DESIGN & DEVELOPMENT OF AN INTELLIGENT BIOMEMETICS ROBOTIC SYSTEM

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UNIVERSITI SAINS MALAYSIA
KAMPUS KEJURUTERAAN
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UNIVERSITI SAINS MALAYSIA

Laporan Akhir Projek Penyelidikan Jangka Pendek

Design and Development of an Intelligent Biomemetics Robotic System

by

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UNIVERSITI SAINS MALAYSIA

PEJABAT PENGURUSAN & KREATIVITI PENYELIDIKAN
RESEARCH CREATIVITY AND MANAGEMENT OFFICE [RCMO]

LAPORAN AKHIR PROJEK PENYELIDIKAN JANGKA *PENDEK*
FINAL REPORT OF SHORT TERM RESEARCH PROJECTS

1) Nama Ketua Penyelidik :
Name of Research Leader :

Ketua Penyelidik *Research Leader*	PTJ *School/ Centre*
Prof. Madya Dr. Mohd Rizal Bin Arshad	Pusat Pengajian Kejuruteraan Elektrik dan Elektronik (PPKEE)

2) Tajuk Projek :

Rekabentuk dan Pembangunan Sebuah Sistem Pintar Robot Biomemetiks
(Design and Development of an Intelligent Biomemetics Robotic System)

3) Abstrak penyelidikan:

Objektif penyelidikan ini adalah untuk mengkaji, menyelaku dan membangunkan sistem pengawal sebuah sistem robot berasaskan sistem biologi yang wujud di dalam persekitaran kita. Sistem biologi ini diwakili oleh serangga dan haiwan yang mempunyai sistem kawalan yang sempurna yang dapat menyelesaikan permasalahan kestabilan jasad, pandu-arah, pemacuan dan penggabungan penderia. Penyaringan pelbagai sistem kawalan biologi ini adalah amat penting untuk memastikan sistem kawalan yang digunakan di dalam sistem robot semasa adalah optima. Satu faktor penting adalah isu kepintaran sesebuah sistem robot. Jumlah minima "kepintaran" yang diperlukan oleh sesebuah sistem kawalan adalah yang membolehkan ia untuk membuat keputusan di dalam implementasi secara masa nyata. Secara khususnya, projek ini menerangkan tentang kelebihan merekabentuk sistem pemacu sebuah kenderaan dalam-air kendiri berdasarkan pemacuan haiwan akuatik berbanding rekabentuk konvensional. Ia membandingkan prestasi pemanduan, pemusingan dan penggunaan tenaga di dalam rekabentuk tersebut, dan menganalisa kelebihan dan kekurangannya. Pemacuan haiwan akuatik seperti belut, obor-obor dan sotong telah juga dikaji. Sebuah rekabentuk AUV biomemetiks telah dibangunkan yang dapat meniru gerak pemacuan haiwan akuatik.

Research Abstract:

The objective of this research project is to investigate, simulate and implement the controller system of robotic system based on biological system in nature. Biomemetics robotics system is a new trend in robotics system emulation of nature. Biological system such as portrayed by insects and animals are a perfect control system solving the problems of body stability, navigation, locomotion and sensor fusion. The extraction of various biological control sub-system is very crucial in ensuring that the control system employed in the existing robotic system is optimised. A important factor is the issue of intelligence of the robotic system. Minimum amount of "Intelligence" is needed in the controller system to enable the system to make decision in real-time implementation. Specifically, this project describes the advantages of designing the propulsion system for an Autonomous Underwater Vehicle (AUV) based on aquatic animal locomotion than the conventional design. It compares the maneuverability performance, turning performance and energy consumption in the design, and analyses their advantages and drawbacks. Locomotion of aquatic animal such as eel, jellyfish and squid have also been studied. A biomimetic AUV's design has been developed that mimics an aquatic animal locomotion approach.

4) Sila sediakan Laporan teknikal lengkap yang menerangkan keseluruhan projek ini.
[Sila gunakan kertas berasingan]
Kindly prepare a comprehensive technical report explaining the project
Prepare report separately as attachment)

Senaraikan Kata Kunci yang boleh menggambarkan penyelidikan anda :
List a glosssary that explains or reflects your research:

Biomimetik, Sistem Robot, Kawalan Pintar, Sistem Pemacuan

Biomemetic, Robotics System, Intelligent Control, Locomotion System

5) Output Dan Faedah Projek
Output and Benefits of Project

(a) * Penerbitan *(termasuk laporan/kertas seminar)*

Muhammad Hafiz Kassim and Mohd Rizal Arshad, "The Advantageous of Aquatic Animals Locomotion in Designing the Propulsion System of an AUV", 8th Seminar on Intelligent Technology and Its Applications (SITIA 2007), *9-10 May 2007, Kampus ITS Sukolilo Surabaya, Indonesia.*(Paper accepted)

(b) Faedah-Faedah Lain Seperti Perkembangan Produk, Prospek Komersialisasi Dan Pendaftaran Paten atau impak kepada dasar dan masyakarat.
Other benefits such as product development, product commercialisation/patent registration or impact on source and society

Penyelidikan ini adalah berkaitan rekabentuk dan pembangunan sistem robot berasaskan sistem biloogi atau tabie. Sistem biologi seperti yang dapat diperhatikan di dalam alam merupakan contoh sistem terbaik yang boleh dihasilkan. Teknik pengawalan dan pemacuan yang terbaik dapat dicontohkan dalam sistem robot yang dibina untuk mengatasi masalah khusus dalam kehidupan seharian. Faedah utama projek ini adalah penghasilan satu sistem robot yang cekap dan mampu untuk mengatasi masalah-masalah rumit dalam proses pemeriksaan dan pengawasan. Di samping itu, projek ini akan dapat menaikkan nama universiti sebagai salah satu pusat kajian sistem robotik seumpamanya di rantau Asia.

(Salinan kertas-kerja ada disertakan)

(c) Latihan Gunatenaga Manusia
Training in Human Resources

i) Pelajar Siswazah :
Postgraduate students:
(perincikan nama, ijazah dan status)
(Provide names, degrees and status)

a. Mohd Sofwan Mohd Resali (MSc. – semasa)
b. Muhammad Hafiz Kassim (MSc. – semasa)

ii) Pelajar Prasiswazah *:*
....
Undergraduate students:
(Nyatakan bilangan) - 2 orang (Projek Tahun Akhir)
(Provide number)

a. Kang Chun Heng (2007)
b. Mohd Akmal b. Mohd Yusof (2007)

6. Peralatan Yang Telah Dibeli :
Equipment that has been purchased:

i. *Sensor Suite – GPS Receiver Modules (5x), MEMSIC Accelerometer (5x) and RFID Receiver (5x)*
ii. *Servo Motor (5x)*

Disediakan oleh:

Prof. Madya Dr. Mohd Rizal Arshad
Pusat Pengajian Kejuruteraan Elektrik dan Elektronik

Final Technical Report

Research background:

Recently, an Autonomous Underwater Vehicle (AUV) has been used in wide operations area including oil and gas industry for mapping the seafloor, military mission and scientific research for studying the sea. Advances in propulsion systems and power source technology give these robotic submarines extended endurance in both time and distance. In the domain of AUV, efficiency and agility are interesting features concerning power saving and high maneuverability [3]. The biomimetic term have been used lately in this domain, where researcher tries to imitate the structure and senses from the nature. The research on this topic is only at its beginning but there are several studies have already been done. From an engineering perspective, an animal can be described as a mobile vehicle with multimodal sensors tuned to its environment. The diverse morphological specializations exhibited by animals may be targeted by engineers for technology transfer and effectively reduce the time of development of innovative technological solutions [1]. Currently, propulsion system of an AUV is based on the thruster and propeller that will give the desired speed for the AUV to move. To obtain more speed, the AUV actually need a large thruster that consumes more electrical power. In that case, it will give the drawback to the efficiency of the system. The sensory system is one of the major limitations in developing the AUVs. The vehicle's sensors can be divided into three groups: (1) navigation sensors, for sensing the motion of the vehicle (Cox and Wei, 1994); (2) mission sensors, for sensing the operating environment; and (3) system sensors, for vehicle diagnostics [5].

This research has investigated common solutions from engineering and biology for increased efficiency and specialization by the biomimetic approach. The hypothesis is that by using the biological inspiration based on aquatic animal locomotion in designing the underwater vehicle can significantly increase the robustness and performance exceeds current mechanical technology of underwater vehicle design.

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(b) Objective (s) of the Research

This study embarks on the following objectives:

1) To investigate the maneuverability performance, turning performance and energy consumption in the design of aquatic animals locomotion.
2) To identify the suitable means of providing the propulsion system and hydrodynamic control for the Bio-inspired Underwater Vehicles based on aquatic animals locomotion.

(c) Methodology

Description of Methodology

The overall methodology will consist of the following stages:

a. Determination of system specification:
The overall system will be implemented based on aquatic animal's locomotion especially the squid or cuttlefish. The research will initiate by identify core benefits and strength of this system. The literature review and determination of vehicle's specification will be in this stage.

b. Development of the vehicle's platform and propulsion system for the Bio-inspired Underwater Vehicles:
The vehicle's platform especially the propulsion system will be design and modeling using Solidworks™ software. The simulation test will carry out to analysis the performance of the vehicle's platform. Development of hardware and electrical part for the vehicle's platform and the propulsion system will be perform in this stage.

(d Results

This project presents an investigative study into a bio-inspired underwater vehicle locomotion. The study has highlighted interesting approach to overcome typical difficulties of underwater movement (i.e., maneuverability, turning performance, acceleration). The potential benefits from biological innovations applied to manufactured systems operating in water are high speeds, vorticity control, reduced detection, energy economy, and enhanced maneuverability.

(Please refer to the paper presented in SITIA 07 for some experimental results)

SITIA

Proceedings

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The Advantages of Aquatic Animals Locomotion in Designing the Propulsion System of an AUV

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Abstract *- This paper describes the advantages in designing the propulsion system for an Autonomous Underwater Vehicle (AUV) based on aquatic animal locomotion than the conventional design. It compares the maneuverability performance, turning performance and energy consumption in the design and analyzes their advantages and drawbacks. Further, this paper will discuss about locomotion of aquatic animal such as eel, jellyfish and squid. Finally, a biomimetic AUV's design will be proposes as mimic from aquatic animal locomotion.*

Keywords: *Autonomous Underwater Vehicle (AUV), biomimetic, maneuverability,* biomimetic propulsion system.

1. INTRODUCTION

Recently, an Autonomous Underwater Vehicle (AUV) has been used in wide operations area including oil and gas industry for mapping the seafloor, military mission and scientific research for studying the sea. Advances in propulsion systems and power source technology give these robotic submarines extended endurance in both time and distance.

In the domain of AUV, efficiency and agility are interesting features concerning power saving and high maneuverability [3]. The biomimetic term have been used lately in this domain, where researcher tries to imitate the structure and senses from the nature. The research on this topic is only at its beginning but there are several studies have already been done.

The goal of biomimetics in the field of robotics is to use biological inspiration to engineer machines that emulate the performance of animals, particularly in instances where the animal's performance exceeds current mechanical technology. Copying animals by the biomimetic approach attempts to seek common solutions from engineering and biology for increased efficiency and specialization [1].

From an engineering perspective, an animal can be described as a mobile vehicle with multimodal sensors tuned to its environment. The diverse morphological specializations exhibited by animals may be targeted by engineers for technology transfer and effectively reduce the time of development of innovative technological solutions [1].

Currently, propulsion system of an AUV is based on the thruster and propeller that give the desired speed for the AUV to move. To obtain more speed, the AUV actually need a large thruster that consumes more electrical power. In that case, it will give the drawback to the efficiency of the system.

Compare with the aquatic locomotion, some of the aquatic animals can survive and save a lot of energy moving under the water. Using their fins and streamlined bodies, fish can move fast through the water with the least possible resistance.

Base on this basic idea, researcher start to rebuild more efficient design, which combines the beneficial part from the machine technology with the animals. Both machines and animals must contend with the same physical laws that regulate their design and behavior. These behaviors (i.e., maneuverability, acceleration) can be superior to the performance of machines [1].

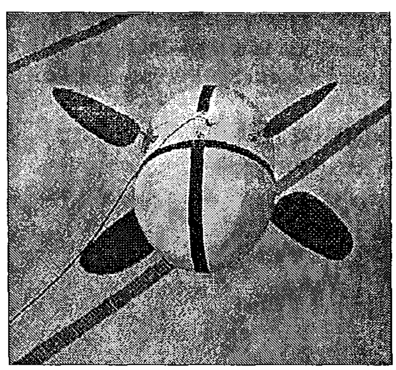


Figure 1: The Pilotfish, one of biomimetic AUV.

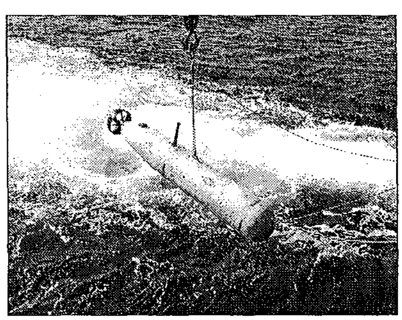


Figure 2: Conventional AUV design.

2. DESIGN APPROACH

In aquatic systems, the emphasis on the biomimetic approach has been directed toward the use of locomotor specializations in animals associated with a reduction in energy input while swimming [1]. To understand how those aquatic animal moves efficiently inside the water, we need to look in biological perspective. It will consider the body shape including fins, the propulsion system, and maneuverability. In this paper, we choose three aquatic animals that basically have different body shape and maneuverability.

2.1 Aquatic animal locomotion

2.1.1 The eel

Eels with their elongate bodies and rectilinearly increasing body wave, represent an extreme case of undulatory swimming and generate thrust along their whole body rather than at the tail. Undulatory swimmers generate thrust by passing a transverse wave down their body. Thrust is generated not just at the tail, but also to a varying degree by the body, depending on the fish's morphology and swimming movements [8].

Two consecutively shed ipsilateral body and tail vortices combine to form a vortex pair that moves away from the mean path of motion. This wake shape resembles flow patterns for a propulsive mode in which neither swimming efficiency nor thrust is maximized but sideways forces are high. This swimming mode is suited to high maneuverability [8].

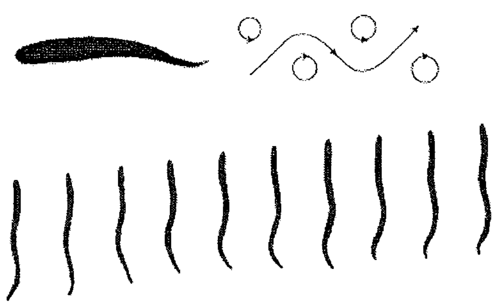


Figure 3: The sketch of eel during forward swimming.

2.1.2 The jellyfish

Jellyfish are related to sea anemones and coral. The body of an adult jellyfish is composed of a bell-shaped, jellylike substance enclosing its internal structure, from which the creature's tentacles are suspended [13]. Basically, jellyfish float and move with ocean currents. But most jellyfish can also swim. They squeeze their bodies in order to push jets of water from the bottom of their bodies to propel the jellyfish forward.

Other jellyfish; the comb jelly, has another way of swimming. It has small hair-like "cilia" that it uses to row through the water. That type of swimming may be examples of convergence of traits that are essential to highly efficient, directed locomotion. Meanwhile, those long tentacles of a jellyfish aren't involved in swimming. That's where the stinging cells and the jelly can pull up its tentacles to feed on captured prey [11].

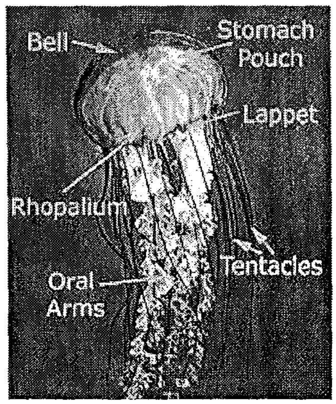


Figure 4: The jellyfish with a bell-shaped body.

2.1.3 The squid

Squid swim using a jet propulsion system and undulating fins. The basic structures and mechanism of jet propulsion in these marine invertebrates are shown in figure 5 and figure 6. Water in the mantle cavity of the squid is pressurized by the powerful contraction of muscles running circumferentially in the mantle wall. That water is then expelled as a jet near the head of the animal. The muscles that power this jet are called the circular muscles. The squid is propelled mantle-first, arms trailing through the water. Nevertheless, squid are able to propel themselves in various directions by muscularly directing their jet. Extrapolating the trend in slip suggests that the elongated jet of squid approaches a state in which jet velocity is equal to background flow, that is, approaches zero wasted kinetic energy from the jet in the wake and 100% propulsive efficiency [10].

Hypothetically, with help from the fins, or an extremely low drag coefficient, the squid could come very close to this state. At much lower speeds, squid hold position less readily. These observations suggest that the preferred swimming speed of squid *L. pealei* coincides with the speed at which both propulsive efficiency and locomotive flexibility are high, and the average number of contractions of the mantle over a given period of time is lowest [9][10].

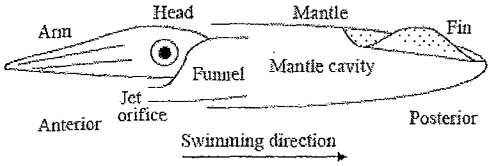


Figure 5: The sketch of squid body structure.

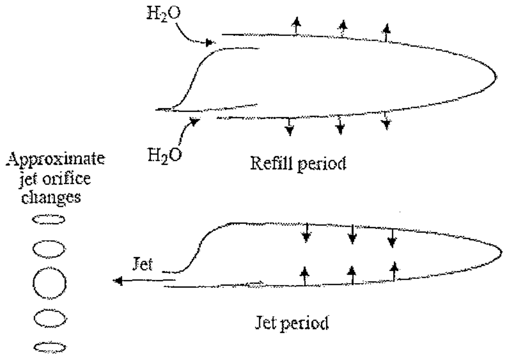


Figure 6: The jet propulsion system of squid.

It is assumed that the eel have high maneuverability using its body movements to "push" against the water and move forward. The jellyfish and squid used the same propulsion method, but the squid are faster with highly efficient jet propulsion system that can propel themselves in various directions. The hydrodynamic form of the aquatic animal can be modified to adapt in current AUV technology especially in AUV stability and maneuverability at various operating speeds.

3. RESULTS AND DISCUSSIONS

3.1 Result

Based on the study above, we are proposing a biomimetic propulsion system design using four fins as a propeller. The 3D model of biomimetic propulsion system design is shown in figure 7 and figure 8. It is based on fish locomotion using pectoral fins. This idea also came from the bell-shaped body of jellyfish and squid's mantle.

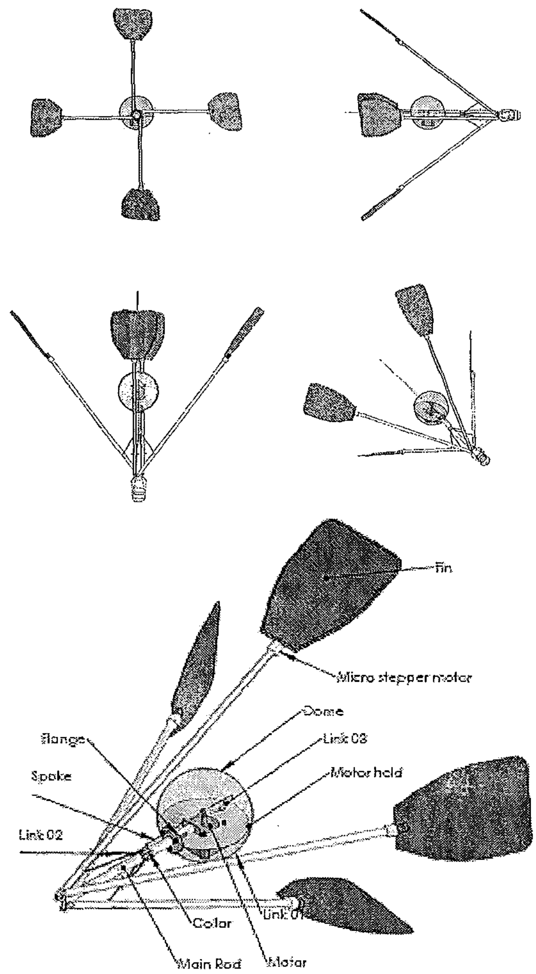


Figure 7: The entire structure of biomimetic propulsion system.

The entire mechanism is actually copied from the bell-shaped body with some modification. Without the cover or mantle on its body, we are only used four steel rods to link with four fins that act as a propeller. The DC motor inside the dome will act as a muscle to create a mechanism for the propeller.

Figure 8: The 3D model of biomimetic propulsion system

The propulsion system will work as an umbrella. It will open and close continuously to create a pressure against the water and move it forward. Without the mantle covering its body, we hope it can remove some the pressure drag and friction drag while operating inside the water.

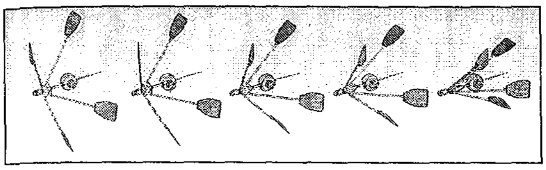


Figure 9: The mechanism of biomimetic propulsion system.

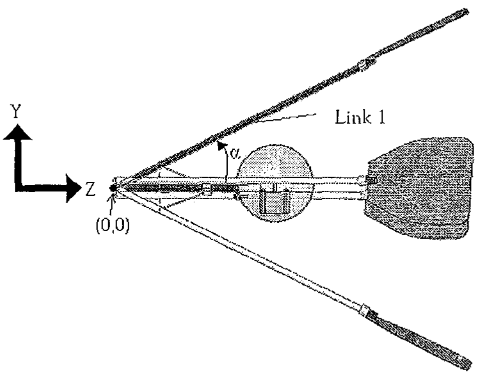
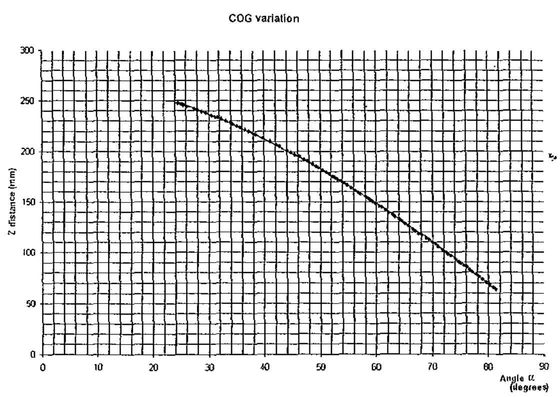


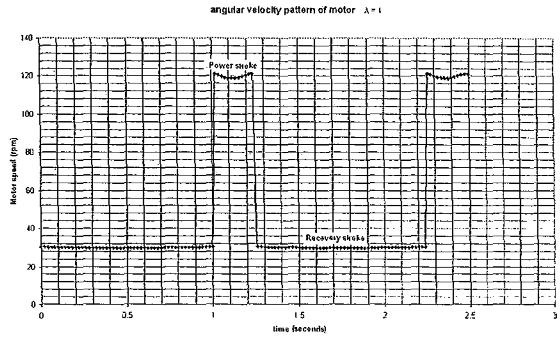
Figure 10: The swimming mechanism study.

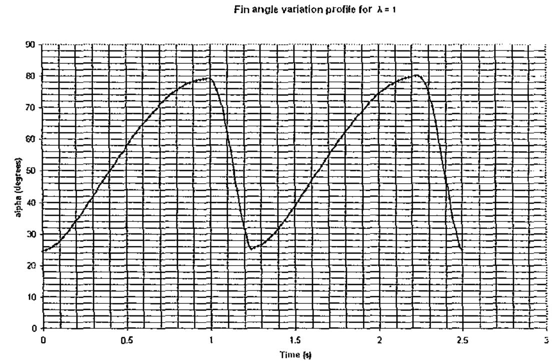
To analyze the swimming mechanism, we take the origin at the hinge where the 4 rods are joined. Alpha represents the angle between the Link 1 and the main rode. While swimming, all Link 1 will open and suddenly close. The alpha will increase and decrease continuously to push the water and create a pressure against the water. We assume that the angle of the Link1; alpha cannot go over 80 degree.

The center of gravity (COG) for this system varies while alpha increase and decrease. When the alpha increase, the COG will go near the origin and while alpha decrease, the COG will go far from origin. The Graph 1 shows the relationship between the COG's distance and the alpha.



Graph 1: Relationship between the COG's distance and the alpha





Graph 2: The plot of recovery stroke and power stroke consists of the motor speed and alpha with time

The Graph 2 indicates the recovery stroke and power stroke with time. Power stroke is when the alpha decreased rapidly from the maximum at the higher motor speed, so that the system will moves forward from the thrust on the fins. Recovery stroke is when alpha increases from the minimum value to the maximum value. The motor speed must be slower because other wise the system may go backwards. Both graphs are plotted with respect to the motor speed in rpm we put in the COSMOS® motion simulation.

3.2 Discussions

Engineered systems are relatively large in size, are composed of rigid materials, use rotation motors, and are controlled by computational systems that have limited sensory feedback; whereas, animals are generally small in size, are composed of compliant materials, use translational movements produced by muscles, and are controlled by complex neural networks with multiple sensory inputs [1].

These comparison shows that animal are ideal example for human to learn how to create the technology in biomimetic domain. Copying from them will give us a better solution for many problems especially under the water. Their ability to swim fast and accurate under the water can, maneuverability and efficient sensor system be applied to the engineered system. The biomimetic propulsion system proposed here needs more modification in order to make it more similar to aquatic animal system. The fins for example, must be in proper position and orientation, to make it useful for low-speed swimming and maneuverability and allow for station-holding. From [1], the design specifications and capabilities suggested for the conceptual design for construction of a biomimetic AUV included:

1. An AUV vehicle that can be handled by one or two men.
2. Maneuverability: Low-speed control authority better than that of REMUS; Back out; Translate Sideways, Up and Down, Hover; and very short radius turn.
3. Weight: Lighter
4. Volume: Increase
5. Vibration: Lower
6. Drive: Two options - conventional and unconventional; In Unconventional, replace conventional drives (motors, gears and shafts) by Artificial Muscle.
7. PROPULSOR: Use 4 - 6 or as many prop foils/blades as needed. Each prop foil independently operable to vector thrust to vehicle axis for maneuverability. Foils may be biorobotic penguin wings. If so, make use of MIT Tow Tank data for design.
8. PECTORAL FINS: Use minimal number of independently operable pectoral fins for maneuverability. May use NRL CFD data on Wrasse or such pectoral fins, for design.
9. VEHICLE DATABASE: May consult the following database for vehicles with Pect Fins: Nekton Pilot Fish: US-Japan NICOP Bass Vehicle. CETUS II, which is a non-biorobotic 2 Prop AUV may be consulted, because that vehicle attempts to achieve biorobotic capabilities via 2 props that provide thrust in axes non-parallel to vehicle axis.

4. CONCLUSIONS

The biomimetic propulsion system proposed is the result of understanding the benefit of aquatic locomotion. The system has been design to mimic the aquatic animal propulsion system with some modification. The potential benefits from biological innovations applied to manufactured systems operating in water are high speeds, vorticity control, reduced detection, energy economy, and enhanced maneuverability [1]. With this system, we hope it can be implementing in the complete biomimetic AUV and create the energy economy, greater locomotor performance, efficient system and high maneuverability AUV.

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