Robo-tic: Development of a Tick-Eliminating Robot

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Tick bites are a calculated risk of enjoying outdoor activities, yet in certain geographic regions deer ticks are more likely than not infected with Lyme disease\(^1\) even to the extent that some medical journals recommend physicians automatically begin antibiotic treatment following bites in high-risk areas regardless of patient symptoms\(^2\). There exists no Lyme vaccine approved for use in humans, and annual reported cases in people are rising with the spread of infected ticks across the northeast United States\(^3\). Undergraduate electrical and mechanical engineering students from the Virginia Military Institute (VMI) have developed a tick-control robot that uses biomimicry to encourage ticks to attach to a pesticide-infused fabric patch. A prototype was found to remove 45±4 out of 50 ticks seeded in a small and non-controlled study by Woulfe et al.\(^3\). A ruggedized prototype was next developed by engineering students from both VMI and Washington & Lee University capable of withstanding a multi-week controlled study by an independent environmental testing laboratory while students from Wake Forest University examined how to commercialize the device.

**Tick-Vectored Illnesses: A Growing Threat**

Tick-borne illnesses are the most common of vectored diseases in the United States according to the US Center for Disease Control and Prevention (CDC)\(^4\) and for reasons not fully understood are becoming
increasingly common. The United States Center for Disease Control (CDC) reports that Lyme disease, carried exclusively by the black-legged or deer tick, almost doubled in the past decade (see Fig. 1), and other studies indicate that high-infection regions are growing in size.  

![Fig. 1: Lyme disease rates in the United States from 1997 - 2012. Data from the US CDC.](image)

Although the number of confirmed cases does not appear high for a country with a population of approximately 300 million it is uncommon to be officially diagnosed with Lyme disease in a manner that the CDC recognizes and therefore only a small percentage of actual cases are reported. Many other diseases less well-known as Lyme but potentially more lethal can be transmitted via ticks, such as babesiosis, ehrlichiosis, Rocky Mountain spotted fever, and anaplasmosis.  

The increase human incidence rate of Lyme disease is, as expected, roughly proportional to the increasing area of ticks infected with the bacteria, yet it is difficult to control tick populations. The only mechanism widely employed involves spraying tick neurotoxins such as permethrin in the habitat of tick hosts. While this is very effective, most states restrict permethrin spraying to certain areas since it is toxic to a number of species other than ticks including cats, fish, and certain waterfowl. A recent
government study funded by the US Army Medical Research Command further implicates permethrin in causing Gulf War Syndrome.  

**A Robotic Solution**

We developed a method to reduce tick populations using robotics and biomimicry. To understand how this is done it is necessary to describe the habitat and hunting practices of ticks. Ticks are not uniformly spread throughout the homeowner’s property, but rather are much more likely to reside along a relatively narrow strip separating manicured lawn from the surrounding woods. Some studies indicate 82% of the tick population lives within 3 meters of this border called the ecotone. Although ticks have limited mobility they can move within the ecotone to maximize the probability of locating a host, and then drop on it or raise their spiny legs to become ensnared in the host animal’s fur as it brushes by.

Ticks have evolved extraordinary sensory capabilities to find hosts; they respond to vibrations from a field mouse running along the forest floor a meter away, changes in temperature from a passing mammal’s body heat, and can sense the elevated levels of carbon dioxide in exhaled breath that falls to the ground after an animal has passed.

To mimic an animal trail we place a hollow tube in the ecotone that slowly emits CO2 through small holes drilled through the wall in regular intervals, as seen in Fig 2. Within thirty minutes ticks consolidate from the ecotone to within a few inches of the tube. The tube also houses a wire that emits a low-frequency magnetic field. The robot senses the field and travels around the tubing, dragging a denim skirt behind it infused with an acaricide such as permethrin. The ticks sense the vibration and slightly-elevated, friction-induced temperature of the skirt and allow spiny projections on their legs to ensnare the denim fibers. This entanglement prevents them from being easily brushed off as the skirt is dragged in the same manner as when they attach to small rodents. Although the ticks only stay attached for a minute or two before recognizing their mistake, in that time they absorb enough
permethrin to kill them within 24 hours. Except for a miniscule amount absorbed by the ticks or rubbed off in leaf litter, the permethrin remains on the skirt and unlike traditional spraying does not contaminate the environment.

![Diagram of the experimental setup](image)

**Fig. 2**: The experimental setup. A robot autonomously follows a carbon-dioxide-emitting tube around the periphery of a lawn. Ticks are drawn to the tube area and attach to a pesticide-embedded skirt dragged behind the robot.

We constructed a prototype robot to determine if this approach would work. Using the methods described above it was tested in a 10 meter diameter lawn seeded uniformly with ticks and proved effective removing 45 ± 4 out of 50 ticks in a small uncontrolled experiment at Old Dominion University in the laboratory of Daniel Sonenshine, one of the inventors. He has experience with a number of methods of tick collection as the author of Biology of Ticks, and noted it was among the most successful methods he has observed, but the prototype was not mechanically robust and unable to operate autonomously for more than about ten minutes at a time. This paper describes the design of a more
robust robot, capable of withstanding harsher environmental conditions unattended and fielded and serviced by non-engineers.

The second generation tick-collection robot system shown in Fig. 3 incorporated numerous mechanical and software changes to the robot and changes to the frequency–generating base station.

![Second-generation environmentally-hardened robot pulling the tick-collection skirt.](image)

**Fig. 3:** Second-generation environmentally-hardened robot pulling the tick-collection skirt.

Mechanical changes reduced the likelihood that the robot would become disabled while navigating. Long-travel shock absorbers, larger diameter tires, an articulating chassis, and four wheel drive permit any wheel to lift 25 cm above the plane of the remaining three tires while torque is applied to all four wheels. Locking front and rear differentials enable the torque to be redistributed equally to three wheels should one encounter a full-slip ground condition. Four wheel steering was added to drop the turning radius less than the width of the chassis, and the drive motors and electronics cabinet were weather-proofed to allow the robot to operate in wet conditions.

Since it is impossible to design a robot that never becomes stuck due to environmental obstacles, sensors were added to detect a range of failure modes including the robot being flipped over, the steering mechanism becoming fouled by high grass, the robot navigating away from the carbon dioxide-emitting tubing and navigation wire, or the robot becoming stuck in a hole. The software was modified
to include a time-limited spiral-based search routine if it should lose contact with the navigation wire, and a shutdown and audible signaling routine for all other conditions.

**Base Station**

The base station houses a frequency generator and amplifier to create a magnetic field for the robot's tracking sensors that enable it to follow the CO$_2$ tube. A microcontroller (ATMega328P) generates a 7kHz 0-5V square wave, whose fundamental sine wave is isolated by an 8$^{th}$ order Butterworth filter. The current is then increased by a set of parallel op amps, which then flows into a wire located inside the CO$_2$ tubing. The current, and therefore the magnetic field strength, is monitored by passing the signal through a small sense resistor, whose voltage is amplified, rectified, and sent through a low pass filter, whose DC voltage is routed to the microcontroller.

![Diagram of the base station](image)

*Fig. 4: The base station, whose output creates a magnetic field along wires embedded inside the carbon-dioxide-emitting tick-attraction tube for robot navigation. Digital signals are shown in green, analog signals in brown.*
Robot

The schematic in Fig. 5 shows the signal and power interaction of the tracking sensors, the steering and throttle motors, the power, LCD display screen, and the microcontroller. The 7.2V batteries supply power to the microcontroller via a power conditioner and both motors. The left and right sensors receive a signal from the magnetic field and convert this signal to a DC output which is sent to the microcontroller. The microcontroller properly adjusts the steering motors using a proportional-derivative controller to navigate directly over the CO₂ tubing.

Fig. 5: Tick robot signal diagram. Digital blocks are in green, analog in brown, and power in red.

Located at the front of the robot are right and left tracking sensors that allow the robot to follow the CO₂ tubing around the ecotone. Each tracking sensor is composed of an inductor that develops a
voltage whose amplitude is a function of its distance to the navigation wire connected to the frequency generator. This signal is amplified by a differential x100 instrumentation opamp to a voltage of ±2V, which is then rectified and low-pass filtered to provide a DC voltage proportional to signal strength. This signal is read by twin A/D converters in the microcontroller, which is then processed by a fuzzy logic algorithm to produce navigational information sent to the steering servos and the main drive motor.

The steering motors circuitry was designed to provide a feedback voltage to the microcontroller proportional to the current used by the steering servos. This feedback is used to alert the navigation program and ultimately the user if the steering mechanism becomes stuck, which is a possibility as the robot navigates tall grass. The current is measured by a small value sense resistor, which is amplified by an operational amplifier and low-pass filtered, and then sent to a A/D port on the microcontroller.

**Commercialization**

One of the challenges students faced while constructing the second-generation robot involved understanding how the device could be commercialized, who the eventual end-users would be, and to understanding the needs of users who will likely not be engineers or biologists. The students engaged entrepreneurship professor Elizabeth Baker from Wake Forest University and her business students to assist them. She suggested the engineering students first raise some seed capital from their university’s foundation to patent the device, which they did, and then arrange with an independent laboratory to test the system when the ruggedized device is completed. She also advised the students to consider seeking licensure of the intellectual property under the business model of it being used by small independent businesses, since major pest control companies do not have an existing technology infrastructure capable of supporting a robotics business, and allow the independent businesses autonomy to decide whether to pursue small private contracts from homeowners or larger contracts from local, state, or federal agencies for parks or military training facilities.
She conveyed concern under this business model for safety issues associated with the use of permethrin, and recommended the team develop protocols for small business owners describing how to apply, store, and dispose of the chemical. For instance, when working with the permethrin-soaked denim skirt, the protocol requires the user to wear gloves, describes how to mix concentrated permethrin with water, how to load it into spray bottles, and how to apply it to both sides of the denim skirt. After the robot completes its tick removal process, the protocol specifies that the denim skirt should be stored in a sealed plastic container at room temperature. Since brushes are used to remove ticks and debris from the skirt, the protocol also describes how to properly dispose of these brushes in accordance with the U.S. Environmental Protection Agency guidelines.

**Testing and Future Work**

The engineering student team arranged testing at the Calder Environmental Field Laboratory in Fordham University during the summer of 2012. Unfortunately, Calder experienced one of the most intense droughts since 1962, which killed enough of the available tick population to make it impossible to test whether the robot was able to further reduce the tick population. Nevertheless the engineering portion was a success and the robot logged no mechanical or electronic failures during two weeks of field tests. It now waits for a two week set of environmental field tests at Old Dominion University in Virginia in the summer of 2013 to coincide with the start of the nymphal tick season.

If these tests show promise, the students hope to raise enough capital to make and sell several to business people interested in providing tick-removal services. As ticks do not migrate large distances, a treated property is expected to stay relatively tick-free for at least one tick life-cycle, which is about two years. Half-acre suburban lots typical in many high-risk areas of the northeast require about 150 meters of tubing laid on the surface around the perimeter and take about 15 minutes for the robot to traverse. Preliminary trials indicate the weighted tubing takes less than 30 minutes to reel out by walking around
the 150m perimeter. Initial carbon dioxide seeding takes an additional 30 minutes, and 4 traverses by the robot would take an hour. If the tubing takes an additional 30 minutes to reel up, a house could be treated in less than three hours, for the cost of labor plus $15 of carbon dioxide and a battery charge.

Even if successful, the question remains whether it will work well enough to make a noticeable impact on rising tick populations. The CDC has reported a three-fold rise of Lyme disease infections in the past 20 years, and this trend appears to be continuing. It is our hope that robotic technology may provide one way to reverse this trend in an economically-efficient manner without leaving potentially harmful pesticides in the environment.

Read more about it

About the authors

Chris Baber is from Glen Allen, Virginia. He joined the Virginia Military Institute as a business major and switched during his sophomore year to electrical engineering. Chris was the vice president of VMI’s rugby team. After graduation Chris will attend the US Navy Nuclear Power School to become a submarine officer.
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