Robotic Control of Tick Populations

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Abstract—**Tick-borne diseases are becoming increasingly common in the United States, including Lyme, Rocky Mountain spotted fever, ehrlichiosis, and babesiosis. Their increase in infection rates closely tracks a rise in the geographic area of infected ticks, prompting interest in new methods of tick population control. The most common existing method involves spraying the environment with permethrin, which, although highly effective, also poisons fish, fowl, bees, and other wildlife. This paper describes a novel robotic method designed to reduce tick populations without the associated environmental toxicity of chemical spraying. It employs a robot that follows a wire emitting a magnetic signal beacon around the perimeter of a property while dispensing a chemoattractant. The magnetic signal is generated by a small battery-run constant-current frequency generator. The robot's steering is controlled by proportional-integral controllers that compare the magnetic signal detected by left and right side resonant inductors mounted on the robot, and its forward speed is controlled by a second proportional integral controller calibrated to move the robot at the speed of a slow walk. A chemoattractant, such as CO_2, is released by the robot, which, with the vibration associated with the robot's movement, establishes the biomimicry necessary to cause the tick to latch onto the robot's fabric-covered drag mat and wings. The fabric is infused with permethrin, killing the ticks in seconds while leaving virtually no trace of the chemical in the environment. An early prototype of the robot showed it acutely reduced tick populations by 88% ± 10% after 5 passes, but 48 hours after treatment the population returned to approximately pre-treatment levels. This was hypothesized to occur because only a percentage of ticks emerge from stasis on any given day to feed, but the early prototype robot proved unreliable and difficult to use for repeated-day operation needed to test this theory. The robot described in this paper incorporates a number of changes to allow multi-day testing including improved steering algorithms, water-resistant electronics, a manual mode to allow the user to remotely pilot the vehicle back on track should it lose tracking in a tight turn, and multiple indicators to assist debugging in the field. This will enable time-longitudinal studies of the robot's effects on tick population reduction planned by researchers in the summer of 2020 and may ultimately lead to a new method for tick population control.**

Keywords—biotechnology, robotics, biomimicry

I. INTRODUCTION

In an alarming trend that began in 2000, the incidence of tickborne illness in the United States has risen dramatically. Lyme disease has tripled during this period (Figure 1), and the combined rate of all tickborne disease increased by 22% in 2016 alone [1]. The number of cases reported to the Center for Disease Control (CDC) are only a fraction of the actual cases. Recent research estimates actual Lyme rates in the United States approach 300,000 annually [2].

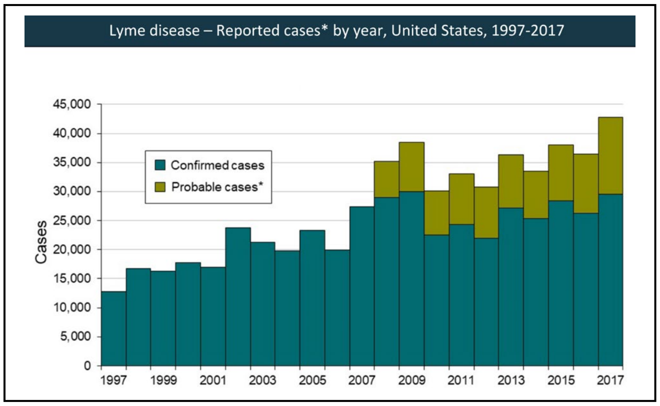

Fig. 1. Lyme disease rates in the United States from 1997 to 2017. Note the near-linear rise in reported Lyme disease cases each year [3].

Part of this increase is due to the spread of the geographic range of infected ticks. According to the CDC, the number of counties in the northeastern and upper midwestern United States that are considered high-risk for Lyme disease increased by more than 300% between 1993 and 2012 [3]. Since the reason for this expansion is still unknown, it is unlikely that an effective containment strategy will be devised within the foreseeable future. A safe and effective method is needed to reduce tick populations.

A. Existing Methods

The majority of ticks are located in the ecotone, an approximately fifteen-foot wide band that separates the boundary between manicured lawn and adjacent woods. Research shows that 80% ± 10% of ticks can be found in this relatively narrow swath [4]. The current "gold standard" to reduce tick populations involves spraying this area with a powerful acaricide such as permethrin, which, although highly effective, is also toxic to many animals including fish, birds, cats, and particularly bees [5]. For this reason, the U.S. Environmental Protection Agency (EPA) prohibits permethrin spraying in the runoff area near waterways and acknowledges the potential for human danger by recommending personnel wear protective equipment to reduce the degree of skin exposure [5].

B. Robotic Solution

In contrast to the method of broad chemical application, we have developed a robot that greatly reduces environmental damage using biomimicry to encourage ticks to latch onto removable permethrin-infused fabric. A navigation wire emitting a magnetic field is placed in the ecotone around the perimeter of the property to be treated. A robot dragging permethrin-covered fabric follows this navigation wire (Figure 2). The robot attracts ticks by carrying small, perforated dry ice containers that slowly exude carbon dioxide in similar amounts to a large mammal. Ticks, sensing a potential host, latch onto the fabric where they absorb a lethal quantity of permethrin through their exoskeleton and die within seconds. The only permethrin left in the environment are trace quantities in the dead ticks and microquantities that rub off the cloth when dragged along the ground. This focused approach drastically reduces the permethrin in the environment yet has been shown to be highly effective in field tests by Old Dominion University [6].

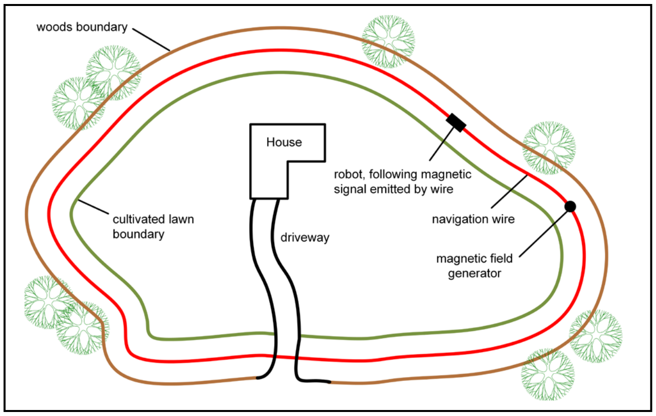

Fig. 2. Tick rover system. The rover navigates around the navigation wire, in red, dragging a cloth mat behind it that is sprayed with permethrin. The robot exudes a chemoattractant that causes ticks in the ecotone to cluster near the robot's path, where they latch onto the mat, believing it to be a host. Within minutes the neurotoxin kills the ticks, leaving virtually no residual permethrin in the environment.

II. TICK ROVER

The electronic hardware that comprise the rover can be divided into seven main subsystems (Figure 3). The power supply subsystem provides separate digital and clean bipolar analog power rails. Separate microcontrollers govern the throttle, steering, and user I/O systems, significantly simplifying their programming. A radio-frequency subsystem allows the rover to switch from autonomous, navigation-wire following mode to manual, remote radio control if the robot temporarily loses tracking. The following sections describe each subsystem in greater detail.

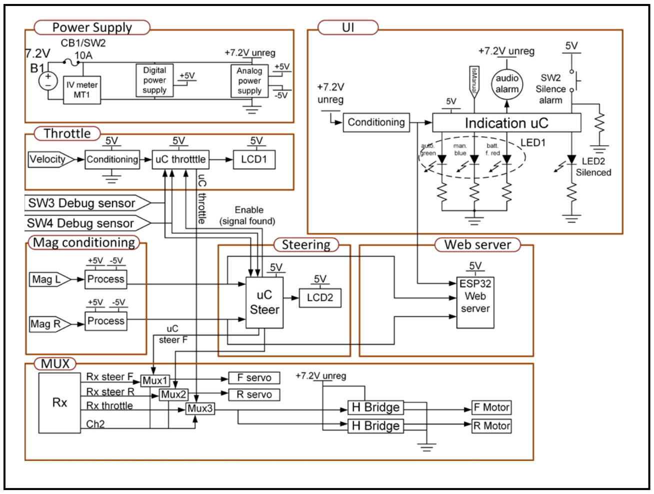

Fig. 3: There are seven major subsystems of the rover, involving power supplies, analog navigation signal conditioning, digital steering and throttle control, and user I/O.

A. Electronics

Two printed circuit boards (PCBs) are needed to fit the circuitry required for throttle and steering operation into a water-resistant box attached to the top of the rover. The bottom board houses a voltage regulator for the digital supply and a DC-DC voltage converter to create a pair of ±5V supplies for the analog signal conditioning electronics. Two separate power subsystems are needed to ensure the noise from digital components (three microcontrollers, steering servos, and H bridge motor driver) does not affect the small analog navigational signals processed by the magnetic field detection circuit. The two power supplies have separate return lines joined at a single star ground. The bottom board also houses the low-battery alert system, which sounds an alarm and flashes a panel-mounted LED when the battery voltage falls below 6.2V, and a multiplexer (MUX), which allows the rover to be controlled either manually (by the user operating a remote radio controller), or autonomously (by the on-board microcontroller following the navigation wire). Autonomous navigation is the default mode for the robot. If the robot loses tracking, the navigation code shuts off the throttle; manual mode permits one to drive back over the wire and then remotely return the unit to autonomous navigation mode.

The circuit shown in Figure 4 is the magnetic signal conditioning circuit. The two inductors (L100 and L101) on the left are used to detect the magnetic field created by the navigation wire, and make up half of a resonant tank circuit. The inductors and matched capacitors were chosen to resonate at the frequency used in the navigation wire. The resonant signal is amplified 100-fold by instrumentation amplifiers (U4 and U6). Next, precision rectifier circuits are used with low-pass filters to create a DC signal proportional to the distance between the sensor and navigation wire. This distance signal is fed into the A/D port of the steering microcontroller and the Wi-Fi network server.

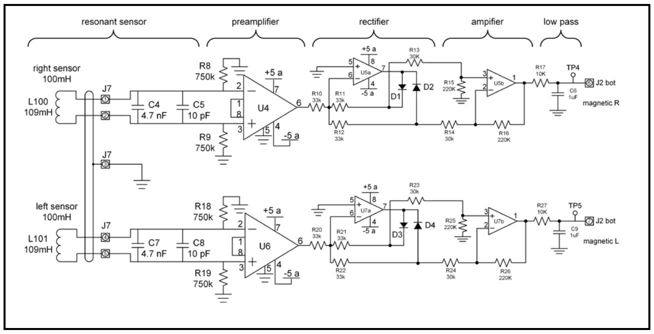

Fig. 4. Magnetic field sensor conditioning circuit. The signal is picked up by the LC tank circuit on the left, amplified by the instrumentation amplifiers, rectified into a pulsing DC signal by the precision rectifying circuit, and finally lowpass filtered into a DC voltage proportional to navigation magnetic field strength.

The web server microcontroller is an ESP32 that reports the battery voltage and the left and right magnetic sensor readings using the microcontroller's built-in 802.11a Wi-Fi access point. This permits the user to remotely troubleshoot the robot by observing the robot's battery voltage and readings from its navigation strength sensors using any Wi-Fi-enabled smart phone up to 200 feet away. LCDs on the robot also continuously display left and right navigational sensor readings, forward speed, and battery voltage. Tilt switches provide another mechanism to debug in the field. If the robot is powered on while held vertically from its front bumper then it enters a steering-only mode in which the forward throttle motor is disabled but the steering servos turn according to readings from the magnetic sensors. Turning the robot on while the robot is held from the rear bumper causes it to enter a throttle-test mode in which the robot ignores the magnetic sensors and instead drives in a "figure eight" pattern at a constant speed. Two Atmel Mega 32U4 microcontrollers run proportional-integral (PI) control code to manage the throttle and steering of the rover when the control mode is in the (normal) autonomous mode.

B. *Code*

The use of multiple microcontrollers greatly simplifies the code, since the PI controllers need to operate at the same time as the navigational code and the web server.

In autonomous mode, the rover navigates using the magnetic sensors and maintains a constant walking pace. The steering microcontroller uses a PI controller tuned to quickly react to changes in the magnetic navigation field. A linear mapping follows the PI controller that has custom set endpoints for each of the four steering servos (the robot uses four-wheel steering) allowing each of the slightly different servo and steering linkage mechanisms to rotate as far as mechanically possible without pegging their limits. Another PI controller running on the throttle microcontroller quickly adjusts torque to maintain a constant speed under a variety of inclines and terrain.

The user has the ability to enter and exit manual mode by pressing a button on a remote controller. If the rover encounters unexpected terrain or a sudden bend in the navigation wire that causes it to veer too far from the navigational wire, protective code causes the robot to halt. The user can then either physically move the rover back over the wire, or more simply, press a button on the remote controller to enter manual mode, drive it back over the wire, and then press a button to resume autonomous driving.

C. *Mechanics*

The rover must traverse rough terrain. To accomplish this, it was built using a modified radio-controlled crawler chassis, and implements four-wheel drive, four-wheel steering, locked axials, and has a suspension capable of up to 60° of torsion between the front and rear axials. The rover is also able to withstand light rain and has removable batteries of the same type as the base station for fast replacement in the field. Figure 5 shows the frames used for cloth side wings and a rear dowel that will drag another collection cloth, all of which are impregnated with permethrin. Twin silver CO_2-releasing chemoattractant containers are visible in the figure. These containers eliminate the need for CO_2 distribution lines that would otherwise be needed to wake the ticks from their normal low-energy stasis condition.

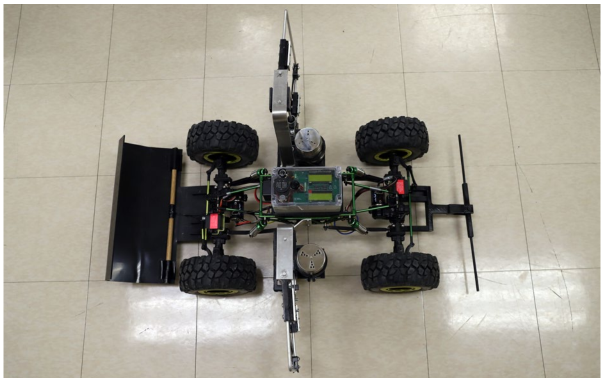

Fig. 5. Rover with fabric wings and drag mat removed for clarity. The robot's front is to the left of the image. The magnetic field sensors are attached on either side of the front vegetation plow. A suspension system including shock absorbers help it navigate hilly terrain. The weather-proof box containing both PCBs can be seen on top of the rover, between the two wings. The battery compartment is directly beneath this holder. The spring-loaded wings on both sides and the drag bar in the rear will hold fabric squares that have been sprayed in permethrin; ticks will attempt to attack these areas, and in seconds will absorb a lethal dose of permethrin.

III. BASE STATION

The base station creates the navigation beacon for the robot to follow by creating a magnetic field using a microcontroller-controlled constant-current AC source.

A. *Electronics & Code*

The system uses feedback to create a current regulator that can maintain a constant current of $45mA_{RMS}$ through an 18 AWG guide wire for lengths from 1 foot up to 1 mile. The proportional-integral (PI) controller enables the system to achieve a stable current in less than 3 seconds after the system is actuated (Figure 6). To accomplish this, the microcontroller emits a 7 kHz square wave that ranges from 0-5V, which is changed into a ±4V sine wave by a low-pass filter, high-pass filter, microcontroller-controlled variable gain circuits, and finally a fixed-gain output stage.

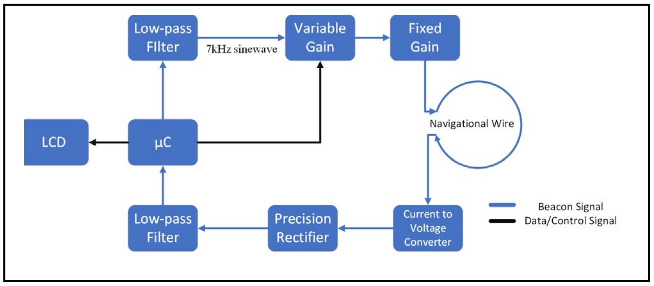

Fig. 6. Base station signal forming. The beacon signal is used to create the magnetic field seen by the rover. The data/control signal is used to display pertinent information to the user via an LCD and to dynamically adjust the system to account for changes in navigational wire length.

This signal is passed through the guidewire that is laid around the perimeter of the yard to guide the robot. The magnetic field that it produces is proportional to the current; experiments have shown a 45mA_{RMS} signal at 7kHz works well for robotic navigation. However, the signal described above is a constant voltage signal, and the current it develops varies as guide wire length around the perimeter varies. Therefore, a feedback system was created to adjust the output voltage level so that a 45mA_{RMS} signal is maintained regardless of guidewire length.

A sense resistor is used in the guide wire current loop to create an AC voltage proportional to the current. A precision rectifier changes this AC voltage to a pulsed DC signal, which is converted to a DC voltage by a low-pass filter and sent to a microcontroller's A/D converter as a feedback signal. The microcontroller uses a PI controller to adjust a variable gain circuit to maintain the desired current regardless of load. To increase the voltage compliance of this constant-current circuit, fixed-gain operational amplifiers were added in parallel to the signal generator's output.

In addition to its primary function of providing a navigational beacon for the rover to follow, the base station also reports the battery voltage and instantaneous loop current on an LCD. The system requires an operating voltage between 6V and 8V. Field testing showed the users did not monitor the battery voltage, and became confused when the base station's battery became discharged and the robot lost its ability to navigate. To remedy this, a low battery function was added that sounds a loud alarm when the battery is discharged below 6.2V. A push button temporarily disables the alarm, should the user need a few extra minutes of runtime.

B. Physical Design Considerations

In order to simplify the user experience, the base station was designed with a single power toggle switch and a push button to silence the low battery alarm. The battery is attached to the exterior of the base station using hook and loop fasteners, making it possible to swap in fresh batteries in the field without stopping to recharge. The electrical components and circuitry are encased in a weatherproof container to allow the system to be used in wet weather conditions (Figure 7).

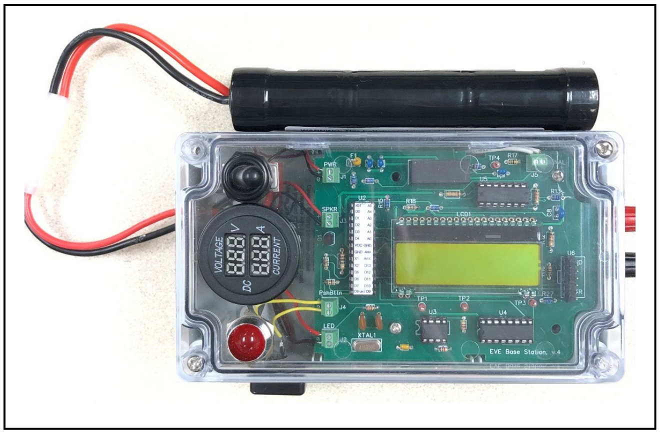

Fig. 7. Weatherproof base station with battery attached to the side via hook and loop fasteners. The power switch is in the upper left-hand corner. Beneath that is the battery voltage/battery current monitor. The low battery light can be seen below that, and its associated low-battery audible alarm is just visible on the side of the box on the lower left. The LCD reports the current in mA_{RMS} and is updated at 10Hz. The wire used for navigation will be connected to the binding posts visible on the right.

IV. CONCLUSION

The design of an improved tick-collecting robot and its associated base station has been described. It will be field-tested by a biology team at Old Dominion University during the summer of 2020 to measure the degree and length of time that tick populations are reduced with different treatment plans in a residential, bordered environment. The tick rover could be re-engineered to target other pests such as carpenter ants in lumber yards, cockroaches in food-processing facilities, and bedbugs in hotels. Although this technology is still in its infancy, the general approach of using robotic biomimicry for pest control has many potential applications.

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