Potential Role of Insects in Rescue Mission - A Boon for Artificial Intelligence

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Abstract: This article presents an extensive global review of literature on the role of insects in "rescue mission". From times immemorial, insects were used as a biological weapon on a foe country and it's an age-old concept wherein they were targeted against healthy crops as well as used as vectors for transmission and dissemination of diseases in animals and human beings. In both the former cases their after effects are devastating. Apart from the bane, exploitation of potential role of insects in the rescue mission is now a boon for mankind with ample scope due to the present day advancement of artificial intelligence which is in vogue in military operations such as search, rescue and explosive detection.

Key words: Insects, search and rescue operation and explosive detection

As we all know that insects are mankind's greatest foes, ironically, they have become sources of innovation for advanced military technology (Lockwood, 2012). The significance of this article is to reveal the potential role of insects in a rescue mission and also the multitudinous ways in which their services can be exploited in various military operations such as search and rescue operations and sniff out the explosives.

1. Walking/running insect species in: search and rescue operations

For search and rescue missions that require navigating narrow, unreachable spaces with rubble and debris, crawling insects are the best choice (Table 1 and 2). For example, crawling cyborg insects could explore disaster zones and aid in search-and-rescue operations. By effectively surveying areas inaccessible to rescue teams, these remote-controlled insects equipped with artificial intelligence could help find people buried under collapsed buildings (Maharbiz and Sato, 2010).

1.1. HI-MEMS (Hybrid Insect Micro-Electro-Mechanical Systems)

The hybrid insect micro-electro-mechanical systems (HI-MEMS) program, also known as the cyborg program powered by energy harvested from the insect itself, to drive various electronic devices is a proposal from the defence advanced research projects agency (DARPA) in 2006 to encourage the development of cyborg insects that can be controlled by humans.

1.1.1 Cyborg cetonid beetle

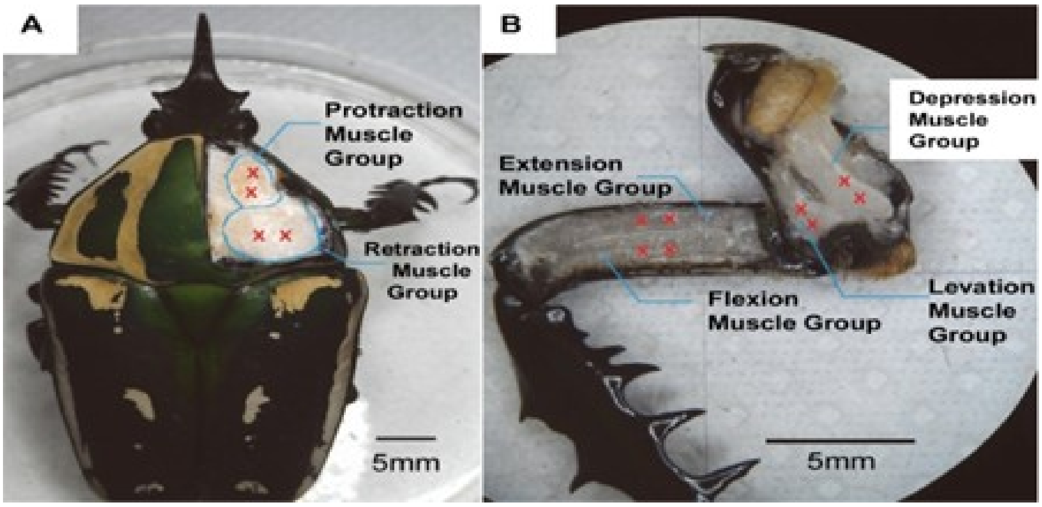

Fig. 1. Anatomical view of a beetle's front leg. Anatomical view of the three pairs of antagonistic muscle groups that control a beetle's front leg. Red crosses indicate the implantation sites for stimulation electrodes (A) The protraction/retraction muscle groups inside the prothorax, connect the coxa to the pronotum, and control the protraction/retraction motion of the coxa. (B) The levation/depression muscle groups inside the coxa control the levation/depression motion of the femur. The extension/flexion muscle groups inside the femur and control the extension/flexion motion of the tibia. [*Source*: Photographs were adapted from Sato *et al*. (2014) with permission].

In this study, a biological microactuator was demonstrated by closed-loop motion control of the front leg of an insect (*Mecynorrhina torquata*, beetle) *via*. electrical stimulation of the leg muscles (Fig.1). The three antagonistic pairs of muscle groups in the front leg enabled the actuator to have three degrees of freedom: protraction/retraction, levation/depression, and extension/flexion.

Protraction, retraction, flexion, and extension motions of a beetle's front leg elicited by electrical stimulation with a positive pulse train at 1 V, 100 Hz and a 1 ms pulse width. Each locomotion type was first stimulated individually, as shown in the upper four images; two muscles were then stimulated simultaneously to produce combined leg motion, as shown in the lower four images (Fig. 2). Each light-emitting diode (LED) near the beetle's head indicated the time when a particular stimulation site had been switched on. These findings related to and demonstrations of the leg motion control offer promise for the future development of a reliable, low-power, biological legged machine (i.e., an insect–machine hybrid legged robot) (Sato *et al*., 2014).

1.1.2 Locomotion control of hybrid cockroach robots

Locomotion control was achieved through electrical stimulation of the prothoracic ganglia, via. a remotely operated backpack system and implanted electrodes (Fig. 3). The hybrid discoid cockroach (*Blaberus discoidalis*) was able to move in forwarding motion, and turn-in response to an electrical stimulus to its nervous system but lack backward movement control. Initiation: Applying a controlled stimulus (2 V, 20 Hz) to the pro-ganglion elicits movement in the 1st set of legs. Left turn: Stimulating the right side of the ganglion with 2.5 V, 20 Hz. Right turn: Stimulating the left side of the ganglion with 2.5 V, 20 Hz. Cessation of walking or running: Any monostable signal above 2V applied for a long period. Application of another asymmetric signal will reinitiate movement (Liang *et al*., 2015). Eventually, Liang *et al*. (2015) were successful in finding the remote-controlled initiation, turnings and

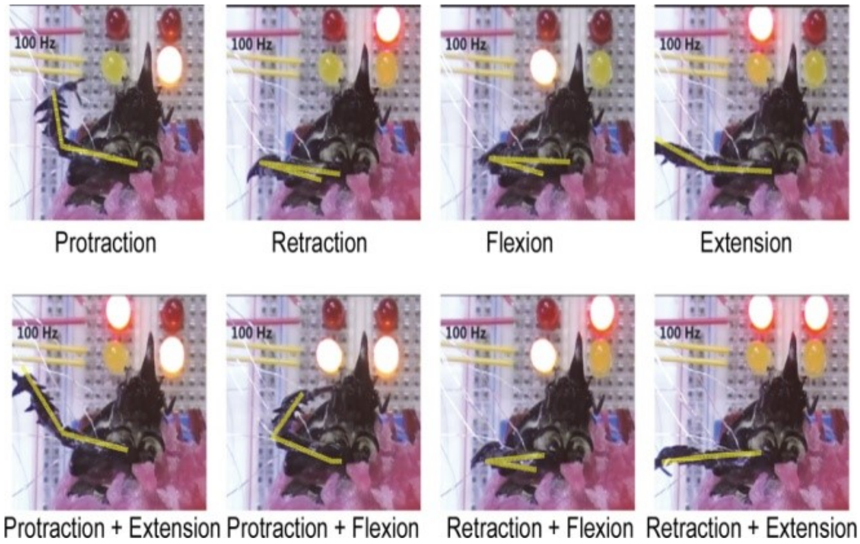

Fig. 2. Demonstration of controlling a beetle's front leg motions by electrical stimulation of muscles. Protraction, retraction, flexion, and extension motions of a beetle's front leg elicited by electrical stimulation with a positive pulse train at 100 Hz and a 1 ms pulse width. Each locomotion type was first stimulated individually, as shown in the upper four images; two muscles were then stimulated simultaneously to produce combined leg motion, as shown in the lower four images. Each light-emitting diode (LED) near the beetle's head indicated the time when a particular stimulation site had been switched on. [*Source*: Photographs were adapted from Sato *et al*. (2014) with permission].

cessation of cyborg cockroach. However, the fro movement of cockroach has to be fine-tuned.

1.1.3. Cyborg Darkling beetle

Zophobas morio, also known as darkling beetle, was used as the platform for this insect machine hybrid robot. The insect is an ideal model for this study because of its relatively small size (2-2.5 cm), lightweight (0.4-0.6 g), and long-life span (3 months). First scientists anaesthetized using CO_2 and implanted two electrodes in both antennae (Fig. 4) to stimulate the beetle. Two outputs are used to generate pulse trains at frequencies of 1–50 Hz for each of the antennae, and one input is used to receive command signals. The infrared (IR) receiver module is connected to this input to receive the IR signal emitted by the computer. One light-emitting diode (LED) is connected to each of the outputs to indicate the side, which is being stimulated (Sato *et al*., 2017). A pulse applied to the left antenna muscle produces a rightward motion; Right antenna muscle produces a leftward motion. The success rate ranges from 65% to 80% for stimulation frequencies between 1 and 10 Hz respectively, whereas, for the range from 20 to 50 Hz, the success rate is more than 85%. Stimulating both antennae with 2.5 V, 2 ms pulse width at the same time drove the beetle backwards. Eventually, Sato *et al*. (2017) found wireless control for initiation, turnings and cessation and even backward movement too.

2. Futuristic Bio Unmanned Aerial Vehicle in India

Proceedings of 4th national conference on "Emerging technologies and applications of UAVs" held on 22nd and 23rd march 2017 at International Institute for Aerospace Engineering and Management (IIAEM), Jain university, Bangalore reported the following proposal for search and rescue operation (Anonymous, 2017) (Table 3).

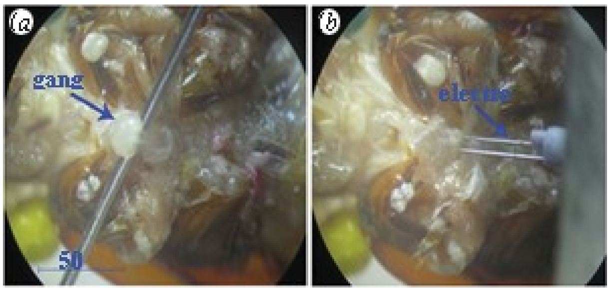

Fig. 3. Dissected images of (a) the location of the first thoracic ganglion (b) placement of two electrodes for localized stimulation in discoid roaches. [Source: Photographs were adapted from Liang et al. (2015) with permission]

3. Flying insect species in: - search and rescue operations.

3.1 Remote-controlled cyborg beetle:

Sato *et al*. (2009) presented the first report of radio control of a cyborg beetle in free-flight. The microsystem consisted of a radio-frequency receiver assembly, a micro battery and a live giant flower beetle platform (*Mecynorhina torquata*).

The assembly had five electrode stimulators implanted in between the left and right optic lobes, brain, posterior pronotum (counter electrode), right and left basalar flight muscles. Flight commands were wirelessly transferred to the beetle-mounted system via a radio frequency transmitter operated by a laptop running custom software (Beetle Commander V1.0) through a USB/Serial interface.

3.1.1 Flight Control

Flight initiation and cessation:

Above figure shows that flight initiation was triggered by applying a 2 V, 100 Hz, 20 % duty cycle that means 10 % positive pulse and 10 % negative pulse this way, alternating positive and negative potential pulses initiate flight in the beetle. One longer pulse to the

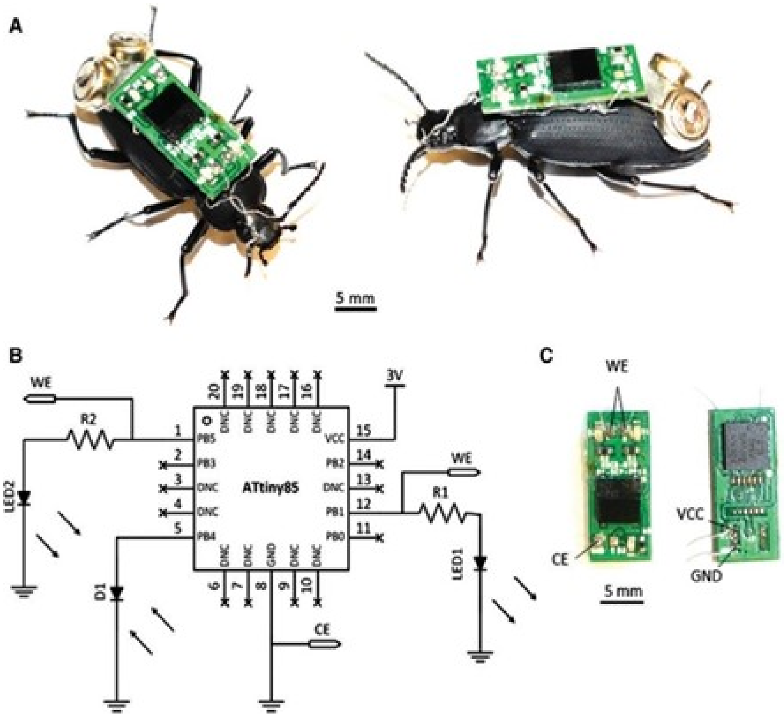

Fig. 4. (A) An overview of the insect–machine hybrid robot. A wireless stimulator backpack was mounted on to the living insect platform (*Zophobas morio*), with two WE, one implanted in each antenna and one CE implanted in the pronotum of the beetle. (B) Schematic view of the backpack. (C) Top view (left) and bottom view (right) of the backpack. CE, counter electrode; GND, ground terminal; VCC, positive power terminal; WE, working electrodes. [*Source*: Photographs were adapted from Sato *et al*. (2017) with permission].

same area stopped the wing oscillation completely.

Left and right turn

The turn could be elicited in free flight by applying 2 V, 100 Hz, 2.5 milliseconds positive potential pulses to either left or right basalar flight muscle. Right basalar muscle stimulation was elicited turn into the left side and left basalar muscle stimulation was elicit turn into the right side.

The flight path of a flying beetle wirelessly stimulated for turn control. T0 (0.00 sec) is the start time of the filming. At T1 (0.6 sec), the operator signalled a left turn from the base station (right basalar muscle stimulation). At T2 (1.6 sec), the operator switched the stimulated side from the right to the left basalar flight muscle, and the beetle turned right. At T3 (3.1 sec), the right basalar flight muscle was stimulated (left turn). At T4 (4.2 sec), the left basalar flight muscle and turning right again. At T5 (4.8 sec), the beetle touched on the curtain and stopped the flight.

They present the first-ever wireless flight control microsystem using a small RF receiver mounted on a live beetle and an RF transmitter operated from a base station. Flight initiation and cessation were accomplished by neural stimulation of both optic lobes while turning in free flight which were elicited by muscular stimulation of basalar flight muscle on either side. Finally, the first-ever wireless flight control microsystem using a small RF receiver mounted on a live beetle and an RF transmitter operated from a base station were presented.

3.2 Cyborg moth

Tsang *et al*. (2010) reported the first remote flight control of an insect using microfabricated flexible neuroprosthetic probes (FNPs) that directly interface with the animal's central nervous system. The FNPs have a novel split-ring design that incorporates the anatomical bi-cylinder structure of the nerve cord and allows for an efficient surgical process for implantation. Additionally, they have integrated carbon nanotube (CNT)-Au nanocomposites into the FNPs to enhance the charge injection capability of the probe. They created the insect-based Micro-Air-Vehicles (i-MAVs). The two basic components of the i-MAV are the telemetry system and the neuroprosthetic probe. The telemetry system provides a communication link between the insect and the base station, while the probe interfaces with the nervous system of the insect to bias the insect's flight path.

3.2.1 Implantation

They can implant the CNT- Au FNPs into adult moths as well as pupal stages (7-2 days before eclosion). The implantation is performed at the position of the ventral 4th abdominal segment for pupae and the ventral 1st abdominal segment for the adult moths.

3.2.2 Neural Stimulation & Flight Control

The observations were made on that stimulation of CNT- Au FNPs could elicit multi-directional abdominal movements in both pupae and adult moths. The directions of abdominal movement depend on the specific stimulation sites selected for stimulation, and the magnitude of the movements increased with increases in either voltage magnitude or pulse frequency of the stimulation signal. Additionally, the results of the CNT- Au FNPs stimulation of an adult moth using the wireless system are shown vertical and horizontal planes have been achieved with stimulations using various site pairs. Importantly, in the flight control experiment, we can force a freely flying moth to perform turning motions using the abdominal ruddering with these elicited abdomen motions. (Voldman *et al*., 2010).

3.3 Dragonfly Model with Optogenetic insect control backpack

Activate and steering neurons with light pulses
Channel rhodopsin - a photosensitive protein derived from *Chlamydomonas reinhardtii*, used for control neuronal activity - **(ChR).**
Holorhodopsin derived from the species *Natronomonas pharaonic* - **(HR).**
Gene transformation method- plasmid vector (pUAST) used to develop genetically modified dragonfly sensitive to light pulses.

3.3.1 Mode of action of Channel Rhodopsin and Holo Rhodopsin

Both are bacterial photosensitive proteins responding to a light pulse. These two protein genes inserted into dragonfly via a vector (pUAST). In case of blue LED light switch on by backpack system of a dragonfly. It allows **Na^{+}** and **Ca^{2+}** Influx and depolarization will generate the action potential and leads to flight initiation (Channel Rhodopsin). Whereas Halo Rhodopsin responds to the yellow LED light when switch on by backpack system of a dragonfly. It allows **Cl^{-}** influx and hyperpolarization will lead to neural silencing and flight cessation (Ackerman *et al*., 2017).

4. Insect species in: Explosive detection

4.1 Sniffer Bees

The team at Los Alamos national laboratory have begun to explore the potential for bees to be weapons detection devices. Stealthy Insect Sensor Project Team produces very accurate gradient maps showing the distribution of radioactive materials and other toxic contaminants. DARPA-funded research to train free-flying bees to detect certain scents- of landmines, for example-by

placing traces of the explosive chemicals near food sources (Timothy *et al*., 2005).
Pavlovian conditioning of bees just in 6 seconds. First time expose clean air, after exposing clean air with TNT (Tri nitro toluene) vapour and supply nectar water on antennae. Next time expose both TNT vapour and clean air, finally expose clean air with TNT vapour and supply nectar water to bouton. Now, these trained honey bees can detect TNT vapour with a food source. After visiting field (Place) honey bees come back then they are inserted into the cartridge to be placed in the monitoring apparatus to detect chemical traces.

The above photograph shows that automatic machine for training bees and detecting explosive chemical traces. It was first started by Ivan Hoo chief executive of Inscentinel (Entrepreneur Company) in Harpenden, UK. Now they have used trained bees in the airport to check passengers and sniff out explosive chemicals.

4.2 Sniffer moth:

Insects, such as moths, can be trained to respond to explosives odours. A prototype system that can be used to train insects such as moths to detect explosives were designed, assembled and tested (Tony *et al*., 2004). It compares the electromyographic signals of insects trained to respond or not respond to a target explosive vapour to determine whether or not explosive devices, such as bombs or landmines, are present. Sniffing moth detecting the bomb vapour within 5.5 to 10.5 seconds.

5. Conclusion

HE-MEMS creates a platform to invade personal privacy, national security and cybersecurity, on the other hand, the integration of global positioning and autonomous navigation systems create a danger as nefarious users could command this technology, Whereas Bio Unmanned Aerial Vehicles (Bio-UAV) is emphasizing its focus vividly in recent times on academics and also in myriad applications of the research to unfold several other astonishing aspects but the present works being carried out are restricted only to prototypes being used in the laboratory. However, after Biological and Toxin Weapon Convention (BTWC, 1972) the insects has a potential role to play military as real-time situation awareness, location of trapped persons and detection of buried hazardous material.

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Table 1. Walking/running insect species in search and rescue operations

S.No.	Insect species	Family	Order	Specific role	References
1.	*Mecynorrhina torquata*	Cetonidae	Coleoptera	Protraction/retraction motion of the coxa; levation/depression motion of the femur; extension/flexion motion of the tibia	Sato *et al.*, 2014
1.	*Blaberus discoidalis*	Blaberidae	Dictyoptera	Initiation, turnings, cessation and lack of backward movement	Liang *et al.*, 2015
2.	*Zophobas morio*	Tenebrionidae	Coleoptera	Initiation, turnings and cessation and have even backward movement	Sato *et al.*, 2017

Table 2. Indian insect cyborgs proposed at Defense Research and Development Organization, India

S.No.	Common name	Scientific name	Family, Order	Proposed institutes
1.	Ground beetle	*Anthia sexguttata*	Carabidae Coleoptera	UAS, Raichur; Inst. of wood science, NDRF
2.	Jumping cyborg Cricket	*Gryllus* Spp.	Gryllidae Orthoptera	NDRF, IISc, University of Hyderabad

Table 3. Indian insect cyborgs proposed at Defence Research & Development Organization, India (IIAEM), Jain University, Bangalore) for search and rescue operation (Anonymous, 2017).

S.No	Common name	Scientific name	Family, order	Proposed institutes
1.	Hawkmoth	*Agrius convolvuli*	Sphingidae, Lepidoptera	National centre for Biological Sciences