BMS INSTITUTE OF TECHNOLOGY AND MANAGEMENT

Avalahalli, Yelahanka, Bengaluru-560064

DEPARTMENT OF ELECTRONICS AND TELECOMMUNICATION ENGINEERING

Final year Technical Seminar (18TES84) Presentation

on

Development of a Penguin-Inspired Swimming Robot With Air Lubrication System

Under the guidance of:

Dr. SARITHA I G

Assistant Professor

Department of ETE

BMSIT &M

Submitted by:

S.VARSHA

1BY20ET048

CONTENTS

INTRODUCTION

- Mimics the agile movements of biological penguins
- Two degrees of freedom (DOF) wings to achieve flexible planar movement
    - Heaving
    - Pitching
- Buoyancy-driven system for ascending and diving
- Air lubrication system inspired by the BDR phenomenon of penguins jumping out of the water

Item	Characteristic
Size	$\sim 0.71 \times 0.66 \times 0.26$ m^3
Total mass	$\sim$19.4 kg
Number of the DOF	5
Drive mode	DC motors, digital servomotors
Controller	STM32F407 (ARM based)
Power supply	DC 24 V
Communication unit	RF200 (433 MHz)
Operation time	$\sim$3 h

Table 1: Technical Parameters

WHY AQUATIC ANIMALS?

- Aquatic animals possess superior propulsion characteristics including:
  - High Efficiency
  - Low Noise
  - Excellent Maneuverability
- Motion Mechanism
  1. Body and/or Caudal Fin (BCF) Mode
     - Flexible Body
     - Dolphin
  2. Median and/or Paired Fin (MPF) Mode
     - Pairs Of Powerful Wings
     - Manta
  3. Jet Propulsion Mode
     - Jellyfish

WHY PENGUINS?

- Adapted to underwater swimming
- Utilizes the burst swimming strategy of hydrofoil like wings
- Mechanism of penguins jumping out of the water onto the ice
  - Dive with compressive air in their wings
  - Release during ascending
  - Expanding microbubbles form a smooth lubrication coat over the body
  - Making it swim twice as fast as normal
  - Bubble drag reduction (BDR)

LITERATURE SURVEY

TITLE	YEAR	AUTHOR	PUBLICATION	METHODOLOGY
Toward a novel robotic manta with unique pectoral fins	2022	Y. Meng, Z. Wu, H. Dong, J. Wang, J. Yu	IEEE Transactions on Systems, Man, and Cybernetics: Systems	• Improved crank rocker mechanism endows the robot with high swimming speed and efficient flapping patterns. • Distinctive horizontal DOF is employed to coordinate with the flapping movement, allowing remarkable pitch adjustment.

LITERATURE SURVEY

TITLE	YEAR	AUTHOR	PUBLICATION	METHODOLOGY
Biomimetic Realization of a Robotic Penguin Wing: Design and Thrust Characteristics	2021	Y.Shen, N.Harada, S. Katagiri, H.Tanaka	IEEE/ASME Transactions on Mechatronics	• Flapping motion generates the main thrust during locomotion. • Pitch angle can change the thrust direction. • Feathering motion enables active control of the angle of attack. Stalling of the wing occurs near an AoA of 10◦ in the steady state. • The feathering motion can avoid the stall, boost the net thrust and reduce the torque required to actuate the flapping motion.

LITERATURE SURVEY

TITLE	YEAR	AUTHOR	PUBLICATION	METHODOLOGY
Motion Control Strategies for a Repetitive Leaping Robotic Dolphin	2019	J.Yu , Z.Wu , Z.Su, T.Wang , S.Qi	IEEE/ASME Transactions on Mechatronics	• An integrative model that takes account of both kinematics and dynamics is established to explore the possibility of leaping with an untethered swimming robot. • A high-speed swimming control strategy is put forward based on the angle of attack theory, followed by the proposal of orientation control strategy.

LITERATURE SURVEY

TITLE	YEAR	AUTHOR	PUBLICATION	METHODOLOGY
From natural complexity to biomimetic simplification: The realization of bionic fish inspired by the cownose ray	2019	Y. Cai, S. Bi, G. Li, H.P.Hildre, H.Zhang	IEEE Robotics & Automation Magazine	• Low flapping frequency and flexible surface bring low hydrodynamic noise capability. • Pivot turning and roll swimming improves maneuverability. • The complex movement deformation of the cownose ray is split into two main components: chordwise wave transmissions and spanwise flapping movements.

LITERATURE SURVEY

TITLE	YEAR	AUTHOR	PUBLICATION	METHODOLOGY
Thrust force characterization of free-swimming soft robotic jellyfish	2018	Jennifer, Nick, Curet, Erik, Engeberg	Bioinspiration & Biomimetics	• Unique soft robotic jellyfsh with eight pneumatic network tentacle actuators extending radially from their centers. • Manufactured with a different composition of body and tentacle actuator Shore hardness. • Actuator material Shore hardness, actuation frequency, and tentacle stroke actuation amplitude significantly impacted mean thrust force generation.

MOTIVATION

- Robots are fascinating human inventions that are capable of carrying out a complex series of actions automatically.
- Being an interdisciplinary field, it helps to analyze the use of electronics practically in a different field.
- Helps in learning the latest innovative technologies.

OBJECTIVES

- To understand the mechatronic design of the robot
- To analyze the underwater movement generation capability of the robot
- To understand the process of designing innovations through biomimicry

METHODOLOGY

MECHATRONIC DESIGN OF THE ROBOTIC PENGUIN

1. *Biomimetic Robotic Penguin Design*
   - Well-streamlined body for better hydrodynamic performance
   - Divided into four parts
     1. Head cabinet containing a buoyancy-driven system
     2. Pair of wing outer cabinets
     3. Air lubrication cabinet
     4. Tail cabinet with a pair of feet

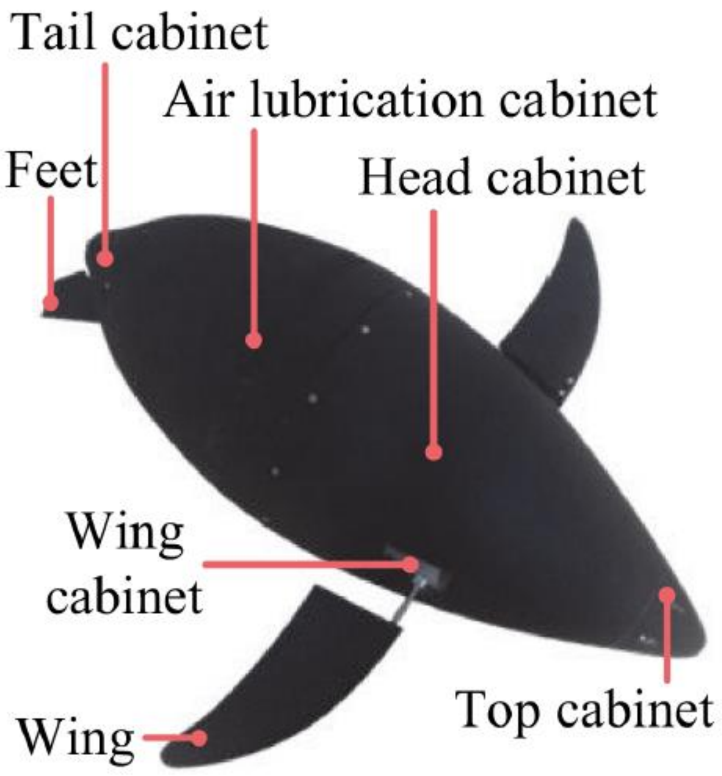

Figure 1: Robotic prototype

- Wings: 2-DOF movement capability
  1. Heaving motion
     - Direct current (dc) motor
  2. Pitching motion
     - Digital servomotor
- Buoyancy-driven System to realize ascending and diving motion
  - Water Injector
  - Piston
- Designed with almost complete symmetry
- Unique Air Lubrication System with a maximum pressure of 3 MPa

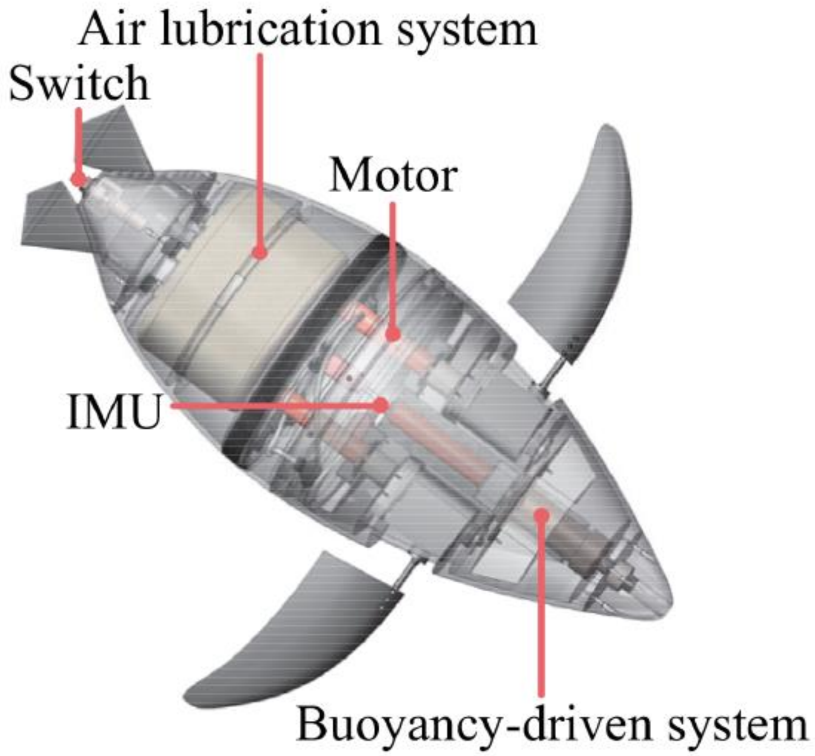

Figure 2: Conceptual design

2. Construction of the Air Lubrication System

- Main Principle
  - To generate stable bubbles around the body through spraying air reducing skin friction and increasing speed
- Designed near the largest cross-section of the middle and rear part
- Divided into three parts

  1) Compressed Gas Cylinder (e)

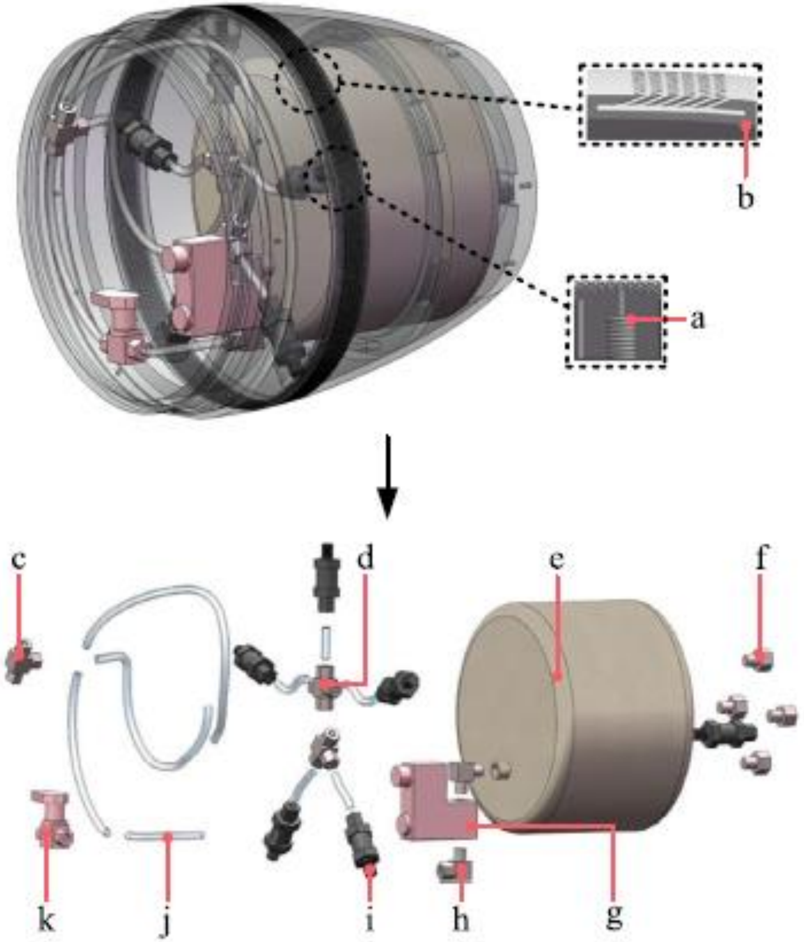

Figure 3: Air Lubrication System

2) Air Control Unit

- Solenoid Valve (g)
- Tee Fittings (c)
- Cross Fittings (d)
- Right Angle Adapters (h)
- Polyamide (PA) Pipe (j)
- Flow Valve (k)
- One-way Valves (i)

3) Cabinet Shell

- Screwed Joint (a)
- Inclined Hole (b)
- Cavity (b)

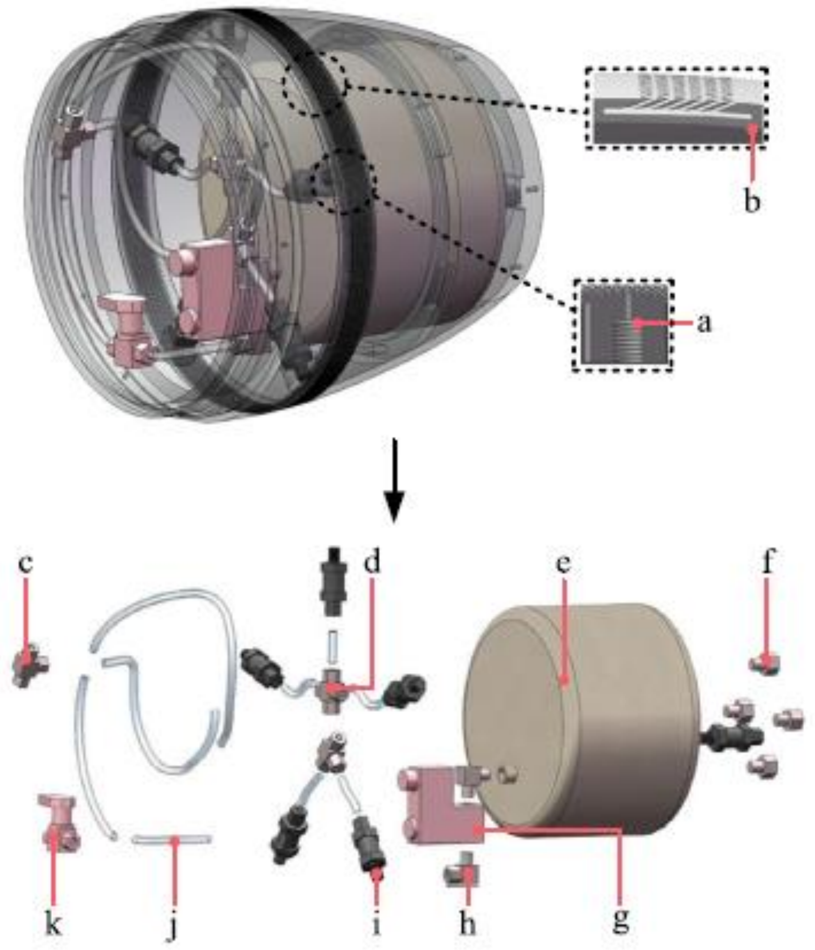

Figure 3: Air Lubrication System

- Operation of the Air Lubrication System
  - Divided into two stages
    1. Air Storage Stage
       - Needs an air compressor to pump compressed air into the cylinder.
       - To avoid air leakage, a one-way valve connects the compressed gas cylinder with air compressor.

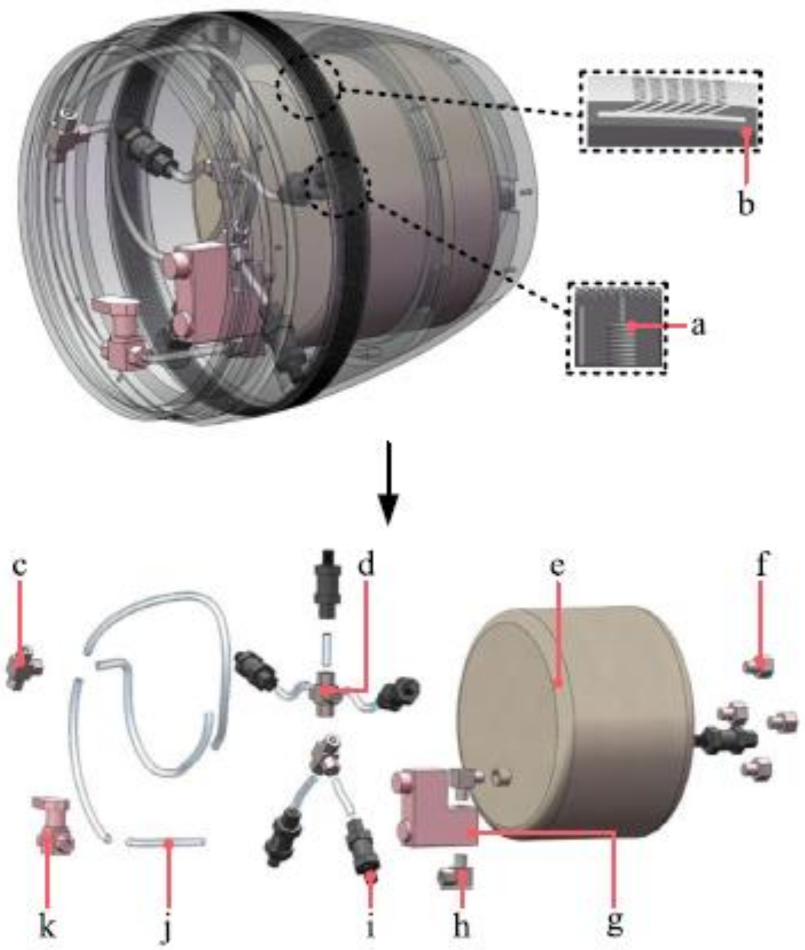

Figure 3: Air Lubrication System

2. Air Releasing Stage
    - Microcontroller unit (MCU) sends an opening signal to the solenoid valve.
    - Pipeline is turned on.
    - Compressed air in the compressed gas cylinder is delivered to the five outlets through the air control unit.
    - Air transits through the cavity and released from the inclined hole.
    - By sending a closing signal through the MCU, the pipeline will be closed immediately.

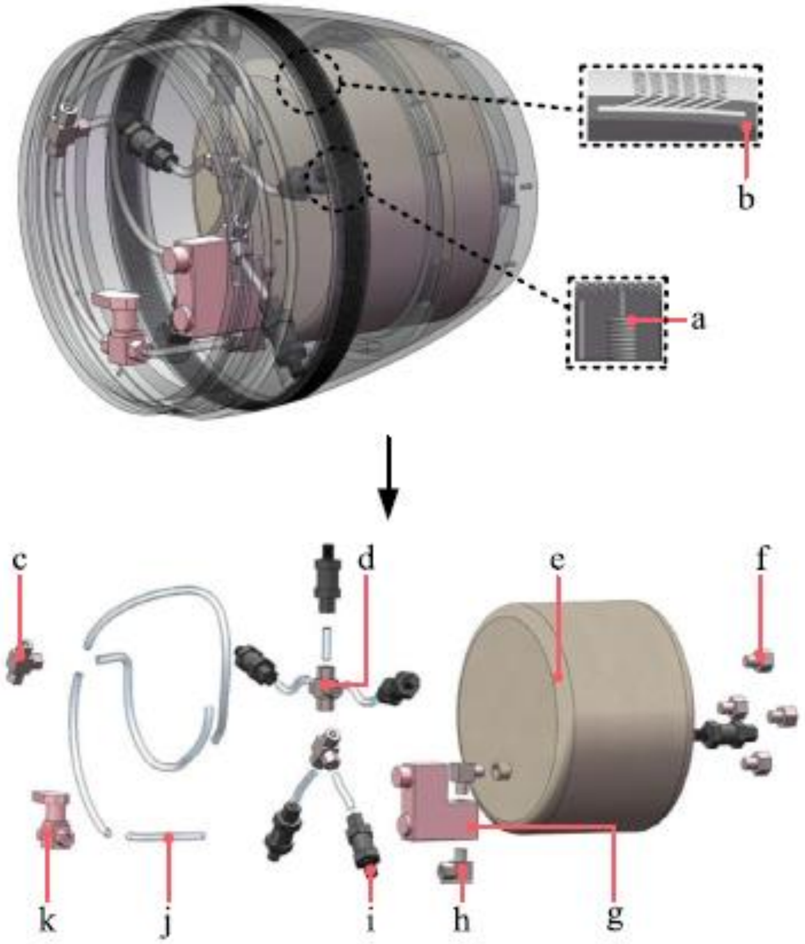

Figure 3: Air Lubrication System

BASIC MOTION STRATEGY

- Turning Schemes
  - (S1): Both sides of the wing maintain the rectilinear mode, one side rotates δ_θ, turning motion is realized by the difference in thrust on both sides.
  - (S2): The wing on one side rotates δ_θ to remain motionless, and the other side maintains the rectilinear mode to realize turning motion.

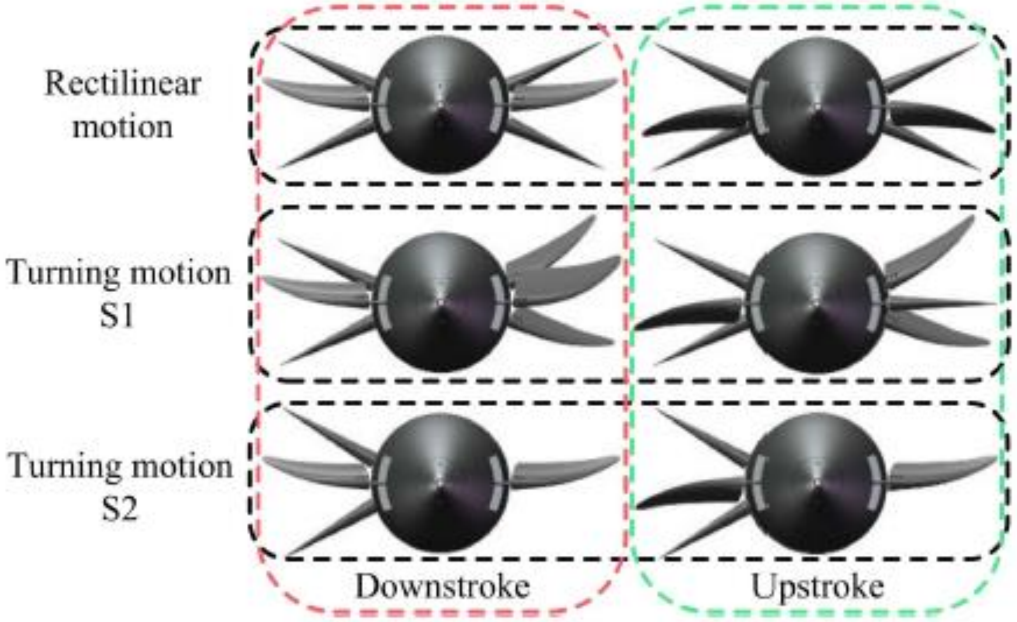

Figure 5: Schematics of motion strategy

RESULTS

- Systematic tests conducted in a 5 × 4 × 1.5 m experimental tank.

1. Rectilinear Motion

- Relationship between forward speed and:
  - Motion frequency (f)
  - Pitching amplitude (A_p)
  - Heaving amplitude (A_h)
- With the increase of f, A_p, A_h the forward speed is faster within the range of the parameters.
- Maximum stable speed = 0.567 m/s when $v = 2.0$ Hz, $\lambda_\varphi = 25^\circ$, and $\lambda_\theta = 30^\circ$

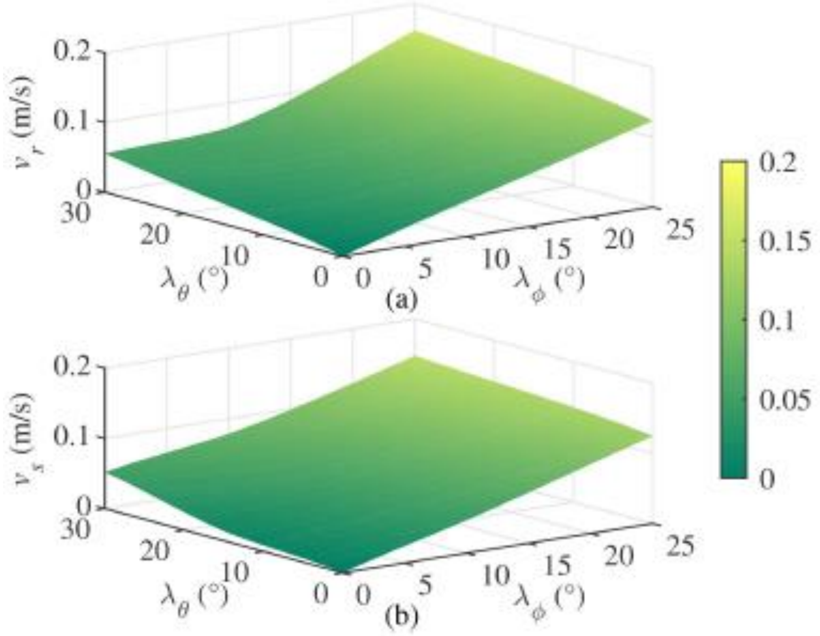

Figure 6: Comparison of forward speed for different λ_φ and λ_θ at $v = 0.5$ Hz
(a) Experimental results
(b) Simulated results

2. Vertical Motion

- Maximum displacement of the piston = 0.07 m
- Yield net buoyancy range = 0.242 N
- Maximum stable vertical velocity of ascending = 0.03 m/s
- Maximum stable vertical velocity of diving = 0.06 m/s

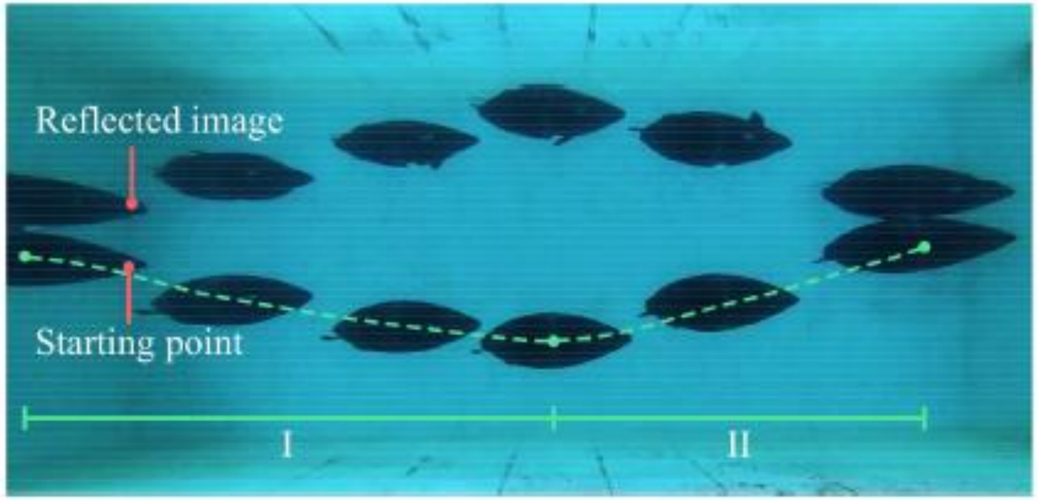

Figure 7: Robotic penguin during ascending and diving motion

3. Turning Motion

- Two main indicators:
  - Angular Velocity ω (red block)
  - Turning Radius r (yellow block)
  - Maximum angular velocity by S1 = 72.155 °/s ($\delta_\theta = 60^\circ$, r = 0.14 m)
  - Maximum angular velocity by S2 = 72.605°/s ($\delta_\theta = 0^\circ$, r = 0.06 m)

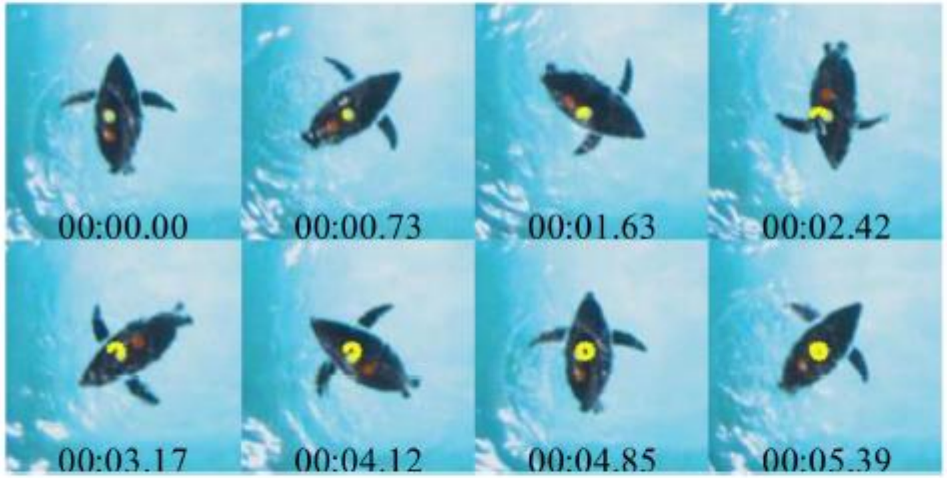

Figure 8: Turning motion with S2

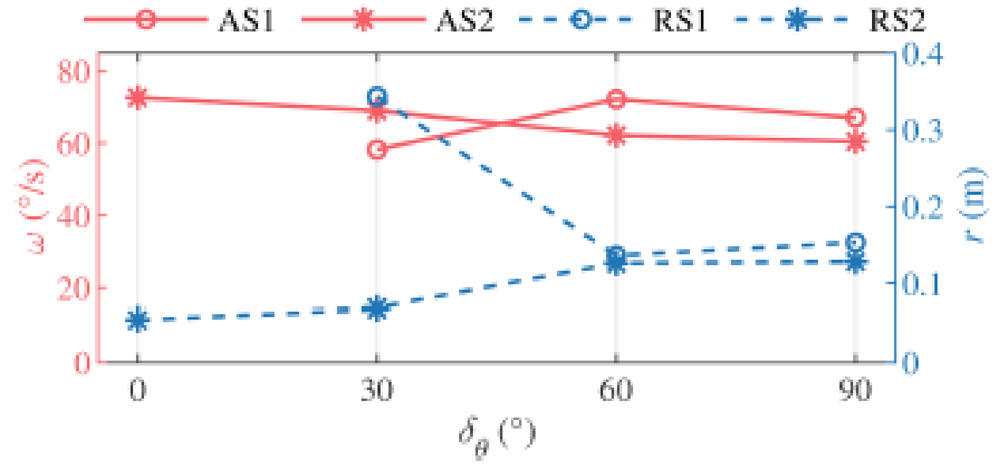

Figure 9: Comparison of different turning strategies

3. Performance of Air Lubrication System

- Air Lubrication System process divided into three periods:
  1. Development Period: Period of bubbles from zero to abundance
  2. Duration Period:
     - Bubbles are attached to the surface and constantly replaced by new ones
     - Significant acceleration stage
  3. Decline Period:
     - Long-lasting recession period, when the pressure of the residual air is difficult to maintain the lubrication layer at the current speed.

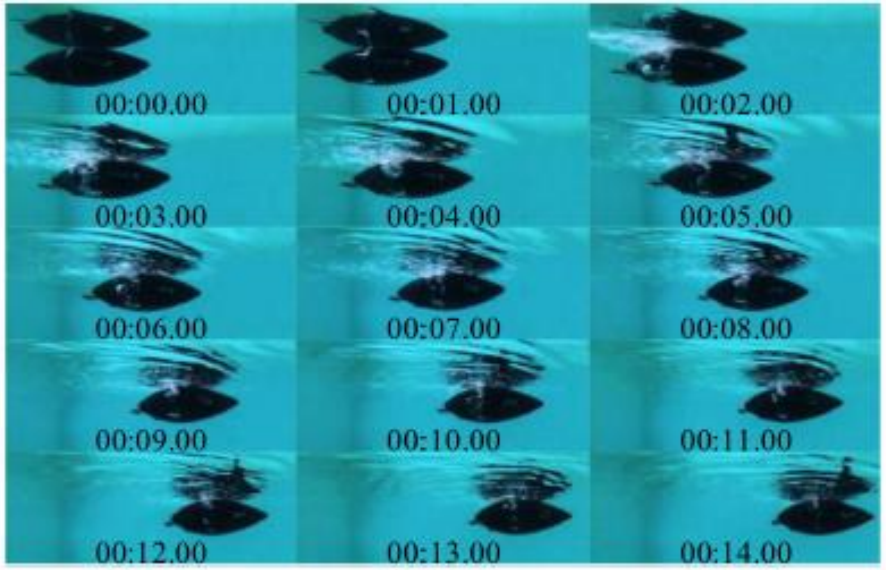

Figure 10: Robotic penguin during air lubrication

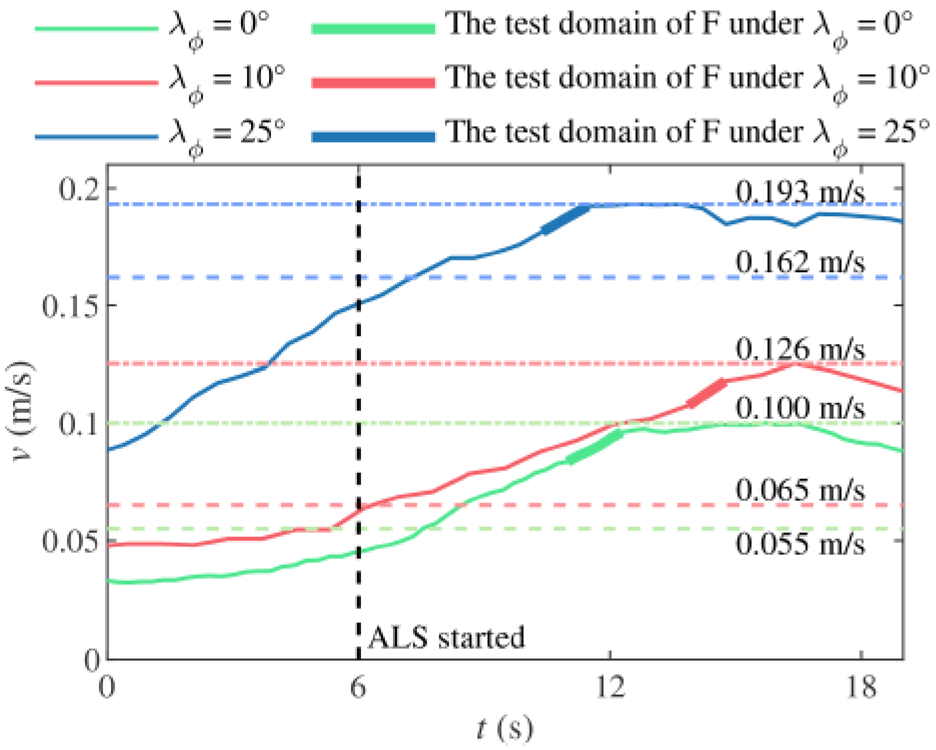

Figure 11: Experimental results of the forward speed for different λ_φ at $\nu = 0.5$ Hz and $\lambda_\theta = 30°$ with air lubrication system

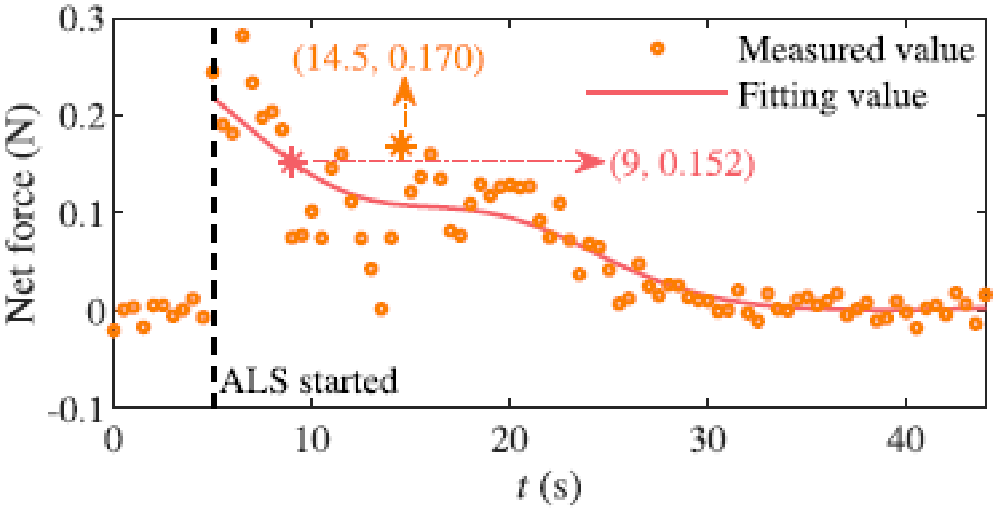

Figure 12: Thrust of the six-axis force sensor results in a static state with air lubrication

Scenario	Net Force	Improvment
Six-axis force sensor	0.152 N	-
$\nu = 0.5$ Hz, $\lambda_\phi = 0°$, $\lambda_\theta = 30°$	0.190 N	25.0%
$\nu = 0.5$ Hz, $\lambda_\phi = 10°$, $\lambda_\theta = 30°$	0.230 N	52.0%
$\nu = 0.5$ Hz, $\lambda_\phi = 25°$, $\lambda_\theta = 30°$	0.195 N	28.3%

Table 2: Comparison of net force for different scenarios

APPLICATIONS

- Marine Science and Research
- Underwater Archaeology
- Ocean Exploration
- Military and defence applications
- Underwater Infrastructure Inspection and Maintenance
- Search and rescue operations
- Offshore Oil and Gas Industry
- Environmental Monitoring and Pollution Detection
- Underwater Transportation

SOCIETAL CONCERN

- Environmental Impact
- Underwater Noise Pollution
- Impact on Traditional Industries
- Privacy and Security
- Resource Exploitation
- Navigation and Collision Risks
- Technological Dependence
- Data Security and Integrity

CONCLUSION

- Compared with the existing MPF-driven swimming robot, the robotic penguin designed achieves an average speed level and has higher steering flexibility.
- The air lubrication system has been proved to be effective in improving the speed of the robotic penguin and can be used as an auxiliary means to enhance the performance of swimming robot in the future.
- There is a big gap between the developed robotic penguin and the biological penguins, but the study of the bionic robotic penguin can advance the exploration of the penguin motion mode.

REFERENCES

[1] J. Wang, Z. Wu, M. Tan, and J. Yu, “3-D path planning with multiple motions for a gliding robotic dolphin”, IEEE Transactions on Systems, Man, and Cybernetics: Systems, May 2021

[2] Y. Meng, Z. Wu, H. Dong, J. Wang, and J. Yu, “Toward a novel robotic manta with unique pectoral fins”, IEEE Transactions on Systems, Man, and Cybernetics: Systems, March 2022

[3] S. Sindagi and R. Vijayakumar, “Succinct review of MBDR/BDR technique in reducing ships drag”, Ships Offshore Structure, 2021

[4] Y. Shen, N. Harada, S. Katagiri, and H. Tanaka, “Biomimetic realization of a robotic penguin wing: Design and thrust characteristics,” IEEE/ASME Transactions on Mechatronics, October 2021

[5] W. Stoll, “Aquapenguin,” FESTO, Esslingen, Germany, Tech. Rep. 54711/EN, 2009

[6]Y. Shen, N. Harada, S. Katagiri, and H. Tanaka, “Biomimetic realization of a robotic penguin wing: Design and thrust characteristics,” IEEE/ASME Trans. Mechatronics, October 2021

[7] Y. Cai, S. Bi, G. Li, H. P. Hildre, and H. Zhang, “From natural complexity to biomimetic simplification: The realization of bionic fish inspired by the cownose ray,” IEEE Robotics and Automation, September 2019

Thank You