Electrostatic Self-excited Actuators for Micro Robots

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Electrostatic Self-excited Actuators

• Why electrostatic actuation?

Simple structure, Low consumption
Electrostatic Self-excited Actuators

• Franklin bells

Gordon’s idea
Electrostatic Self-excited Actuators

- Can we find similar vibration in micro world?

1 – 5 Hz

50 – 500 Hz
Electrostatic Self-excited Actuators

- Vibration in different fashion

![Diagram showing the operation of electrostatic self-excited actuators with input and output stages. The diagram includes a metal beam, discharging, and charging stages, with waveforms indicating stable and unstable decay stops.]

- Stable decay stop
- Figure-of-eight
- Figure-of-oval
Electrostatic Self-excited Actuators

• Summary of advantages
  – Simple structure
  – Low power consumption
  – Easy to drive by DC voltage
  – Large vibration
  – Adjustable fashion
Electrostatic Self-excited Actuators

- Summary of disadvantages
  - High DC voltage up to thousands of volts

4000 – 7000 volts  2000 to 10000 volts
Electrostatic Self-excited Actuators

• Three applications
  – Artificial flying insects (today)
  – Artificial crawling insects
  – Air cleaning robots
Artificial Flying Insects
Driven by Electrostatic Actuators

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Outlines

- What’s the use?
- What’s the problem?
- How do we solve the problem?
What’s the use?

- Potential of robotic insects

  - Get into very small places
  - Hard to be found in open places
  - Safe when crash or hit people
What’s the use?

• Search and rescue in confined places
What’s the use?

• Record our daily life as a personal flying camera
What’s the use?

- Carry out anti-terrorist mission

Overhearing terrorist plans in their meeting room

Attacking terrorists with biochemistry or electric weapons
What’s the use?

• Carry out anti-terrorist mission
Outlines

- What’s the use?
- What’s the problem?
- How do we solve the problem?
What’s the problem?

• Development of artificial flying insects: 4 stages
  – Flapping and rotation motion of wing
    • Achieved by Arai 1995, Miura 1997
  – Tethered flight with the help of power wires
    • Achieved by Woods 2013, Hines 2014
  – Untethered flight with on-board power (Insect-sized)
    • Nobody can achieve that.
  – Auto-flight with both power and control on-board
    • More far away from us.

High performance actuator and power are eagerly needed.
重点说现阶段的热点

在昆虫尺寸的微型扑翼飞行器方面，wood教授影响力最大，目前已经能够“带导线”飞行了。但目前的难点在于微型扑翼动力装置。
What’s the problem?

- Electric motor + battery

Bird-sized

Insect-sized

Unable to fly

Electromagnetic force ↓↓
Damping force ↑↑
重点说现阶段的热点

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What’s the problem?

- Linear actuators + AC power source: Piezoelectric

Tethered flight with the help of power wires

Consuming power, size, and weight
重点说现阶段的热点

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Our work

- Bionic flapping actuator with ceramic capacitors

Extremely simple
Easy to be fabricated
Outlines

- What’s the use?
- What’s the problem?
- How do we solve the problem?
How do we solve the problem?

- Learning from nature
- The bionic flapping actuator
- Single-wing configuration
- Double-wing configuration
- Dynamic modeling
Learning from nature

- **Working principle of real flight muscle**

![Diagram of flight mechanism]

- **Input**: Neural stimulation
- **Output**: Wing motion

**Self-excited vibration**

“Start signal”

Telling the muscle to start the contract and stretch
重点说现阶段的热点

在昆虫尺寸的微型扑翼飞行器方面，wood教授影响力最大，目前已经能够“带导线”飞行了，但目前的难点在于微型扑翼动力装置。
Learning from nature

• Wing motion of real flying insects

Figure-of-eight

Figure-of-oval
The bionic flapping actuator

- Can we find similar vibration in micro world?

- All kinds of metal beam can work, such as aluminum, gold, shape memory wires or films.

- The beam impacts the electrodes alternatively controlled by charging and discharging process without AC feedback circuits.

- Metal beam, Insulated base
- Two electrodes, DC voltage

Self-excited vibration
The bionic flapping actuator

- Working principle and tip motion
Single-wing configuration

- Evolution of the electrostatic actuator

Horizontal rails for testing the lift force visually
Single-wing configuration

• Horizontal flight test

It works!
Single-wing configuration

- Redesign for rotation motion and smaller size

13mm in length, 3mg in weight
Single-wing configuration

• Wing motion and lift force measurement

Flapping: 80 °
Rotation: 90 °
Frequency: 50-70Hz

Average lift force: 1mg
Lift-weight-ratio: 0.33
Double-wings configuration

- Structural design
Double-wing configuration

- Vertical flight test to verify the lift force visually

  - U-shaped rail: Allows the wings to move upward
  - Extended electrodes: Provides continuous driving force

U-shaped rail

Move direction

$F_L$

$F_L$
Artificial Crawling Insects Driven by Electrostatic Actuators

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Artificial *Flying* Insects (last report)

- Search and rescue in confined places
- Anti-terrorist mission in dangerous places
Artificial Crawling Insects

- Can we use these pros to make a crawling robot?

- Simple structure
- Easy to be fabricated
- Easy to be miniaturized
- Low consumption
- High efficiency
Artificial Crawling Insects

• How to convert the vibration of actuator into movement of the robots

Adding some legs to the vibrating beam
Artificial Crawling Insects

• How to covert the vibration energy of beam into moving energy of the robots

Thrust force

Shaking induced movement of a flapping-wing actuator
Artificial Crawling Insects

- Directly use the impact between the beam and electrode to generate forward-driven force
Artificial Crawling Insects

- Propulsion principle

Creeping forward (Top view)
Artificial Crawling Insects

- Propulsion principle

State 1: Beam hits the electrode

\[ f_2 - f_1 > 0 \]

State 2: Beam leaves the electrode

\[ f_1' - f_2' > 0 \]

The whole system will move forward with a shaking movement.
Artificial Crawling Insects

- **Fabrication**

  ![Diagram of artificial crawling insects](image)

  - **Single layer** two orthogonal layers of carbon fiber
  - **Carbon fiber + tinfoil**
  - **Plastic membrane (PET, Nalifilm Company)**
    - *a* Laser machining
  - **(laser cutting + apply heat)**
  - **supporting structure**
  - **Cantilever beams**
  - **Additional mass**
  - **Electrodes**
  - **(cutting)**
  - **Ceramics capacitor (10nF, 3kV, Yageo)**

  ![NiTi beams]
  - **NiTi beams**
  - **Beams**
  - **Legs**

  ![Manual assembly](image)
  - *(b) Manual assembly*
Artificial Crawling Insects

- Fabrication

47mg
Artificial Crawling Insects

- Moving test on smooth surface (Fast)

2500Volts, 30mm/s (1.5 body length)
Artificial Crawling Insects

• Moving test on smooth surface (Fast)

2000 Volts, 2 mm/s for 10 seconds
Artificial Crawling Insects

- Moving tests on 3 different rough surfaces (Slow)
Artificial Crawling Insects

- Moving tests on 3 different rough surfaces (Slow)

Foam
Artificial Crawling Insects

- Moving tests on 3 different rough surfaces (Slow)

Sand paper
Artificial Crawling Insects

• Moving tests on 3 different rough surfaces (Slow)
ME 138/238 LAB 2
for Micro Robots

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Laser cutting process

Electrodes

Supporting beams

Supporting plates

Vibrating beams / Legs
Laser cutting process

- Supporting plates
Laser cutting process

• Supporting beams
Laser cutting process

- Electrodes
Assembly the actuator

- The vibrating part of the robot
Test the actuator

• Measure the operating current
  – Calculate the frequency and power consumption
Assembly the robot

• Three steps

Insert

Glue

Adjust
Test the robot (optional)

- Walking on different surface profiles

(a) Foam
- 0s
- 0.81s
- 1.60s
- Foam board

(b) Sand paper
- 0s
- 2.77s
- 5.39s
- Sand paper

(c) Water
- 5.69s
- 2.04s
- 0s

(d) Sand paper