A robo-tick killer

Justin H. Woulfe, Glenn B. Hammond, Dennis J. Crump, David L. Livingston, and James C. Squire

Ticks have become a major health concern across the country. People who live near wooded areas know that ticks are a nuisance and potentially dangerous; they infest pets and vector human diseases. The most common infection carried by ticks is Lyme disease, which struck nearly 17,000 Americans in 1998, the highest number of cases ever reported, according to the U.S. Centers for Disease Control (CDC). Symptoms include fatigue, chills and fever, headache, muscle and joint pain, and a characteristic circular rash. Untreated, Lyme disease can lead to joint and nervous system damage including arthritis, numbness, chronic pain, and heart rhythm problems. Another serious illness spread by ticks, Rocky Mountain spotted fever, annually strikes some 300–400 Americans according to the CDC. Symptoms include a spotted rash that spreads from the wrists and ankles, high fever, and muscle pain. Some years, as many as 5% of victims have died. Another disease, ehrlichiosis, was long thought to only afflict dogs; in 1998 four people in Oklahoma were the first reported to contract the disease. Four more cases involved people in Missouri, Oklahoma, and Tennessee in 1999 according to a report in the 15 September 1999 issue of *The New England Journal of Medicine*, and it has since spread. Meanwhile, researchers have discovered other reasons to worry about ticks. On 13 January 2000, *The New England Journal of Medicine* reported the case of a six-year-old girl who nearly died of tick paralysis caused by toxic substances produced by ticks themselves. Ticks are so small that they can attach and feed unnoticed for hours and possibly days, increasing the risk of contracting disease. A team of four engineering students advised by two engineering professors and an entomologist sought to reduce tick-borne disease by designing a robot (Fig. 1) that travels the perimeter of a yard, clearing the area of ticks.

The ecotone, a 15-ft wide swath defining the boundary between cultivated lawn and woods, is the tick's natural habitat (Fig. 2). Research shows that 80% ± 10% of ticks can be found in the ecotone. By placing a small perforated tube around the yard that emits a chemoattractant, such as carbon dioxide, ticks are drawn from surrounding areas in the ecotone into a narrowly defined path. A signal generator provides a 10-kHz sinusoidal signal that is connected to a wire placed inside the perforated tube. The rover uses inductive sensors tuned to the specific frequency of the magnetic field produced by the wire. The signals received by these sensors are digitized by a microcontroller and used in a fuzzy logic control algorithm to keep the rover centered over the tube and the ticks as it moves forward.

The robot's passive collection system consists of a denim skirt, a material to which ticks naturally attach. Ironically, this common material has been found better in this regard than any other man-made or natural product. The skirt is soaked in promethren, an effective acaricide with little or no harmful mammalian side effects. The robot is designed to be low with a large contact area close to the chemoattractant tube since ticks live primarily within 12 in of the ground.

After completing one lap of the yard, the robot returns to the specially designed shed that recharges and cleans the robot. Upon entering the shed, the robot skirt is cleaned of dead ticks and debris by rotary brushes. While this occurs, contacts on the bottom of the rover touch points on the floor to recharge the batteries, a method similar to many desktop cellphone chargers. After charging and being sprayed with a fresh coat of promethren, the robot will exit the shed. This process like the rover itself is fully automated. The shed also provides a weather-resistant storage area for the chemoattractant tanks.

The robot is designed be used during the late spring and summer months when it picks up both tick larvae and nymphs. Following treatment for the summer months, the life-cycle of tick growth (see "The Tick Life Cycle") will be broken, and the area will remain relatively tick-free without further treatment for several years.

Rover design

Figure 3 shows a block diagram of the robot. One set of eight NiMH

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batteries generating 12 V powers the motors. To prevent noise from the brushed motors interfering with the analog signal processing and microntrontroller, a second set of eight NiMH batteries powers these modules. This voltage is regulated by buck/boost dc-dc converters to provide ±12 V for the sensors and +5 V to the microntroller as long as the batteries are not discharged below 9 V.

The robot follows a navigation wire embedded in the chemoattractant tube using two inductive sensors. An off-the-shelf invisible dog fence provides 10 kHz signal generation for the navigation wire, which is sensed using a pair of standard 100-mH wire coil inductors mounted to the robot's undercarriage. The inductors are connected in parallel to a capacitor, forming a tank circuit to resonate with the 10 kHz signal and filter out all other frequencies. The differential signal the tank circuit receives is converted into a ground-referenced signal and is amplified 40 dB by an AD621 instrumentation amplifier. The dual-polarity signal is then rectified and passed through a low-pass filter that both removes high-frequency noise and converts the signal into a dc output with strength inversely proportional to the inductor's distance from the wire. The signal strength is displayed on a bar graph for debugging purposes (Fig. 4).

Fuzzy logic controller

We chose to use a fuzzy logic controller, because it is both easily programmed and more robust in the presence of uncontrolled environmental conditions (think climbing a muddy hill versus traversing a grassy plain) than a linear proportional integral derivative (PID) controller. The signal from each of the rover's sensors was mapped to a fuzzy set of five members, specifically

- very far
- far
- medium
- near
- very near.

Fuzzy logic processing of the instantaneous and rate-of-change of each sensor's membership to these functions provides appropriate signals to the motor control modules to keep the robot over the wire as it traverses the course. For instance, if the robot is very far left of the wire and the error rate is increasing to the left, which moves the robot further away, then a strong corrective action to the right is necessary. If the robot is slightly to the right of the

Fig. 1 The authors and the tick-collecting robot. The power supply is visible at the rear of the vehicle; the micro controller and sensor PC boards are in the center. Not shown is the fabric skirt that the ticks naturally adhere to or the chemoattractant tube/navigation wire that draws the ticks to a narrow region and provides a signal for the rover to follow.

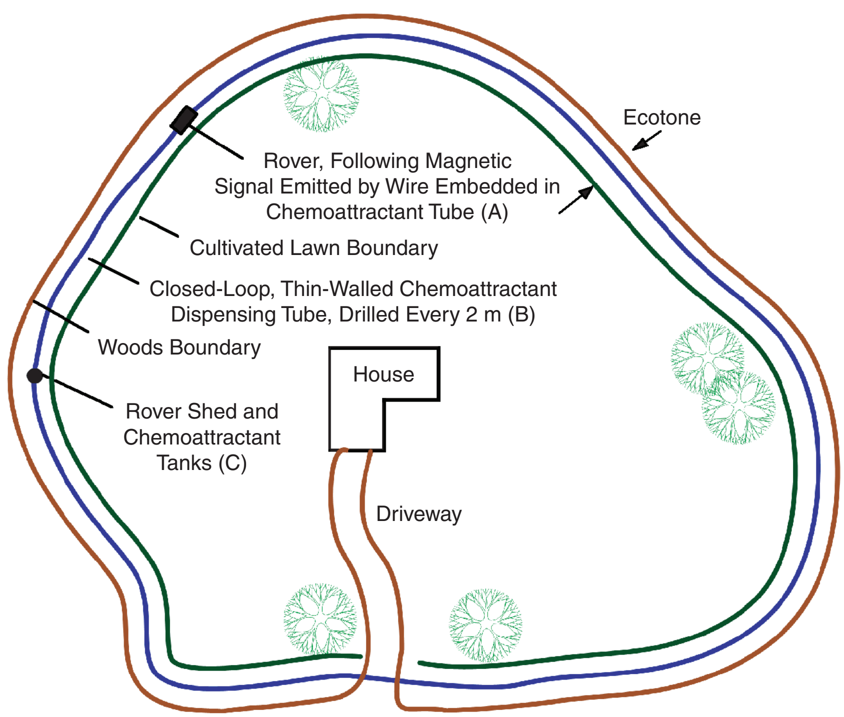

Fig. 2 The tick rover (A) follows a signal from the wire (B) to follow the ecotone around a home's perimeter. Coaxial with the wire is a tube drilled to dispense a gaseous tick chemoattractant. The rover pauses in a shed (C) every lap to recharge and self-clean.

wire and the error rate is strongly increasing to the left, meaning the robot is moving back toward the wire, then a small corrective action to the right needs to be taken to keep the robot from overshooting the wire.

Because of the environment's heterogeneity, the rover may go over rocks, sticks and other objects that may cause temporarily inaccurate sensor reading. Nonlinear fuzzy programming has been empirically found to often be more robust than linear control in the presence of such artifacts.

The microcontroller was programmed in C. The program's only purpose in the prototype phase was to keep the robot centered over the chemoattractant tube as it moved forward, although future versions will include system diagnostics. There are seven principle software modules:

- *digitization,* which runs the microcontroller's embedded analog-to-digital (A/D) converter
- *preprocessing,* which scales and adds appropriate offset values to the digitized sensor signals
- *fuzzification,* which converts "crisp" signal values to their fuzzy counterparts
- *fuzzy_inference:* for instance, if the error is X and the error rate is Y, then turn Z
- *defuzzification*, which finds the centroid of the output fuzzy sets to get a "crisp" output value
- *post_processing,* to map the results to a square-wave duty cycle
- *pulse_width_modulation,* which develops sample-accurate pulse width modulation output for the motor controllers.

The robot will soon undergo field testing to establish collector efficacy under the advisement of an entomology professor specializing in tick research. This will be done using a current prototype designated Phase I. A larger prototype, Phase II, is in design that will implement several enhancements including better traction, which is particularly important if the robot is to run unattended for several months.

Applications

Although the most obvious application for this technology is in residential tick control, campsites and military training areas are primarily ecotone and may benefit from tick population control. The student team is also researching the robot's efficacy and marketing potential for other pests that could be eliminated in a similar manner. The robot can easily be modified by changing the type of skirt, insecticide/pesticide, and chemoattractant to attract and exterminate a variety of pests, including field mice, mosquitoes, and carpenter ants. For example, the robot could be

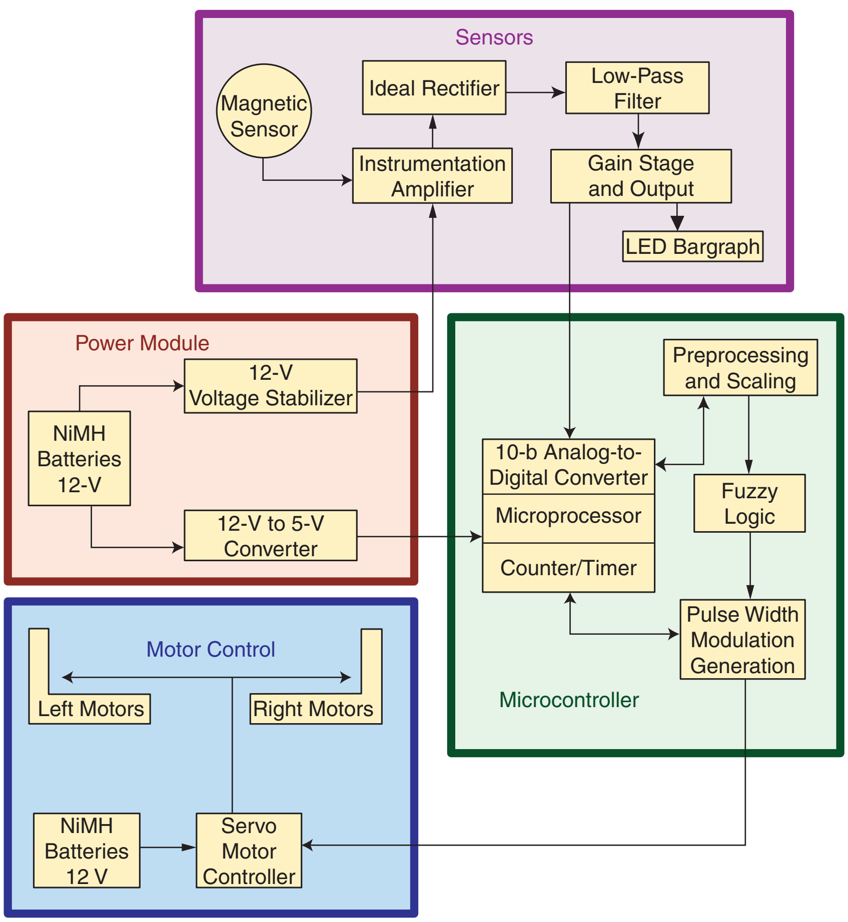

Fig. 3 A block diagram of the rover's electronics. Two magnetic field sensors are placed at the front of the rover. Their data are filtered by a high *Q* analog filter to remove nonsignal data and then sampled and digitized by the microcontroller. The microntroller implements a fuzzy logic algorithm to instruct the motor controller to take the necessary corrective action to keep the rover centered over the guide wire/chemoattractant tube.

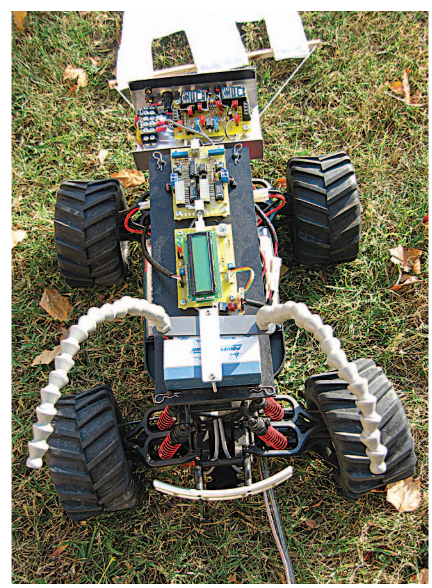

Fig. 4. A closeup of the Tick Rover without its protective fiberglass cover during operation. The navigation wire wrapped around the chemoattractant tube is visible in the front. From front to back are the battery, the microcontroller, the sensor conditioning boards with debugging bargraph displays, and lastly the power conditioning and recharging electronics. The tick drag mat is visible to the rear.

employed in a lumber yard in early spring when carpenter ants swarm, using aerosolized fructose as a chemoattractant and chlorpyrifos (Dursban) as the insecticide. Field mice can simply be attracted to the rover by placing bait directly on the robot as it traverses the ecotone in a slow stop and go manner. Mosquitoes can be attracted to the tube using carbon dioxide, as was used with ticks, and by coating the skirt of the rover with a mixture of lactic acid, a floral scent, and an insecticide. Other pests may also be targeted with similar modifications. One advantage of the robot over present pest-removal methods is its maneuverability and mobility, permitting a single device to autonomously traverse a large area. There are applications for this device besides pest control; tick collection, for instance, is currently accomplished by a researcher (i.e., a graduate student) dragging a sheet across the ground in a manner similar to the robot's denim skirt. The robot could automate this process, making tick collection cheaper and safer.

This autonomous rover is capable of eradicating dangerous pests such as ticks not just temporarily but for several years. The invention has the potential to influence several aspects of society, including public health in residential and recreational sectors and industries subject to loss of income by pests. The autonomous rover will effectively eliminate ticks and the deadly diseases they carry for nearly any application, from a tick infested backyard to a large commercial area.

About the authors

Justin Woulfe, Glenn B. Hammond, Dennis J. Crump, and David L. Livingston are seniors in the Electrical and Computer Engineering Department at the Virginia Military Institute. They presented their research at the 2005 IEEE Student Paper Competition and won first place in the Virginia Mountain Section and second place in the Region III Conference. With their advisors, including James C. Squire <squirejc@ vmi.edu>, they are jointly listed as inventors on a provisional patent on the tick rover technology. After graduation, Justin plans to work at Raytheon's Intelligence and Information Systems and earn an MBA. Dennis, currently the team captain of VMI's NCAA Rifle Team, will commission in the U.S. Navy and become a nuclear power officer on a submarine. Barry will commission in the U.S. Air Force as a research and development officer and has orders for Edwards Air Force Base.

The Tick Life Cycle

The life cycle of the deer tick comprises three growth stages: larva, nymph, and adult. In both the northeastern and midwestern United States, where Lyme disease has become prevalent, it takes about two years for the tick to hatch from the egg, go through all three stages, reproduce, and then die.

Eggs laid by an adult female tick in the spring hatch into larvae later in the summer. A larva, no bigger than the period at the end this sentence, will wait on the ground until a small mammal or bird brushes up against it. The larva then attaches itself to its host, begins feeding, and over a few days, engorges. If the host is already infected with the Lyme disease spirochete from previous tick bites, the larva will likely become infected as well. In this way, infected hosts in the wild serve as spirochete hosts, infecting ticks that feed upon them. Other mammals and ground-feeding birds may also serve as hosts. Most larvae, after feeding, drop off their hosts and molt into nymphs in the fall.

The nymphs remain inactive throughout the winter and early spring. In May, when the nymphs become active, they wait on vegetation near the ground for a small mammal or bird to approach. Humans are often the hosts that come into contact with infected nymphs during their peak spring activity (late May through July). Although the nymphs' preferred hosts are small mammals and birds, humans and their pets are suitable substitutes. Because nymphs are about the size of a poppy seed, they often go unnoticed until fully engorged and are therefore responsible for the majority of human Lyme disease cases.

In the late spring, the nymph will molt into a fully grown adult. The summer months are the ideal time to target ticks for eradication as both the host-seeking larvae and adults are active. Upwards of 50% of ticks in the Northeast may carry Lyme disease.

After mating in the spring, the female lays approximately 3,000 eggs. The eggs hatch later in the summer, beginning the two-year cycle anew.