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Sensitive Avian Robotics for Aerospace Applications

A Major Qualifying Project Report

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Abstract

The goal of this project is to develop and test a new sensor, for robotic aircraft, that has the ability to sense airflow conditions, similar to that of a bird. This project focuses on the concept of having numerous sensors to detect the environment instead of a single sensor such as a pitot tube, which is often used on standard aircraft. By using their feathers, birds have the ability to sense the airflow over their entire wing. This is why they are capable of more stable, yet complex flight patterns. The feathers are mounted on a AH 93-W-300 airfoil, while strain gauges are used to measure the vibration of the feathers. The feathers are designed so that they can vibrate at a frequency near the vortex shedding frequency that is caused by the wake flow of the airfoil. This biologically inspired sensor is designed, constructed, and tested to be utilized on a robotic aircraft platform.

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Chapter 1: Introduction

The unpredictable nature of wind affects aircraft flight. Wind gusts cause turbulence which affect the flight of the aircraft. When flying on a commercial airplane, turbulence often causes passengers to feel uncomfortable. Turbulence often causes the aircraft to vibrate, which is necessary for the aircraft to survive the turbulence. UAVs, Unmanned Aerial Vehicles, sometimes have a difficult time combating turbulence. It is important for aircraft to be able to adjust to the unpredictability of the wind.

Many years before the first airplane, birds mastered the ability to fly. Unlike human made aircrafts, birds have the ability to better adapt to the wind. Birds have the ability to spread their feathers during flight to adjust to the airflow. This allows for birds to have a easier flight time. Birds spread their feathers during flight in response of how they interpret the airflow over their wing.

By mimicking a bird’s ability to sense airflow over its wing, flight can be made easier. This group studied ways to design a sensor similar to the feathers on a bird to help improve flight. Adding sensors to sense the airflow over a wing allows an aircraft to autonomously combat against gusts of wind. The group studied developing a sensor to achieve this feature.

Chapter 2: Literature Review

2.1 Avian Study

By reviewing previous studies on how birds use their feathers to sense the airflow over their wings, the group was able to design feather sensors for an aircraft. Many studies have found that birds uses a sensory receptor that responds to pressure or distortion. This receptor is called a mechanoreceptor.

2.1.1 What Are Mechanoreceptors?

Mechanoreceptors are simply an organ or cell that can sense and respond to pressures or sensations such as touch or sound. The skin of the human body has many mechanoreceptors that aid in allowing for a human to have a sense of touch. Mechanoreceptors work in many different ways. Mechanoreceptors are used in humans to sense forces against hairs just like they are used in birds to sense the movement of feathers (Human). This is done by the use of sensory terminals at the root of the hair. **Figure # 1** shows the mechanoreceptors in skin.

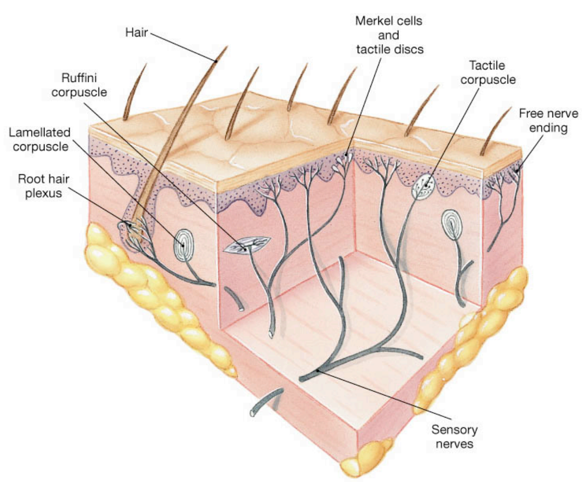


Figure # 1: Mechanoreceptors in the skin (Malachowski).

Every time the hair is displaced, by a force, there is a potential that is sent to a nerve ending. A nerve impulse is sent when the potential at the nerve ending is great enough to send it (Human). Mechanoreceptors can be stimulated very rapidly. This means that the movement of the hair can be changed rapidly and still be sensed by mechanoreceptors.

2.1.2 Mechanoreceptors and Feathers

Mechanoreceptors on humans are very similar to the mechanoreceptors on birds. On bird wings, mechanoreceptors are used at the root of the feathers, just like the hair on humans. These mechanoreceptors allow a bird to sense how their feathers are moved by the airflow over their wing.

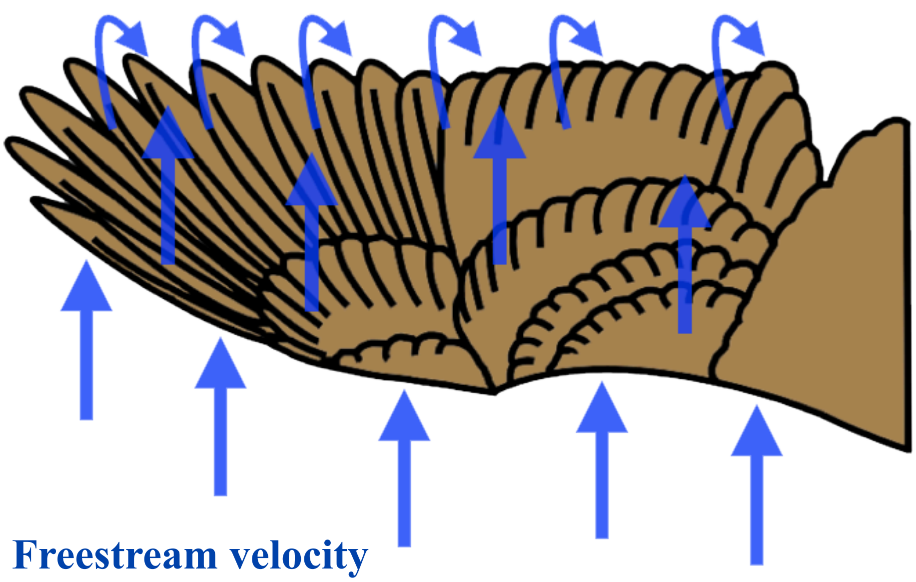


Figure # 2: Sample of airflow over a bird's wing.

Mechanoreceptors are primary neurons that give signals when stimulated when a cell rapidly raises or falls. These mechanoreceptors are thus triggered when a feather moves and applies pressure on it. By having mechanoreceptors attached to their feathers, birds are able to sense the frequency in which the feathers are oscillating (Brown). Stall can be sensed, by measuring the frequency of the feather vibrating. Stall occurs when there is a reduction in lift because of an increase in the angle of attack. **Figure # 3** shows the airflow during the stall condition.

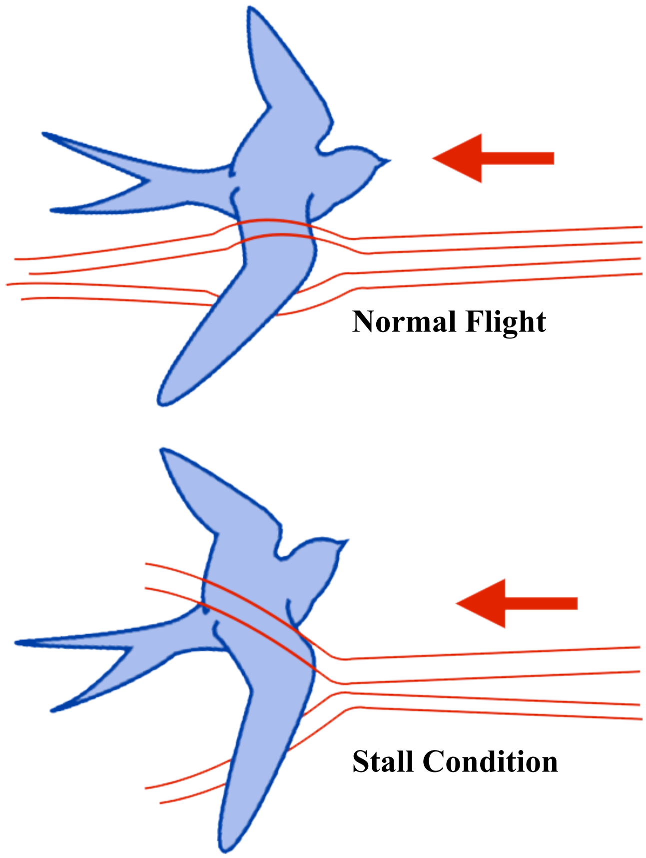


Figure # 3: Airflow over a wing during normal flight and stall condition.

With the stall condition, like the example shown in **Figure # 3**, it was found that birds had the ability to sense the stall condition. The stall condition causes feathers in birds to vibrate wildly which tells the bird about the sudden loss in lift (Brown). This ability to sense the stall condition would be very valuable for modern day aircraft. This allows for birds to control their flight during the stall condition. This can be seen when birds land. When birds start to land, they increase their angle of attack and enter the stall condition. This allows for a loss in lift and allows them to land in a shorter distance. By sensing the stall condition, birds have the ability to fly more complex flight patterns.

2.2 Sensitive Robotics

There have been numerous methods used on robots to help them detect the environment they are in. These methods vary from sensors used to detect light, heat, and forces. When creating the design for a feather sensor, many tactile sensors were considered from piezoelectric sensors, strain gauges, and force sensing resistors.The original concept and prototype for sensing forces off a feather were based off of the sensors developed by Eduardo Torres-Jara. Eduardo Torres-Jara's sensors were constructed to be able to sense forces in an unknown environment while maintaining minimal effects on the environment around it.

2.2.1 Sensitive Robotics at WPI

The sensors developed by Professor Torres-Jara consist of a molded hollow silicone dome. The dome rests over a small circuit. There are two main variations of the circuit currently used. The first variation relied on magnets and was used on a robot named Obrero, shown in **Figure # 4**, while the second variation was used on Go-Bot, **Figure # 5**, which relied on light.

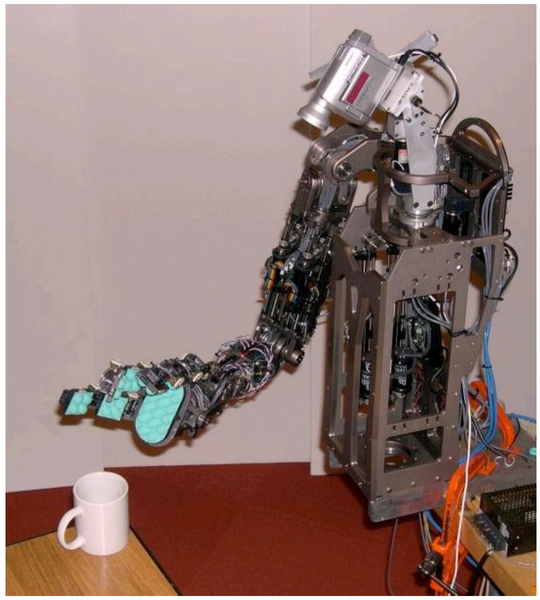


Figure # 4: Obrero shown about to grab a cup using tactile sensors.

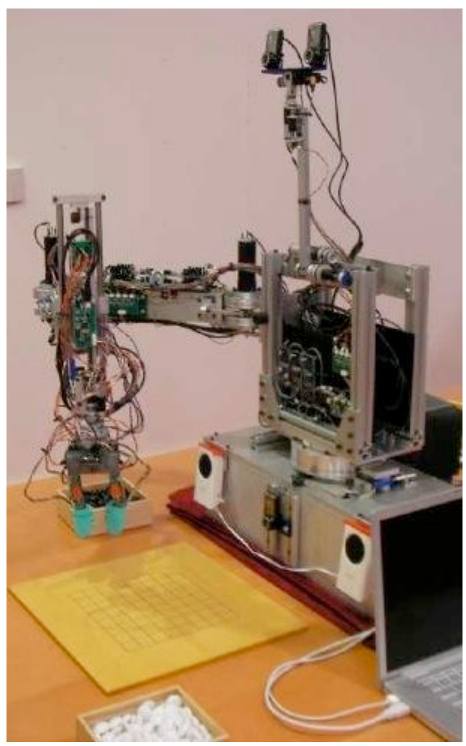
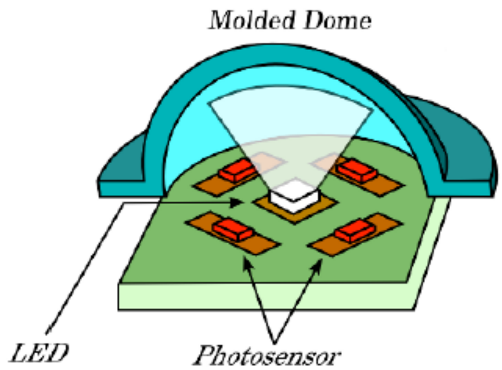
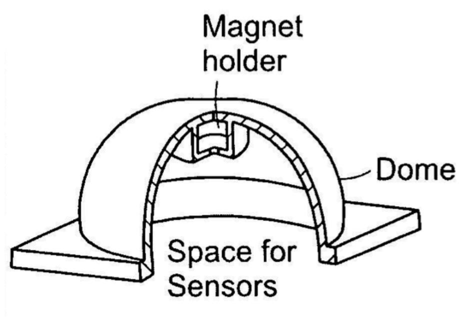


Figure # 5: GoBot prepared to grab smooth stones for the game Go

Both variations of the circuit consist of four sensors spread around in a square. The light based sensor uses photo resistors while the magnetic based sensor uses hall effect sensors. For the light based circuit, a small light emitting diode is placed in the center of the circuit as shown in **Figure # 6**. The magnetic sensor differed slightly here by placing a small magnet at the top of the silicone dome itself as shown in **Figure # 6**.



Sensor Variation using Light



Sensor Variation using Magnets

Figure # 6: Molded hollow silicone dome sensor design.

Chapter 3: Methodology

Redacted on the request of Professor Eduardo Torres-Jara. For the full report, contact him at etorresj@cs.wpi.edu

Chapter 4: Results and Analysis

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Chapter 5: Future Development

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Chapter 6: Conclusions

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Appendix

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