GIZMO mechanical duck report

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# Introduction

This mechanical duck is an attempt at biomimicry, something that man has been doing for a long time. Prominent examples include the Wright Brothers getting inspiration for the aeroplane from birds and the Japanese bullet train front nose cone taking inspiration from the kingfisher beak. In this case, ducks have fascinated the author, very much so after coming to London and seeing the ducks in the various ponds in London. In this project, a prototype mechanical duck has been built and tested in the pond, in water. The objective was to create a duck that would seamless blend in with other ducks in the pond and swim with them. This had to be done by as realistically mimicking duck locomotion as well.

There are many simpler method of mimicking a duck. One could be to fit the motors and propeller from a remote control boat into a duck decoy. However, it would not have come close to the locomotion method of real ducks in the pond.

# Early prototypes

# Bill of Materials

# Human interaction

Control of the duck comes from the human operator, who changes the position of the stick on the remote-control transmitter. The duck uses 2 channels to transmit information. One channel transmits the speed and one channel transmits the direction of movement of the duck. Therefore, the operator can control the velocity of the duck by controlling its direction and magnitude. This allows the operator to send the duck anywhere he wants on water, including behind other real ducks on the pond.

# Electrical subsystem

The electrical system is the most important system, taking signals from the remote-control transmitter, decoding them and accordingly moving the legs of the ducks.

## Power supply

The mechanical duck is powered by a 3-cell lithium polymer battery, generating a voltage of 11.1V. The voltage is too high for most of the components so it is brought down to 6V with a DC-to-DC buck converter, theLM...The power then is distributed in parallel to the 4 servos and the Arduino microcontroller. The microcontroller is decoupled from the power supply with 2 large capacitors.

During testing, it was observed that the Arduino microcontroller seemed to brown-out a few seconds after the feet started moving. On further inspection with an oscilloscope, it was seen that when all 4 servos switched directions at the same time, the voltage across the microcontroller terminals dropped dangerously low to approximately 4 volts. According to the datasheet for the Arduino microcontroller, it expects an input voltage of 6-12 volts.

Onboard the Arduino Nano is a voltage regulator that supplies a stable 5V to the microcontroller, the ATmega328P. The voltage regulator, the A78M Positive-Voltage Regulators made by Texas Instruments has a drop out voltage of 2 volts. Therefore, the input voltage should be at least 2 volts above the target voltage, which will be regulated down to the target 5V. Any lower and the voltage regulator would not be able to maintain the target 5V to the microcontroller. When the input voltage fell to 4 V due to electrical noise, the voltage regulator could not maintain the 5V and its output seems to have dropped below the minimum voltage of the microcontroller.

However, the microcontroller, the ATmega328P can tolerate voltages as low as 1.8 V or 2.7V depending on the precise variant. The variant on the Arduino Nano was not determined. However, it appears that during the low voltage troughs due to electrical noise, the output of the voltage regulator to the microcontroller fell below the low voltage threshold of the MCU. This caused a brown out and reset.

The solution was to place a large capacitor across the power input pins of the microcontroller to supply current to the microcontroller during a voltage drop to maintain a high enough voltage across the power line and ground. The capacitance value was chosen to be 400uF. The decoupling capacitor acts a local energy store that instantly supplies current to the microcontroller during a voltage drop, thus maintain a relatively stable input voltage. This solution worked and no further browning out of microcontroller was seen during normal operation.

A better solution would have been to directly power the Arduino Nano from the battery and power the servos and other electronics through the buck converter. It is likely that boost converter reacts too slowly to the power needs of the motors when all servos draw a large amount of current at the same time momentarily. The buck converter therefore does not supply enough current quick enough. Therefore, the voltage drops off, causing the microcontroller to brown out. Instead, the microcontroller can be directly connected to the battery, since the battery voltage is within the acceptable region of the Arduino Nano. The Arduino will then bypass the boost converter, drawing current directly from the battery. The battery would respond much quicker to supply the required current to the Arduino Nano.

## Power consumption

## Communication protocol between components

The radio receiver and servos uses the same protocol. The protocol for data transmission is a Pulse Width Modulated (PWM) signal with a duty cycle that indicates a value. The receiver outputs a PWM signal with a duty cycle proportional to the angle at which the operator rotates the remote-control stick. The servo sets the angular position of its arm according to the duty cycle of the PWM signal input.

In the mechanical duck, the radio receiver is ***NOT*** coupled directly with the servos. Instead, the signal from the radio receiver passes through the Arduino Microcontroller, gets processed and then instructions are sent to the servos from the microcontroller that control each servo arm’s position.

The Arduino microcontroller reads the PWM signal from the radio receiver, processes it, and accordingly sets the position of the arm of all the 4 servos that control both legs with another internally generated PWM signal.

## Electrical water proofing

The electrical subsystem was designed to be robust to shock and water ingress. Electronics and water don't mix well. However, in unfortunate and unexpected case that the duck sinks and electronics gets wet, it should be forgiving enough to survive.

All the electronics, from the micro controller board, radio receiver and servo circuitry were covered in one of two types of waterproofing compounds: Acrylic Conformal coating manufactured by MG chemicals and CorrosionX manufactured by Corrosion Technologies. Each works in a different way.

Corrosion X is a green, oily liquid that clings and is drawn into all the nooks and crannies of the electronics components via capillary action. This envelops all the components. This substance completely prevents water from passing through, completely water-proofing the components. The substance does not solidify. It stays in its liquid form for a long period of time, in the order of years.

The disadvantage is this substance can be wiped off on contact since it is a liquid. Ideal use is for moving parts. The substance could In this project, Corrosion X was used to waterproof the internal electronics of the SG90 servos. The casing was opened, PCB extracted and dipped in Corrosion X. It was reassembled, trapping the CorrosionX inside the casing. For static electronics components such as the Micro controller breakout board (Arduino Nano), The whole board was coated with Acrylic Conformal coating. The substance came in a spray can and was sprayed on to the boards.

## Water proofing performance

The bottom line is, the electronics worked flawlessly after completely drenching the electronics in fresh-water during testing. All electronics continued to work 2 days after immersion (during the actual live demonstration for examiner) and 2 weeks later during a static demonstration. Looking more closely at the PCBs, it was noted that there was indeed some corrosion at a component. This is possibly due to improper application of the coating. In the long run, it is likely that the water ingress would cause failure of the electrical system if it was improperly waterproofed. However, water proofing is only a last resort barrier and should not be put to use in normal operation of the duck. More external sealing of the electrical system would be necessary.

# Mechanical Subsystem

The feet have 2 degrees of freedom, each foot controlled by 2 separate servos. This allowed for plenty of optimisation of the gait of the duck by fine tuning the velocity of each servo. In theory, since the duck feet follow the same path with each stroke, it is possible to drive each foot with a single motor using gearing or other transmission means. However, during the design of the duck, it was very beneficial to tinker with the gait of the duck through software and *two* independently controllable servos than to completely redesign the mechanical structure each time the gait had to be changed while running on a single motor.

## Propulsion

The duck is propelled with a unique flapping mechanism inspired by real duck feet. The flaps open to its limit on the down stroke, accelerating water backwards, thus providing forward thrust to the duck. On the up stroke, the flaps close up due to drag force applied by the rushing water, minimising resistance. As a result, there is a net force in one direction in each cycle of the feet movement.

The hinge is made from PVC insulation tape. It has a very low stiffness at that thickness, allowing it to flex and behave like a hinge. The flaps are made from 3mm thick acrylic, like the rest of the duck frame, that each have a surface area of 596mm2‑.

## Feet design

Each leg of the duck is a four-bar linkage with 2 independently controlled motors. This allowed for iterative adjustment of the motion of the foot. All the arms are constrained by a revolute joint, allowing a single axis of rotation function. Arms are allowed to rotate around a M3 bolt and lock nut. This type of joint and material proved sufficient in this application. The joint had a good balance of low friction as well as a small form factor, seamlessly fitting in to the 4 bar linkage structure while avoid major protrusions. Large protrusions can cause a reduction in propulsion efficiency as they induce drag in the water in both the up and down stroke.

## Velocity control

The direction and speed of the duck movement is controlled by controlling the rotational frequency of the left and right feet of the duck. The rotation is simple:

* For turning left, the left leg is not moved while the right kicks.
* For turning right, the right leg is not moved while the left kicks.
* For forward motion: both feet kick.

The rotational velocity of each feet in controlled to control the rate of rotation.

Real duck, as observed in numerous underwater video clips of duck feet, have kicking frequency of \_\_. Therefore, the Mechanical duck was also designed to kick at that rotational velocity. The servos selected could rotate at \_\_, well above the rate of ducks. This additional speed allowed for inefficiencies in the propulsion system, allowing it to at least reach the swim velocity of ducks in open water.

Both feet are locked at a constant phase difference, at 90 degrees. This is important for straight, forward motion. The left and right feet provide alternating thrust one after the other so that the duck sticks to a straight line. Since the motion of the duck feet is periodic, with each kick the duck veers in one direction and turns the other way with the kick from the opposite foot. This means that the duck proceeds forward in a zig-zag motion. However, the deflections to the left and right during each kick cycle was small: only around 2-3 degrees.

Note that the duck cannot propel itself backwards. The only way to reverse course is to completely change the heading by 180 degrees and move forward.

## Top speed

## Motors

The motors used were coupled with potentiometers to allow precise positional control of the feet of the duck. The motors + potentiometers came in the SG90 servo package that could rotate at 60 degrees/0.1s. The servo had an angular range of 0-180 degrees according to the data sheet. However, in practice, it was observed that the range was from 0-150 degrees at most.

## Overheating issues

Running the servos at full throttle, at the maximum rotation velocity specified by the servo data sheet, was risky at best. At full speed, the gears tended to overheat and wear out very quickly, in a matter of a 3-4min of continuous running. The damage rendered the servos completely non-functional after such a short time. It is likely that the nylon gears melted and fused together. This is likely because the servo could not be turned by rotating the shaft without using a large amount of force.

In order to keep maintain the gears, the top speed was limited to 70% of full maximum speed. On a side note, during a testing in the pond, it was noted that the water cooling by immersion (i.e accidental sinking) of the duck did wonders to keep the servo gears cool.

# Mass of duck

A typical Mallard duck weighs between 0.72 – 1.6 kg (Adult). The mechanical duck weighed in at ….. The mass was a very important parameter that determined if the duck would sink or swim.

# Software

The duck is a simple state machine. It is either turning left, turning right or moving forward. Each state has a velocity associated with it. For example, the moving forward state can have a velocity of 0 where it is not moving.

The program reads the value of the 2 channels from the radio receiver every 20ms and changes it state according to the information received.

# Aesthetics

A machine that paddles like a duck but does not look like a duck would not be accepted as a fellow duck. Therefore, an enclosure that has the appearance of a duck was used to hide away all the electronics and mechanical system. The enclosure is sold as a duck decoy: a figurine of a duck used by duck hunters to invite other ducks to the pond so that they can be shot. These figurines are float on the surface of the pond with a long string attached to shore so that they do not float off.

These duck decoys were very suitable for this project because they naturally float and have a ballast built in, providing stability from capsizing. The ballast is a bar at the bottom of the duck, filled with sand.

The decoy comes fully pond-worthy, completely sealed and water proofed and painted. The material is likely to be High Density Poly Ethylene(HDPE), around 2mm thick and injection moulded. The material could be easily cut with a Stanley knife, allowing the back to be opened, slots cut for the legs and electronics fit in.

# Testing and reliability

The duck needed to be able to work on cue during the live demonstration. It worked flawlessly . It did so 2 weeks later as well after being kept in storage with adjustment on only one screw. The duck was immersed in fresh water 2 days before the live demonstration, specifically in the Round Pond in Kensington Gardens. This was a live test of all the components to see its performance in its natural habitat, the pond. The Mechanical duck had a swim with its fellow ducks in the pond and got away unscathed.

During the testing process, the duck got fully immersed in water (i.e. sunk) in fresh water. All systems continued to perform as expected.

# Future Improvements

# Acknowledgements

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# References