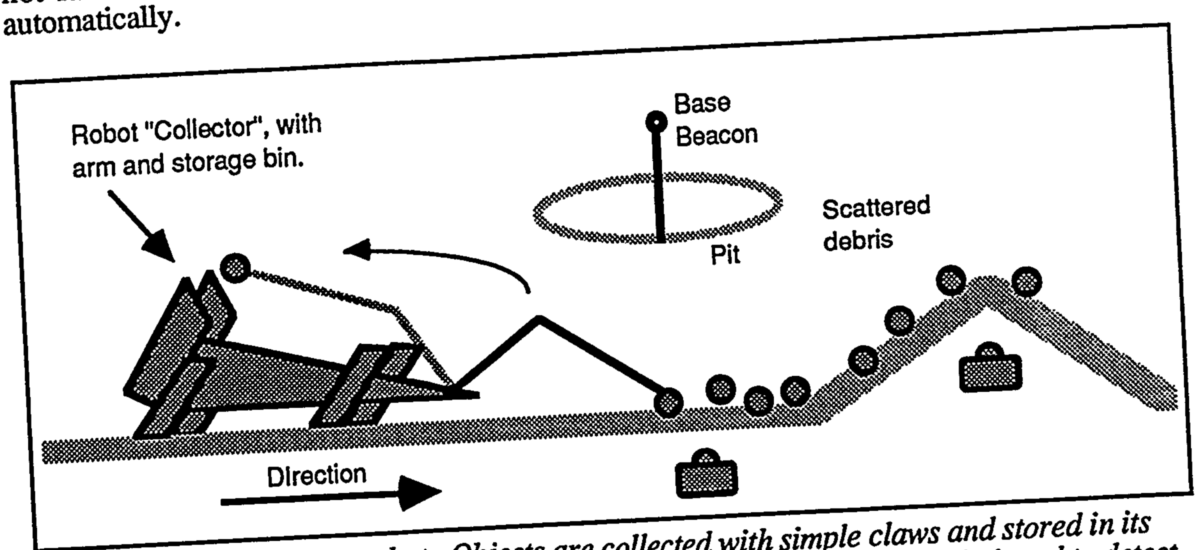


The ground-pounding "Turbot" design. A two-legged robot "barbell" for many terrain applications. Initial lab tests on a seven inch prototype have indicated that not only does the pounding action work well, but the device naturally travels in large spirals that thoroughly "covers" the terrain.

This design is a brute force technique and can only have effectiveness where plant life will not dampen the impact effects (as in Yuma scrub-zones). However, as an obvious, inexpensive, "test-if-it's-live" technique, the Turbot is an example of an alternate design based upon alternate need. Because of its travel technique, it would be unlikely that complex sensors would be deployed on the device. It is a steel beast of burden, and in sufficient sizes and quantities, has the potential of randomly clearing an area of live UXO.

The fourth proposed design is the most complex, and is based upon evidence of cooperative behavior in Biomech research prototypes. The idea is that "herds" of careful Biomech machines would carefully orbit a Base Beacon in unpredictable but bounded circles looking for small, surface UXO. When they find some they will carefully collect it, and move on to the next. When they have a full load they would go to the Beacon which is a solar-transponder in the center of a large remediation pit and dump their load. If a robot survives this procedure, it will then return to its hunter-gatherer operations and repeat as long as able.

When the pit is full (to the automatic beacons satisfaction), it can then detonate an explosive charge at it's base and "clears" the collected UXO by the classical technique (subject to human checks and authorization). The robots would then move on to orbit another beacon not far from the first in an overlapping but different area, and cleanup can proceed automatically.



A "Walkman" gatherer robot. Objects are collected with simple claws and stored in its collector bin. The gatherer can retrieve any unique object its sensors are designed to detect.

This remediation technique has some advantage because the robots do not have to be of the same type to perform this task. Indeed, any subsets of the previous robots discussed would allow for multi-level, multi-sensor, multi-terrain, multi-mode cleanups for as long as the population can last. If various "species" of Biomorph designs, optimized for particular terrains are applied to a complex area, the more types applied, the more thorough the coverage. This is because many robots will go over ground covered by others but in a different manner, thus increasing remediation probabilities.

For more level Yuma terrains like fields, deserts, or sand, lower, wider robot designs would do better at avoiding blast-shock. This is an example of where the machine must be adjusted to fit the environmental constraints first. Mine removing robots are of little use if they cannot handle the complexities of a particular terrain. Survival is always key, but research is required just to make a machine that won't get stuck. By the time the Gatherer robot technique is tested and operational (possibly during the sumer of 1996), research will have become an applied engineering discipline

Current Biomech Design Approaches and Results:

In September of 1995, six diverse Biomechs were first introduced to the harsh Yuma environment in a typical scrub zone of cleared rock and sand. They were only proof-of-concept prototypes and not built with Yuma in mind, nevertheless, three managed crude progress while three others failed immediately. Of the failures, all were heat related and were due to both solar cells and power capacitors operating well outside their tolerance ranges. The Nv (Nervous Network) control cores themselves did not fail in any device which was encouraging. It meant that the brains survived, only the bodies were weak.

Of the devices that did manage to move, the twenty-four inch battery powered "Jerry" did best except that its feet dragged more than lifted, and eventually just wound up digging in the sand. The second was an eight-inch long "Sunspot" solar design which had the problem of digging its spade-like feet in loose sand and stalling out. The final machine, the foot-long "Walkman Solar 1.0" did quite well with its high center and fine, steel feet, but was hindered by two-percent efficient solar cells which limited foot lift. It worked, but far to weakly to carry a significant payload.

The first generation experimental "Walkman Solar 1.0" making a nasty discovery during the first Yuma Biomech Test. Although not equipped with adequate sensors to detect the 180mm mortar shell, it did walk around it as part of the environment.

Later analysis of this group showed that the strong alkali air had also corroded the fine brushes on the DC drive motors. Circuit oxidation was also in evidence, meaning that either sacrificial anodes, conformal coatings, or both would be necessary to keep future circuitry from eventually eating away altogether. Furthermore, the fine dust in the air had severely damaged the open gear bearings on several fine medical-quality motors, and the hot sand had rapidly worn the fiberglass feet used on several of the walkers. All this from just half a day exposed to a typical Yuma summer.

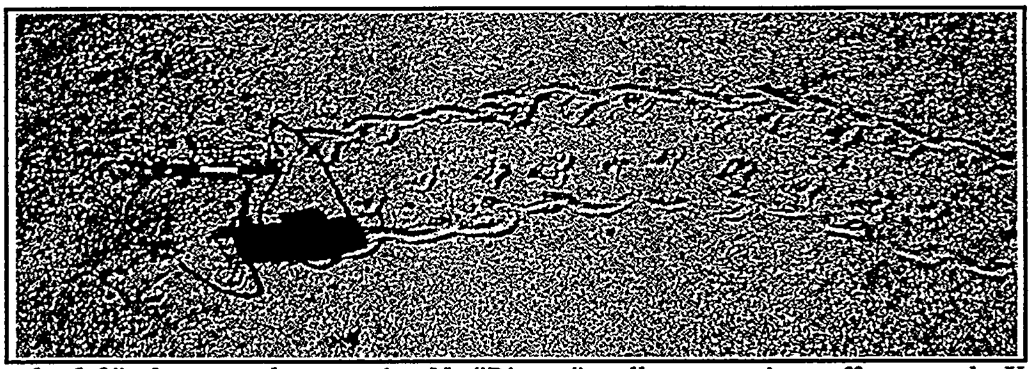
Results from these first devices lead to a series of questions about the capability of Biomech designs for various Yuma terrains; scrub, sand, desert, and manganese persulphate rock. Questions of design, power, control, and even foot shape had to be answered but the sample space was too indistinct to indicate one particular design. As such, seven second generation designs were proposed to help pinpoint the best, Yuma-specific survival design parameters. These designs were as follows:

"TUMBLER" Designs:
1 - Stepper Turbot
2 - Snake Turbot

"WALKER" Designs:
3 - Stepper walker
4 - High-speed walker
5 - Bicore walker
6 - Microcore walker
7 - Large-scale Biomech leg prototype

These represented the broadest range of possible high-reliability controllers and physical design parameters. Each machine was made heat and dust resistant, and designed with variable structural and electrical parameters to assess their function under a variety of terrain conditions. The results would then be analyzed to determine the most likely design constraints for the proposed third-generation Yuma Walker (the one meter high test platform, capable of carrying test sensor and transponder payloads).

In January 1996, a second field test using the seven new Yuma-specific Biomechs showed that progress had been made. The stepper Turbot, Microcore, Bicore, and Stepper-walkman (stepper motors have no brushes to corrode) did very well in both loose sand, rock, and high-boulder terrains. Microcore walker was the champion machine at negotiating tough terrain, which was significant as it was also the only solar powered machine working that day. Details are lengthy, but there is now sufficient confidence that a third generation, large scale machine can be built to try and satisfy the first Yuma operations criteria; a "Tagger" robot for UXO remediation.



"Gumby 1.0", the second generation Nv "Bicore" walker struts its stuff across the Yuma outback (Jan. 96). Analysis of the tracks left by such travels gives a good indication of walking efficiency.

This first, large-scale Biomech machine will be designed with replaceable modules to test various GPS, sensor and control features, and is currently intended for a several week test in the Yuma environment, summer 1996. Feedback from Yuma personnel (anecdotes, complaints, suggestions) will shape the range of further advances in the next generation.

Of course, the data may also indicate that different machines are optimal for different environments, much as nature has proved. The original seven will be remodified and reintroduced during the summer to determine why some (the snake and high-speed

"Skitter" walker) failed to operate as expected. Nonetheless, it is hoped some optimal robot design parameters will emerge, and engineering principles can be formalized.

The principle investigator will gladly demonstrate his robots on request. A video is also available detailing the results of the first Yuma Biomech tests.

Is all.

Mark W. Tilden
Feb. 28, 1996.

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Pointers to Electronic Info Sources on Biomech Tech:

WWW sites:

http://sst.lanl.gov/robot/
http://www.cuug.ab.ca:8001/~hrynkiwd/index.html

Anonymous FTP:

address: math.uwaterloo.ca
user name: anonymous
password: your email address
directory: /pub/beam/lm.papers
file: lm.ps.Z.txt

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