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STING OF DEFEAT: INSECT AS PROTECTIVE CYBORG: A REVIEW

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ABSTRACT

Cyborg insects, which are insects integrated with microelectronics or other mechanical enhancements, have emerged as a fascinating area of research and development with several important implications and potential applications. Cyborg insects can be equipped with sensors and cameras to navigate through rubble and debris in disaster-stricken areas. Their small size allows them to access places that would be challenging or impossible for humans or larger robots to reach. These insects can be used in military and security operations for discreet surveillance. Their natural ability to blend into environments makes them ideal for gathering intelligence without detection. Studying cyborg insects can provide insights into insect behaviour, physiology, and neural control. This knowledge can contribute to broader scientific understanding and inform the development of new technologies in robotics and bioengineering. In this review we were focusing on the status of insects, sensor implication and its application.

***Key words*:** Beetle, Cockroach, Cyborg, Dragonfly, Honey bee Moth, Insect, Locust.

Introduction

Insects are widely employed in art, entertainment, fashion, research, and the food sector. Due to their ability to adapt to a wide range of environmental conditions and their distinctive style of flying that involves rapidly flapping their wings, insects are found all over the planet. Motivated by the distinct benefits of insects' ability to fly, scientists have created bionic robots and micro aerial vehicles (MAVs), even employed the inspiration to the design of aerospace vehicles (Pines and Bohorquez, 2006; Sane, 2006). Cyborg The words "organism" and "cybernetics" are compound. It is common to see cyborgs as half machine, half human. In 1960, Manfred E. and Nathan S. Kline came up with the name "cyborg". By creating an appropriate interface between a human and a computer, a human has been artificially converted into a machine (Breugel *et al.*, 2008). This pertains to an organism that has been endowed with improved capabilities or function as a result of the incorporation of artificial elements or technologies. Cyborgs are also referred to as androids, bionics, or bio-robotics. It refers to an organism that, as a result of the integration of some artificial element or technology that depends on feedback, has regained function or developed new capacities (wustl.edu). Cyborgs could theoretically be any sort of organism, even though they are typically thought of as mammals, including humans (Ding *et al.*, 2021; Bermudez and Fearing, 2009).

The creation of hybrid insects' micro-electro-mechanical systems, or "cyborg insect drones," dates back at least ten years. Humans are using the inherent talents of insects, first developed by the Defense Advanced Research Projects Agency, or "DARPA", to accomplish tasks that are currently unattainable with purely mechanical technology, like as drones. This HI-MEMS technology can be used for counter terrorism, search and rescue missions, environmental monitoring and restoration, and mapping of challenging locations (Pimentel, 2017). These advantageous applications come with some clear drawbacks as well, such worries about surveillance.

Differences between cyborg and robot

Cyborg	Robot
Combination of living organism and a machine.	Robot is a machine, that is very, advanced
Not necessarily to be human and developed from other organisms like rat, dog, birds etc.	It is automated
Part of living things and biodegradable	Not alive and not biodegradable
Chemosensory is inbuilt in nature	Chemosensory parts are artificially implanted

Cyborg classification: Cyborg can be classified as human cyborg and animal cyborg.

Human cyborg: Human cyborgs are well developed because of advancement of technology

Example: Neil harbisson- Spanish born british- irish cyborg with antennae implantation. Antennae used to modify the information to audible format, that is information present in his mind.

Animal cyborg: Animal cyborgs are developed by Defence Advanced Research Programme Agency (DARPA)-USA (2007). It's used as a spy agent in army. Example: birds, dogs, rats, insects (Pimentel, 2017).

Cyborg insect: Implantation of electrodes into the brain, optic lobes, antennae, muscles of insect electrically stimulating the muscles could make the insect to fly or lift, legs extend or retract

Micro-Air-Vehicles (MAVs), or tiny fliers, were created prior to these. Their mission duration and autonomy have been restricted by the power source needed to fly them while producing lift, supplying electricity to flight control sensors and actuators, and preventing collisions. The study of naturally occurring fliers has shown to be extremely beneficial to researchers in their design of individual biomimetic structures for use as MAV components (Nguyen *et al.*, 2023). Despite enormous efforts to integrate these structures into a single MAV, no system that can take off, navigate, and land on its own for extended periods of time hours or days has been successfully demonstrated. Using insects, which are naturally efficient flyers, as MAVs is an additional concept that has been proposed. Insects have incredibly effective muscle actuators to propel themselves, and they are sized in centimetres. Because of the insect's small size (2-7 cm) and amazing walking ability, as well as its low weight (0.5-8 g), senses, and several modes of locomotion, this hybrid system may be used for search and rescue operations in the wake of a disaster (Mohseni *et al.*, 2001; Riley, 2005). Furthermore, because they can be readily mass manufactured, use less energy, and decompose completely, cyborg insects are more environmentally friendly. Buprestidae, Platypezidae, and Empididae are the species with the strongest fire and smoke sensing mechanisms. Insects can have artificial electronic devices implanted in them to monitor and regulate their flying through the recording and activation of individual or combined neurological, muscular, and sensory systems (Taubes, 2000; Ellington, 1999). With a wireless electrical backpack stimulator placed on its thorax, the robot resembles a living insect. The robot uses a supple body composed of stiff exoskeletons, flexure hinges, and soft actuators, all of which it inherited from the biological insect. A living insect platform with a tiny electrical device mounted to control it makes up this type of insect-machine hybrid robot. When unveiled the first walking insect-machine hybrid robot in 1997, it had an electronic backpack with two photosensors and an on board algorithm installed on a live cockroach to steer it in a straight route (Holzer and Shimoyama, 1997).

Brain-Computer Interface (BCI)

Every cyborg organism uses it as a primary mechanism. It is both a software and hardware system. It is a sophisticated, diverse field of ongoing research with foundations in hardware, signal processing, neuroscience, and biological sensors, among other areas. An external world and the human brain are now intimately connected thanks to the Brain-Computer Interface (BCI) system. It is a brain-machine interface that interacts with outside factors in real time. The BCI system uses signals from the user's brain activity, converted into the necessary output, as a means of communication between the user and the computer. Through brain activity, it allows users to control external equipment that are not under the control of muscles or peripheral nerves. Signal capture, pre-processing, feature extraction, categorization, and device control make up the fundamental components of BCI. Knowledge extraction from signals and brain-computer interfaces are made possible by signal acquisition. The related signal's increased usability is the result of the three processes of pre-processing, feature extraction, and classification (Khan and Lonkar, 2012). Finally, the main driving force behind the control of the devices is evident: using the signals for a prosthetic or other application. Consists of sensors implanted in to the brain of insect

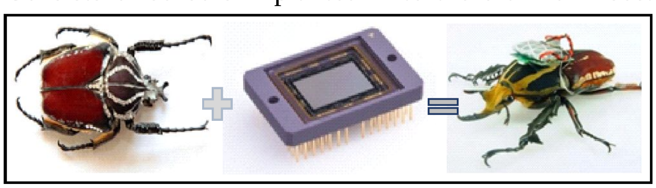

Fig. 1: Cyborg insect.

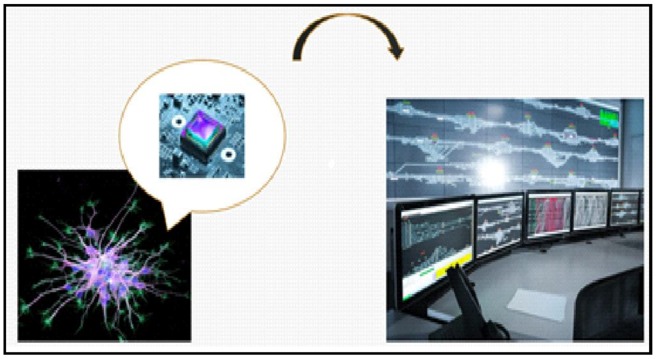

Fig-2: Brain-Computer Interface (BCI).

and devices that analyse the brain signals. Signals generated by the brain are interpreted and translated to the computer commands (Crichton, 1990; cyborg-and-bionicham.html.)

Insects used for cyborg: Insects which can be used for cyborg are given bellow (Fig. 3, 4, 5, 6, 7 and 8).

Sensor implantation and application

Locust

Even in the presence of many backgrounds or distracting stimuli, insects exhibit a remarkable ability to sense some biologically relevant chemicals and odorants at levels as low as a few parts per trillion (Blaney WM, Chapman, 1970). Dogs might not be the ideal bomb detection animal in favor of a much smaller, far more futuristic creature; grasshopper cyborg Although we detect scent mostly through our noses, grasshoppers employ receptor neurons in their antennae to pick up scents in the surrounding air. An electrical signal is sent to the "antennal lobe," a region of the insect's brain, by any of the 50,000 neurons that can be found inside an antenna whenever they detect a fragrance (Furton and Myers, 2001; Yinon, 2001; Simoes *et al*., 2011; Saha *et al*., 2013). The researchers inserted electrodes into the antennal lobes of grasshoppers in order to access this mechanism. Following that, they subjected the insects to a variety of smells, including the explosive TNT and DNT, a substance that is used to make TNT, and discovered that the various smells triggered various neurons in the antennal lobes of the grasshoppers. Mehta *et al*., 2017, carried out an experiment using a cyborg sensing platform

Fig. 3: Tobacco horn worm: *Manduca sexta* - Spy the terrorists (Bozkurt *et al*., 2008a; Bozkurt *et al*., 2008b).

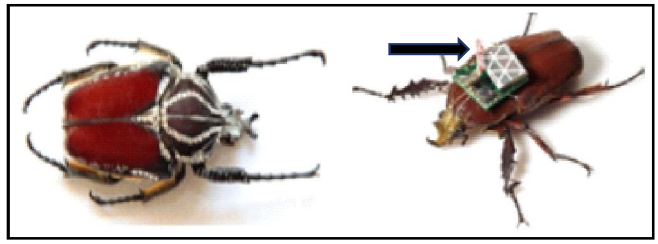

Fig. 4: Flower beetle: *Mecynorrhina torquate* or *M. polyphemus* - Spy the terrorists (Doan *et al*., 2015; Sato *et al*., 2008).

and locusts' (Schistocerca americana) olfactory sensing capacity for standoff chemical detection. It has been demonstrated that locusts can develop both aversive and appetitive associations with respect to taste, odor, color, or spatial stimuli (Kosek, 2010; Saha *et al*., 2015). Locusts examine food surfaces by touch and taste using their maxillay palps, which are sensory appendages near the mouth. Generally, locusts move their palps in anticipation of food. A locust uses its palps to direct food toward its mouth once it has decided it is safe to eat. Similar to the salivation of vertebrate animals, the reflexive movement of the palps in anticipation of food makes it an appropriate behavioral cue (Simes, Rains). The infrared emitter, infrared block, infrared detector, and silver reflector comprise the cyborg platform. The assembled proximity sensor patch and locust make up the cyborg platform. A tiny printed circuit board (PCB) with all the circuitry completed has been put close to the palp using wax. It is estimated that the backpack weighs less than 0.8 grams in total. Even though the LED consumes 20 mA of electricity, its power consumption can be decreased by pulsating at a duty cycle of 1% and a frequency of about 100 Hz. Our goal is to use less than 1 mW of power overall on average. Locusts were exposed to hexanol (a conditioned stimulus) for ten seconds during training sessions. Five seconds after the odor was first detected, the food reward (an unconditioned stimulus) was administered. For an hour, the conditioning procedure was repeated every ten minutes. Within a few hundred milliseconds of coming into contact with hexanol, the locusts were able to recognize it and reacted to this

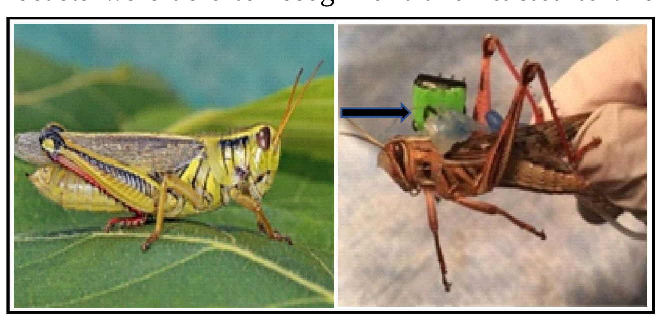

Fig. 5: American grasshopper: *Schistocerca americana* - Sniff out the bombs (Mehta *et al*., 2017).

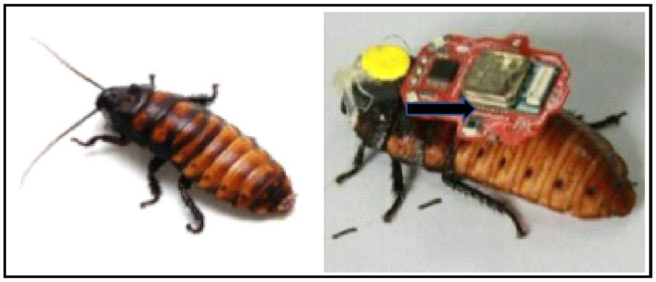

Fig. 6: Madagascar hissing roach - Search and rescue opertions to seek out the humans under rubble and collapsed buildings (Xuan *et al*., 2021).

training odorant by opening their The POR response generalized when an untrained odorant that was chemically identical to the trained cue (for instance, two alcohols: 2-octanol and hexanol) was used, but it did so at a lower level than the taught odorant (Saha *et al*., 2013; Firestein, 2014).

A strategy to chemical sensing hybrid locust-based explosive detection *via* insect antenna was developed by Singamaneni *et al*., in 2017. There are two components to the cyborg locust: Backpack with electricity: It is usually the largest weight and is made up of electrodes that are implanted into the insect's brain without the need for a battery. Instead, the energy is harvested directly from the locust's movement. Thus, the locust itself serves as a battery, and the command signals are transmitted wirelessly using that energy. Tattoos: This biocompatible silk is applied to the locust wings, producing a gentle heat and assisting in the locusts' remote control movement toward certain targets. Moreover, the tattoos, which are embedded with plasmonic nanostructures, have the ability to gather samples of volatile organic chemicals nearby. This enables the researchers to perform a secondary examination of the compounds' chemical composition using more traditional techniques (wustl.edu; https://boingboing.net/2020/08/27/the-pentagon-is-training-an-ar.html).

Honeybee

Bees have been employed in combat since ancient times, when bases, tunnels, caverns, and attacking armies

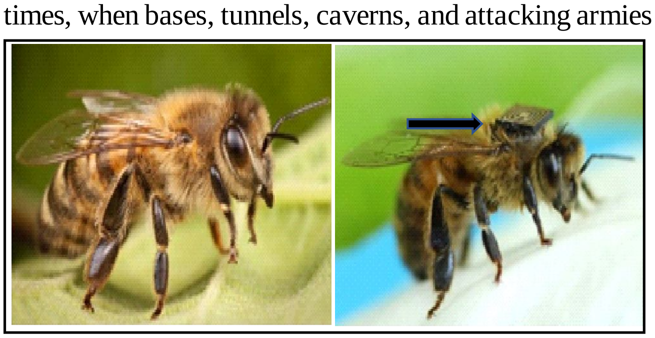

Fig. 7: Bees – Sensing of chemicals and spy the terrorists (Kosek *et al*., 2010).

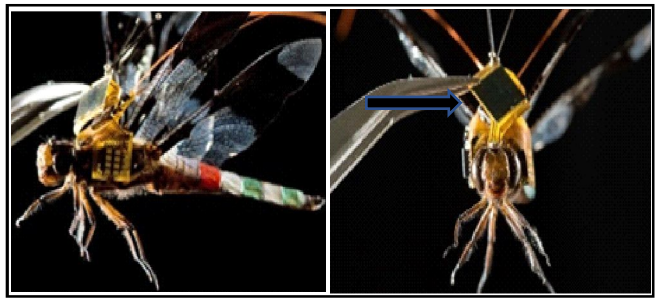

Fig. 8: Dragonfly- Navigation, monitoring and migration patterns (Pimentel, 2017).

were targeted with beehives or thrown into these defensive structures. Bees are now engaged in the hunt for things that are outside the realm of human perception, as opposed to only being employed as military weaponry. First became aware of bees while working on forest politics at Los Alamos National Laboratory in a defense industrial milieu (Kosek, 2020). The ability of humans to perceive more has been made possible in large part by the behaviour and physiology of bees. Now, bees are zoosensors. New and close relationships have arisen from the deployment of bees, or what military scientists refer to as "six-legged soldiers". Experts have incorporated military and commercial designs into the nervous system and movement patterns of honeybees (Xuan and Wang, 2021). Bee managerialism is a new concept. Bees' abilities to detect and acquire intelligence have been used for beneficial purposes. Kosek, 2010 trained bees to spy on terrorists and identify chemicals. The study team has concentrated its training efforts on a particular bee's response. Bees are positioned and taped into separate Styrofoam cells. The bees should then be trained over a few days or even hours using food and the aroma of TNT (trinitrotoluene). The response of the bees was both magnified and graphed by the computer. This signal is translated by computers into a flashing message or alarm that indicates the presence of a chemical, explosive, or biological agent on a screen. This tongue response works 99 percent of the time with military grade TNT (Kritsky, 2010). Insect motion can be influenced by the physical actions of antennas. To give physical support for controlling live honeybees, electro antenno graphy (EAG)

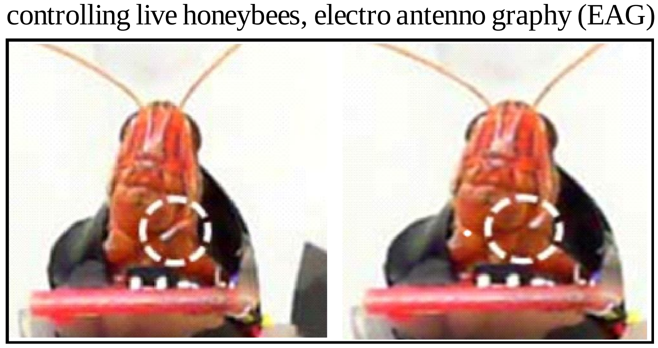

Fig. 9: Closed palp Fully open palp

of honeybees under various scents was studied to examine sample response (Zhao *et al.*, 2020). A technique for electrical stimulation to regulate tethered honeybee flight behaviour. This provides the researchers with a computer readout that graphs and magnifies the response of the bees. In this interspecies assembly, bees' tongue-out action becomes a signal for other species. Recently, social insects have been subjected to electronic tagging using RFID (radio frequency identification) technology. Due to their ability to be affixed to insects and their distinctive encoding, RFID tags have shown to be beneficial for the identification of thousands of creatures in a single experiment (Schneider *et al.*, 2012; Crall *et al.*, 2015).

Dragonfly

In 2007, Draper, a biomedical solutions enterprise, revealed that as part of the Chairman of Wheeler project, they will be developing a drone that looks like a living dragonfly. Optogenetic stimulation is the process of genetically altering an insect's nervous system to enable it to react to light pulses. The drone dragonfly will be fitted with a little backpack that can fly on its own thanks to a guidance and navigation system and a tiny solar panel. It is anticipated that Dragonfl Eye will be an ideal drone for usage in busy indoor spaces where public safety is a priority. Drones can record high-speed video, which can be used to monitor public events, terrorist activities, criminal behaviour, and bee migration patterns (Pimentel, 2017).

Cockroach

Micro-electronic mechanical systems (MEMS) and neuro-mechanism research have demonstrated that electrical stimulation is a useful tool for manipulating the flight or walking behaviors of insects. The first way to manipulate insect behavior was to electrically stimulate the antenna. By stimulating the antenna of a live cockroach with an electrical backpack, Holzer R, Shimoyama, 1997 achieved a revolutionary feat of controlling the cockroach to travel along a black line. The effectiveness of the insect was examined by using a variety of major barriers, including beams that resembled grass, pillars, gaps, and bumps Antennae were cut with a pair of scissors to a length of 1 cm and a depth of 3-5 mm. Electrodes with a length of 3-5 cm were created using silver wire coated with teflon and placed into cerci or antennae with a diameter of 0.005 inches (Xuan *et al.*, 2021). The insects' movement is controlled by the electrical stimulation that the backpack releases through these wires. The two cerci may be made to turn by applying electrical currents through the electrodes, giving the scientists control over which direction they travel in (Cao *et al.*, 2016; Baba *et al.*, 2010; Xuan *et al.*, 2021). When the left cercus was triggered, the insect rotated clockwise to the right, and vice versa. Recently, a cockroach biobot with an automatic 10% curve-following success rate and 74% left- and right-turning success rate was shown by the Bozkurt *et al.*, 2016. Their stimulation protocol, which fixed the electrical stimulus and simply modified the stimulation side, would be the cause of their low success rates. With a 50% success rate, changed the stimulus amplitude to show the graded response of the cockroach behaviour (Erickson *et al.*, 2015).

Moth

The first direct control of insect flying through wing motion manipulation using microprobes and electronics inserted through Early Metamorphosis Insertion Technology (EMIT) is reported by [38]. EMIT is a unique hybrid biology method that places electronics in the pupal stage of insect metamorphosis to create intimate electronic-tissue interactions for autonomous centimeter-scale robots. Micro-Air-Vehicles (i-MAVs) based on insects were developed by Tsang *et al.*, 2010. These vehicles combined the advantages of MEMS and electronics (sensing, actuation, and information processing) with the small size, efficient energy storage, and navigational ability of insects. The two main components of the i-MAVs were the telemetry system and the sensor. In order to improve the probe's capacity for charge injection, FNPs are used as a communication link between the insect and the base station (Bozkurt *et al.*, 2009; Bozkurt *et al.*, 200b; Whitney and Wood, 2010). A flexible neuroprosthetic probe that interacts with the insect's neural system to skew its flying path. Tobacco hawkmoth Manduca sexta pupae were implanted with probe-based microsystem platforms using EMIT seven days before to emergence. Due to its very short three-week metamorphic period, structures can be put into the pupae at an early stage of metamorphosis, allowing the body to adapt to the implanted structures during development and emerge as an integral part of the body to create insect cyborgs. With a carrying capacity of 1-2 grams, a flying range of miles, a wingspan of 10 cm, and a lifespan of 2-3 weeks. Abdominal movement directions are determined by the particular stimulation sites that are chosen for stimulation, and the size of the movements increases as the stimulation signal's voltage magnitude or pulse frequency increases. In their normal state, moths flap their two wings simultaneously. The moth's wing motion was controlled by anchoring it, which allowed us to alter the direction of the insect's flight (Bozkurt *et al.*, 2009b; Trimmer and Issberner, 2007).

Beetle

A microcomputer backpack (neuromuscular electrical stimulator), a microbattery, and a living beetle platform (*Mecynorrhinatorquata*) formed the cyborg beetle. One of the main flight muscles of the beetle, the left or right subalar muscle, received two thin wire electrodes implanted from the backpack's outputs. When the operator laptop's customized software communicated commands wirelessly to the backpack, the implanted muscle was activated in free flight whenever needed (Vo Doan *et al*., 2015; TV *et al*., 2015). Electrical pulses were applied to the insect's antennae of beetle, (*0.5 g) *Zophobasmorio* through working electrodes to cause the insect to turn through its escape mechanism. This is the first time antenna stimulation succeeded on the beetle, although it was applied on the cockroach. The power consumption for wireless communication is about 1.5 mW, whereas that for electrical stimulation is around 180 lW, high success rate in turning control (85%) and maintained the long-term performance (5 days) of the living robot. Moreover, we were able to control and grade backward walking of the beetle by alternating left/right antenna stimulation

The flight-control microsystem of a cyborg with a body weight of 7-10 g and a payload capacity of 1.4-2.0 g was presented by Riley, 2005. The electrodes placed two weeks into the three-week pupation phase, during the pupal stage, into the dorsal metathorax of Japanese Rhinocerous beetles. Implants made during the pupal and emerging adult phases had a 50% success rate. These implanted controls worked in individuals who had emerged fit for flight.

Limitation

- Insects having short life span.
- DragonflEye technology is representative of the potential benefits of cybernetic insect research, it equally represents the dangers posed by this type of "dual-use" technology.
- These twin applications can be translated into entomological warfare and surveillance applications by governments, terrorist organizations, and private parties.
- Insect vectors are capable of transmitting diseases between humans and animals. Some of the insects are Pests of crops like locust.
- Sensor implantation and commanding control is highly skilled process, there is a risk of command failure if an insect chooses the wrong direction or does not follow the command.
- Mass production of insects is time required process (Pimentel *et al*., 2017).

Conclusion

It's possible that science fiction will lead to the development of cyborg insects for useful purposes. Large-scale autonomous robotics can be implemented on a unique platform offered by cyborg insects. It may change our perception of, interactions with, and manipulation of the world we live in. Cyborg bug drones could soon be a part of our daily life, used for surveying otherwise undiscovered areas and monitoring some of the most valuable ecosystems on Earth. Still, there are several characteristics that put our privacy and national security at risk. However, there is still time to talk about how governance regimes may reduce the hazards while the technology is still in its research and development stage.

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