A Wearable Wireless Platform for Visually Stimulating Small Flying Insects*

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***Abstract*— Linking neurons and muscles to their roles in behavior requires not only the ability to measure their response during unrestrained movement but also the ability to stimulate them and observe the behavioral results. Current wireless stimulation technologies can be carried by rodent-sized animals and very large insects. However, the mass and volume of these devices make them impractical for studying smaller animals like insects. Here we present a battery-powered electronics platform suitable to be carried on a flying locust (2.7 g). The device has an IR-based (infrared) receiver, can deliver optical or electrical stimulation, occupies a volume of 0.1 cm^3, and weighs ∼280 mg. We show the device is capable of powering two white SMD light emitting diodes (LEDs) for ∼4 min and can be recharged in ∼20 min. We demonstrate that our system shows no crosstalk with an IR-based Vicon tracking system. The entire package is made from commercial off-the-shelf components and requires no microfabrication.**

I. INTRODUCTION

An increasing body of evidence indicates that neurons display markedly different response properties depending on whether an animal is actively behaving or not [1]. Thus, a significant challenge in neuroengineering today is to produce devices capable of wirelessly recording from and stimulating neurons during natural behavior [2]. While the functional role of a neuron or muscle can be investigated by correlating measured activity with the observed behavior [3-5], to test causal links it is necessary to inject signals during natural behavior and observe the resulting behavioral perturbations. Although there are wearable platforms available that can deliver stimulation wirelessly [6-11] their weight and size make them unsuitable for use in all but the largest insects.

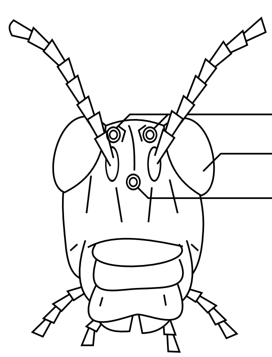

Fig. 1. Diagram illustrating location of ocelli on Schistocerca Americana

*This work supported in part by Draper Laboratories

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II. MOTIVATION

The problem of producing a platform to aid in the investigation of flight control in small insects is particularly challenging due to the severe size and weight constraints involved. A 2 gram insect can carry 400 - 600 mg payload (i.e. 20 - 30% of body mass) and still fly. Our aim was to decrease the weight even further than this estimate in order to get flight that was as natural as possible. Although the device can in principle be used for electrical stimulation or stimulation in optogenetic animals, our particular interest is the visual system of locusts. As shown diagrammatically in Fig. 1 the visual system of locusts includes two large compound eyes and three smaller eyes, known as ocelli. Our primary aim was to make a system capable of stimulating two of these eyes during free flight.

III. SYSTEM DESIGN

The wearable platform has two major components: a backpack mounted on the insect body and a headpiece which relays signals received by the backpack to the insect's senses. In this work, the headpiece was designed to optically stimulate the eyes, and the backpack was mounted on the pronotum of a locust (Schistocerca Americana). A detailed description of the components of our apparatus follows.

A. Backpack

The backpack is composed of an MSP430 microprocessor, an IR receiver, and a battery pack (see table II). The components are connected by soldering fine silver wires to the pins under a dissection microscope. Care is taken to ensure that the IR receiver's optics point upwards such that the module will receive signals from the remote IR emitters placed on the ceiling. Fig. 2 shows the general layout and circuit design.

B. Selection of Components and Assembly

The software running on the microcontroller is a custom program written in C. It makes use of a simple 4-bits-per-symbol communication channel implemented with an interrupt-driven software UART. The onboard MSP430 microcontroller provides a user-programmable platform that can generate various types of user-triggered stimulus trains. We selected the MSP430 microcontroller as it comes in a small package (4mm × 4mm × 2mm), consumes very little power, and contains sufficient hardware peripherals such as multi-channel hardware PWM (used to drive LEDs).

Due to extremely limited battery capacity, power management had to be carefully managed. The experimenter

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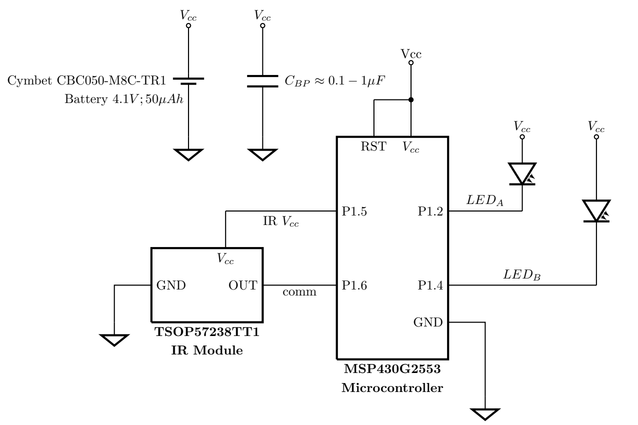

Fig. 2. Schematic for the device circuit. See Table II for specific part numbers and component values used.

can switch between the following operating modes over the course of the experiment to conserve power:

1) *Stimulation Active:* The insect's eyes are stimulated as commanded.
2) *No Stimulation:* LEDs are turned off and the microcontroller waits for further commands.
3) *Sleep Mode:* Microcontroller has been commanded to enter a sleep state. A hard reset is necessary to come out of this state. This mode is useful to conserve battery power between flights.

C. Headpiece

The headpiece consists of two surface mount LEDs connected to the backpack by three micro-springs; Current is sunk directly by the microcontroller output ports. These springs were made of insulated silver wire (75μm bare, 138μm insulated, AM Systems) coiled into a spring to ensure a sufficiently compliant connection that does not interfere with the animal's head movement (see Fig. 3).

IV. Transmitter Beacon and Motion Tracking System

The Vicon motion tracking system emits infrared light at a similar wavelength to that used for communication with the backpack. Though our signals are distinguished by a carrier frequency of 38kHz, the signal had to be reinforced with many transmitters spatially distributed throughout the room in order to ensure full coverage and avoid interference from the Vicon system's own IR lamps.

V. EXPERIMENTAL SETUP

The experiment was performed in a room of length 9 m, width 7 m, and height 4 m in which a commercial IR-based tracking system (Vicon 9-camera system with a frame rate of 120Hz) was installed for the purpose of tracking the insect in free flight. This system tracks a small 3 mm IR retroreflector (Optitrack). The IR transmitter consists of eight IR beacons mounted on the ceiling of the room (see 4). Data transmitted by the IR beacons is picked up by the backpack and relayed to the insect's senses through the headpiece. Multiple flights were performed by launching the insect smoothly into the air. Only flights of greater than one second were analyzed. The room was maintained at 31^{o}C.

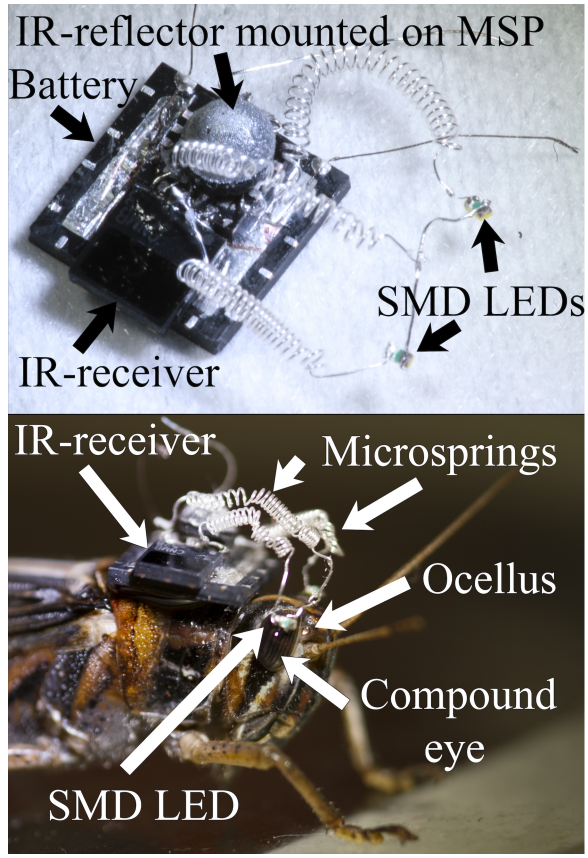

Fig. 3. Locust with mounted device

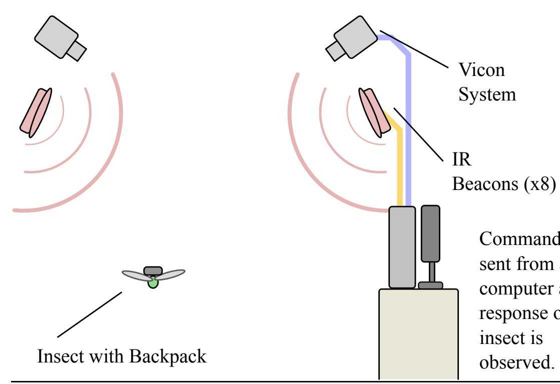

Fig. 4. Experimental setup for free flight experiments

VI. RESULTS

A. Battery Life

By carefully managing power settings on the microcontroller and power cycling various parts of the circuitry we are able to effectively extend the time over which the backpack can last on a single charge. The power usage of the backpack circuitry over different operating modes is shown in Fig. 5.

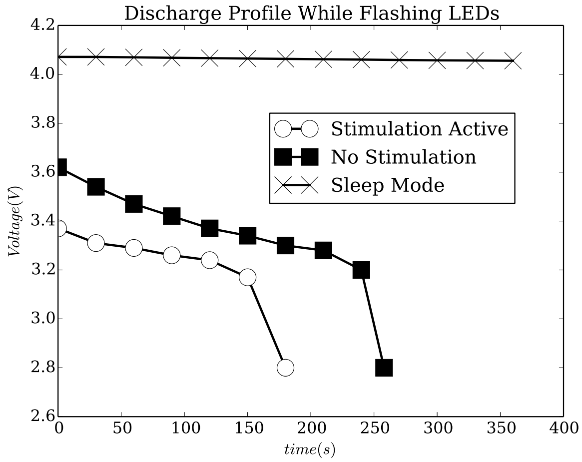

Fig. 5. Profile of battery voltage over time. During sleep mode, the battery did not drop below 3.8v in the next five hours.

B. IR receiver communication coverage

Although fewer than eight IR beacons may have been adequate for our room (9 m $\times$ 7 m $\times$ 4m), to confirm that the ability of the base station to communicate with the device was never a factor in our experiments, we programmed the base station to produce repeated test pulses while scanning the room with the device. Visual inspection verified when these pulses were received. The device was attached to a 1 m wand to scan from 0.5 m to 3 m above the floor. With the device positioned horizontally we could find no dead zones in the room. When we turned the device upside down we found that the only dead zones were within 20 cm of the four corners of the room. This level of coverage was more than adequate for our needs as it exceeded that of our commercial tracking system (Vicon). Furthermore, the Vicon system did not pick up any interference originating from the beacons.

C. Testing in free flight

The average mass of our devices was 280$\pm$15 mg ($n = 5$), well within the 400 mg that we estimated a large female locust can carry, and substantially less than prior insect-mounted devices capable of stimulation (Table. I). The device is small enough to fit on the pronotum (Fig. 3) without impeding the wings or head. We smoothly threw the locust into the air on 15 occasions. In eight cases the locust failed to fly or flew directly to the wall. However, in seven flights we saw characteristic flight patterns previously seen in control animals (Fig. 6). In all successful cases the paths were relatively flat or the insect gained altitude. Thus, our system appeared to allow natural flight.

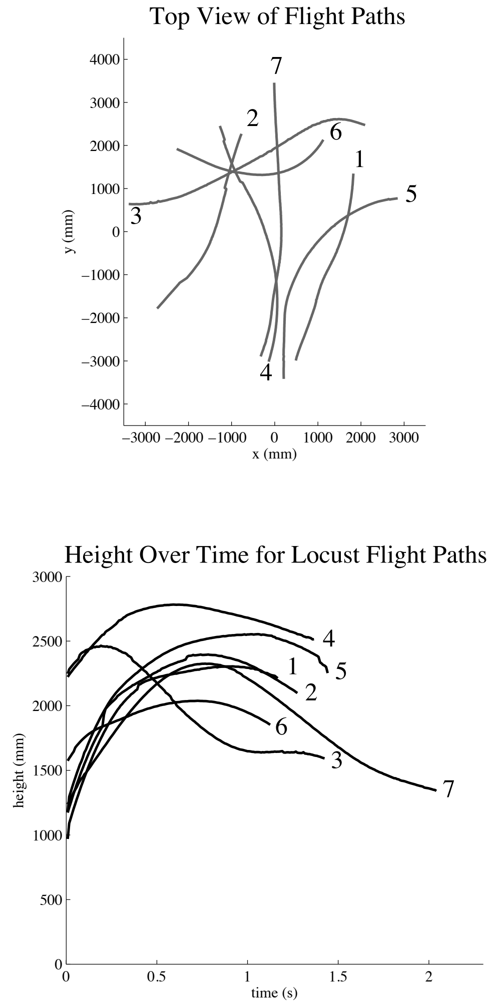

Fig. 6. Example tracks obtained from the Vicon system. The numbers denote the track number and are placed at the end of the flight path. The top panel demonstrates a top-down view, while the lower shows height vs. time.

VII. FUTURE WORK

Our aim is to implement closed-loop control of insects. We believe that adding closed loop feedback that depends on the insect's response will make our control more robust to interindividual variation. The next step in our work is to write software that accesses the realtime Vicon path information and produces the appropriate control signal. We envisage that our device will also have applications as an electrical stimulation device and as an optical stimulator for optogenetic preparations where targeted neurons can be activated during natural behavior. For this purpose our device would require an optical light guide that penetrates down into the animal so that the light is delivered directly to the cell. Given the exceptionally low mass of our devices, it would be possible to use multiple devices on an animal the size of a mouse. Another useful application for our device would be to exchange the white LEDs for IR LEDs and use the system for IR tracking.

VIII. CONCLUSIONS

We have shown that it is feasible to build a 280 mg IR remote controllable stimulus delivery platform that is capable

TABLE I

PREVIOUSLY DEVELOPED WIRELESS DEVICES FOR MEASURING AND/OR STIMULATING INSECTS IN FLIGHT

Year	Mass (g)	Created By	Record/Stimulate
1993	0.26g	W. Kutsch [3]	record
1999	0.4g	Kuwana et al. [12]	record
1999	0.3g	Fischer and Kutch [13]	record
2001	0.74g	Mohseni et al. [14]	record
2002	0.25g	Ando et al. [4]	record
2003	0.2g	Kutsch et al. [15]	record
2004	0.25g	Ando and Kanzaki [16]	record
2008	0.23g	Wang et al. [17]	record
2009	0.65*	Bozkurt, et al. [7]	stimulate
2010	0.461	Tsang, et al. [8]	stimulate
2010	1.33	Sato, et al. [9]	both
2010	1	Daly, et al. [10]	stimulate
2010	0.17	Harrison, et al. [18]	record
2012	0.42	Hinterwirth, et al. [11]	stimulate

* = required use of helium balloons to support its weight.
All systems made use of radio frequency for communication.
Modified from [19]

TABLE II

ELECTRONIC COMPONENTS USED IN OUR EXPERIMENTAL SETUP

Description	**Part Number**	**Mfr.**	**Used In**
Microcontroller	MSP430G2452	Texas Instruments	Backpack
Battery	CBC050-M8C-TR1	Cymbet	Backpack
IR Receiver	TSOP57238TT1	Vishay Semiconductor	Backpack
1μF Capacitor	CL05A105JQ5NNNC	Samsung	Backpack
NPN Transistor	TIP-102	Fairchild Semiconductor	IR Beacon
IR LED	OED-EL-1L2	Lumex	IR Beacon
22.0Ω Resistor	CF14JT22R0	Stackpole Electronics	IR Beacon
1.00kΩ Resistor	CF14JT1K00	Stackpole Electronics	IR Beacon

of being carried by a locust weighing 2.7 g. With eight beacons we could ensure complete coverage of a room with dimensions: 9 m $\times$ 7 m $\times$ 4 m. Importantly this system does not interfere with the IR-based tracking system that we use to measure the insect flight paths.

APPENDIX

A. Bill of Materials

See table II for the list of commercial off the shelf electronic components used.

ACKNOWLEDGMENT

We thank Nishant Kalonia for help operating the Vicon system.

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