HYBRID CHEMICAL AND ELECTRICAL CONTROL OVER INSECT CYBORG AIR VEHICLES

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ABSTRACT
We present a novel hybrid control approach for insect micro air vehicle manipulation that employs both electrical and chemical stimulations signals to control the locomotive activity of *Manduca sexta* moths. We use an implanted microfluidic device to wirelessly dispense neurotransmitters on command which modulate the metabolic behavior and flight performance of the insect, while supply DC pulses that provide a periodic stimulus and facilitate sustained flight. Briefly, we demonstrate that an L-Glutamic Acid solution can override the electrical stimulation signal and induce a reversible, temporary paralysis, and correlate flight performance and dose response using an indoor GPS system.

KEYWORDS: Insect Cyborg, Hybrid Control, Micro Air Vehicles, Microfluidics

INTRODUCTION
The fusion of living insects with electrical control systems represents a new paradigm in the development of microscale air vehicles [1,2]. This fusion is very synergistic since flying insects provide impressive aerodynamic and energy storage capabilities (which are very challenging in the small scales) while electrical systems can offer great on command maneuverability. However, the role of drug delivery and chemical assistance for insect micro-air vehicle control has not been thoroughly explored. Here we show how a wireless implantable microfluidic device capable of dispensing L-Glutamic Acid neurotransmitters can complement the electrical stimulation standard and assist in flight control via the deceleration of a *Manduca sexta* moth.

![Figure 1: A) Operational schematic of hybrid control and B) Experimental Setup](image)

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Figure 1A shows the hybrid operational schematic, in which copper electrodes for electrical stimulation are inserted in the vicinity of a mature moth’s ganglia while the fluidic chip loaded with neurotransmitters is implanted in the dorsal thorax. The full scale experimental system is displayed in Figure 1B. In these experiments, the weight of the wireless transceiver, a 3V battery and the additional circuitry which includes a DC to DC boost converter to accelerate the fluidic chip drug delivery operation, is compensated by tethering the moth to a 6 liter helium balloon.

RESULTS AND DISCUSSION

![Figure 2: Electrical stimulation A) At rest (no shocks) and B) Forced flapping through DC pulses](image)

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The first facet of our work is presented in Figure 2. Figure 2B is the result of delivering 3V DC pulses to the vicinity of the Manduca Sexta moth’s ganglia will bring about wing muscle contraction, leading to effective flight from the stationary position shown in Figure 2A. In addition to enabling take off (Figure 2B), this approach can help ensure continuous flight operation by supplying pulsed electric signals synchronized with the mean wing beat frequency (25Hz). We also employ a delocalized electrode approach (not shown), and by supplying the same type of pulsed electrical signals, the moth can be prompted to fly by forcing into “fight or flight” mode.

Figure 3: Multi-reservoir fluidic chip operation A) Flexible and bio-compatible multi-reservoir drug delivery system schematic B) Assembled drug delivery setup. Inset is a cross section of the top polyimide component. C) Prior to fluidic ejection. D) Targeting top channel fluidic ejection and E) Bottom channel ejection

Figure 3 displays the schematic of our flexible and bio-compatible multi-reservoir fluidic system, which is capable of selectively dispensing distinct neurotransmitters that either enhance or paralyze [3] wing muscle activity as we have previously demonstrated. Briefly, this implantable drug delivery system works by an electrolytic reaction driven between a capping gold membrane (shown in Figure 3A and highlighted at the top of the inset in Figure 3B) and bottom electrode located inside the reservoir as demonstrated by Chung and Erickson [3]. The net reaction builds up the pressure in the closed fluidic system through water electrolysis, and simultaneously, the capping gold membrane is weakened through the formation of a chloro-gold complex. The process continues until the membrane ruptures, and pressure is relieved by ejecting the fluidic contents to the chip’s exterior. This procedure is shown in Figures 3C thru Figure 3E, which display time-lapsed images showing the selective ejection of blue dye from individual microfluidic channels. In addition, the all polymer device (Figure 3B) is also very flexible to help ensure that it does not shatter during the tissue implantation or tissue reconfiguration phases.

Figure 4: A) Chemical override of electrical stimulation and B) Insect tracking through indoor GPS system

The fully integrated system results are shown in Figure 4. First, the Manduca Sexta moth is stimulated from rest into continuous flight through electrically driven pulses (Figure 4Ai). The fluidic chip then ejects a solution of 2.5M L-Glutamic Acid into the moth’s circulatory system (Figure 4Aii), and less than 1 minute later, the moth is fully paralyzed (Figure 4Aiii) after the capping membrane opens inside the moth and the neurotransmitters are dispensed, despite still being electrically stimulated. This paralysis occurs through an over-excitation of the insect’s nervous system through an L-Glutamic acid induced elevation in neuron membrane potential. The paralysis is reversible however, since the moth regained full activity nearly 1 hour later, and we also note that quicker response times were found for lower dose concentrations (not shown). This drug induced paralysis and/or deceleration can be favorable for two reasons: It does not involve a possibly damaging electrical overstimulation procedure, and also does not require the constant streaming an electrical stop signal which can help reduce power constrains. Furthermore, insect flight performance for different drugs is eva-
luated using an indoor GPS system as shown in Figure 4B. This plot presents a typical moth trajectory, and from this data the mean speed velocity can be evaluated since the time stamp is known.

CONCLUSION
Unlike previous cyborg air vehicles, this novel hybrid system can use chemicals to enhance flight performance and in parallel, use electrical stimulus to provide on demand control of wing flapping activity. In addition to enhancing flight behavior, chemical control also provides the ability to enable long term dormant periods without the need for continuous external power. Our work currently focuses on characterizing effective chemical stimulants and in finding adequate mechanisms to increase moth flight longevity.

ACKNOWLEDGEMENTS
This work was supported by the Defense Advanced Research Project Agency, Microsystems Technology Office, Hybrid Insect MEMS program, through the Boyce Thompson Institute for Plant Research. The facilities used for this research include Nanoscale Science & Technology Facility (CNF) and Nanobiotechnology Center (NBTC) at Cornell University.

REFERENCES

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