SEARCH

robotica 2009

Proceedings of the
9th Conference on Autonomous Robot Systems and Competitions

Castelo Branco, Portugal
7th May, 2009

Organized by
Polytechnic Institute of Castelo Branco
Superior School of Technology

Technical Co-Sponsorship
IEEE Robotics and Automation Society

Sponsored by
IEEE Robotics and Automation Society
IEEE Portugal Section
FCT – Portuguese Science Foundation
IEEE Education Society – Student Activities Committee
Portuguese Journal Robótica

Hosted by
Polytechnic Institute of Castelo Branco – Superior School of Technology

Edited by Paulo J.S. Gonçalves, Paulo J.D. Torres, Carlos M.O. Alves. Printed in Portugal

ISBN: 978-972-99143-7-9

http://www.est.ipcb.pt/robotica2009/ec

The Dynamic Modeling of a Bird Robot

Micael S. Couceiro, Carlos M. Figueiredo, N. M. Fonseca Ferreira, J. A. Tenreiro Machado

***Abstract*— This paper presents the development of computational simulation and a robotic prototype based on the dynamic modeling of a robotic bird. The study analyze the bird flight with different strategies and algorithms of control. The results are positive for the construction of flying robots and a new generation of airplanes developed to the similarity of flying animals.**

A bird robot prototype was implemented based on materials used to construct model planes. It consists on a body, wings and tail with servo actuators independently controlled though a microcontroller; a radio transmission system and batteries were also used in order to avoid wired connections between the computer and the robot.

I. INTRODUCTION

If ground robots are now endowed with advanced autonomous abilities, allowing them to avoid obstacles, to build internal maps of their environment, to choose the best action to undertake at any time, their flying equivalents are far from exhibiting such abilities, and a direct application of techniques developed for ground robots is difficult. Therefore, design and control of bird-like robots have been attracting much attention of many researchers, and various models of bird-like robots have been proposed.

Everything about a bird is made for flight and for this reason, the kinematic and dynamic modeling of bird-like robots is more complex than that of serial robots. Therefore, in order to construct a robotic bird, we first need to implement a computer simulation considering every single physical and dynamical aspect [1]. When developing control algorithms for flying robots, a simulation tool proves to be important to reduce the development time, avoid damages and find errors in the control system. A software simulation can be easily manipulated and monitored offering data that would be hard to measure on a real robot.

This paper analyses the major developments in this area and the directions towards future work.

The paper is organized as follows. Section two, presents the state of the art. Section three develops the kinematics of the robotic bird. In the section four it is shown the simulation platform. Section five gives a overview of the electronic system. Section six presents some highlights about the implementation of the first robotic bird. Finally, section seven outlines the main conclusion and future works.

II. STATE OF THE ART

The flight of insects has been interesting subject during the last half century, but the attempts of recreating it are well more recent [2]. Regarding to the flight of birds, airplanes designers are interested in the morphing capacities of wings. This area received a great impulse in 1996, when the Defense Advanced Research Projects Agency of E.U. (*DARPA*) launched a program MAV of three years with the objective of creating an insect with less than 15 centimeters length to make military recognition.

Some works of fixed wings had been successfully demonstrated, especially the black widower, the *AeroVironment Inc.* [3]. Several MAVs had been equally demonstrated, but no group has been capable to obtain a flight with flapping wings that could effectively take off and fly. Recently, several groups have equally studied the concept of morphing wings [4]. Based in these ideas some examples of modern *ornithopters* are in development. The research group of the University of Toronto developed an airplane with flapping wings with an internal combustion engine capable to support a pilot (Fig. 1).

Fig. 1. Plane with flapping wings.

Fig. 2a shows the *Cybird* developed in 2006, that uses a transmitter to control the flight. The direction of the flight can be modified moving the tail to the left or the right and the height is controlled with the flapping speed of the wings. With a battery and an engine, *Cybird* can fly for 8 to 10 minutes and can then be recharged to be ready to another flight.

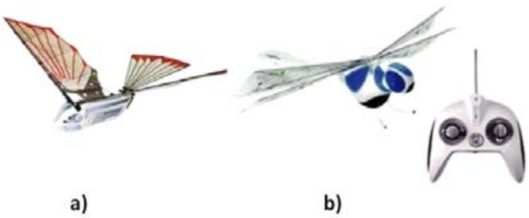


Fig. 2. a) Cybird , b) Dragonfly.

Just like a puzzle, *Cybird* is easy to assemble and disassemble, having the size of a pigeon with spreading wings of almost 76.2 cm. To land, the *Cybird* will have to reduce the flapping speed, gliding until it reachs the ground. Another similar platform called *Dragonfly* was developed in 2007, illustrated in Fig. 2b. Equally radio controlled, it resembles a dragonfly with spreading wings

---

This work was supported by GECAD

Institute of Engineering of Coimbra, Dept. of Electrotechnical Engineering, Quinta da Nora, 3030-199 Coimbra, Portugal `micaelcouceiro@gmail.com; cefigueiredo@gmail.com; nunomig@isec.pt`

Institute of Engineering of Porto, Dept. of Electrotechnical Engineering, Rua Dr Ant. Bern. de Almeida 4200-072 Porto, Portugal `jtm@isep.ipp.pt`

of 40.6 cm with a light body and strong double wings. Another kind of wing structure consists on a set of small airfoil parts throughout the wing, as a regular fixed wing. However, these small parts are connected with a light and flexible material in order to make the wing fold and twist when it beats. This approach leads equally to a similar wing movement of those of real birds (Fig. 3). This ornithopter is one of the most recent constructions of the *Elecktro Vogel* series developed by [5].

Fig. 3. Horst Rbinger EV7 ornithopter.

III. KINEMATICS

A. *The Geometry of the Robotic Bird*

In order to visualize the behavior of the bird during the simulation we developed a 3D model in *AutoCAD* inspired in a seagull as can be seen in Fig. 4. Each adjacent part (with different colors) corresponds to individual elements connected through joints. For simplicity, the structure of the wings is defined in the sense of a human arm, using the terms arm and hand accordingly. The corresponding wing joints will be denoted the shoulder and wrist.

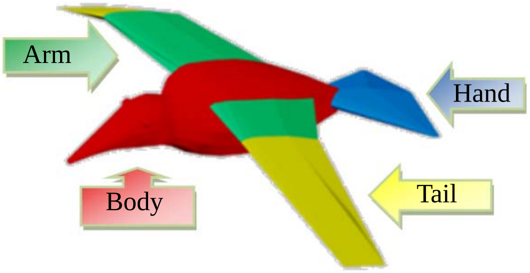


Fig. 4. 3D model of the robotic bird.

B. *The Kinematics of the Robotic Bird*

With the kinematic model we analyzed the bird flight movement and its behavior in different states such as taking off, flying with twists and turns, and others. Through this study, we obtained valuable specifications which helped choosing the initial mechanical design (Fig. 5).

The multi-link model is shown in Fig. 6. The number of joints is limited, when compared with a real bird, but this mechanical structure gives a good mobility. The joints are distributed as follows: two in the shoulder, one in the wrist and two in the tail. Differently from all the others, the wrist joint is not controlled. It consists in a mechanical spring mechanism that allows a movement of the wing similar to real birds. This structure provides a good mobility having a total of six controlled joints.

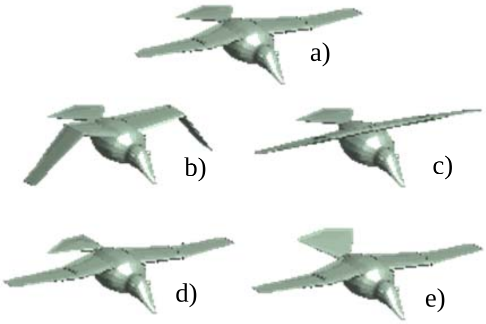


Fig. 5. a) Bird geometry, b) Wing flapping, c) Wing twisting, d) Tail twisting, e) Tail bending.

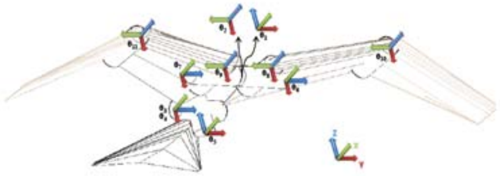


Fig. 6. Kinematic structure of the system.

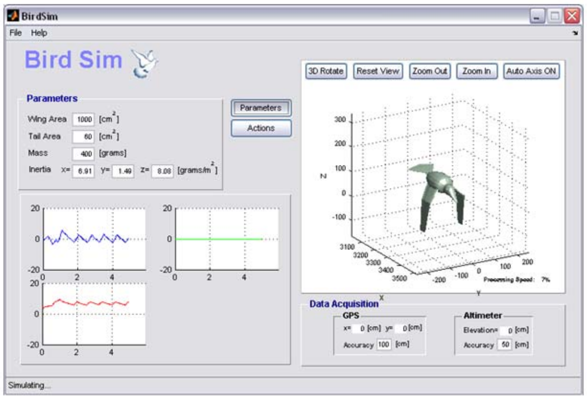
In order to implement the animation of the bird in MatLab it is adopted the Denavit-Hartenberg (D-H) notation to represent frame (joint) coordinates in the robot kinematic chain. The next equation represents the homogeneous transformation A_i, namely a matrix constituted by a product of four fundamental transformations.

$$A_i = R_{\theta i} T_{di} R_{\alpha i} T_{ai} \tag{1}$$

where $R_{\theta i}$ and T_{di} are, respectively, the matrix rotation and matrix translation in *x*-axis and $R_{\alpha i}$ and T_{ai} are, respectively, the matrix rotation and the matrix translation in *z*- axis. With a series of D-H matrix multiplications, the final result is a transformation matrix from a given frame to the initial frame.

IV. SIMULATION PLATFORM

In the last decades robotics became a common subject in courses of electrical, computer, control and mechanical engineering. Progress in scientific research and developments on industrial applications lead to the appearance of educational programs on robotics, covering a wide range of aspects such as kinematics and dynamics, control, programming, sensors, artificial intelligence, simulation and mechanical design. Nevertheless, courses on robotics require laboratories having sophisticated equipment, which pose problems of funding and maintenance. The development of simulation platforms became an important ally of science, and today it is spread in the most varied sectors. The computer programs emphasize capabilities such as the 3D graphical simulation and the programming language giving some importance to mathematical aspects of modeling and control, [6]. However, undergraduate students with no prior experience may feel difficulties in getting into the robotics experiments before overcoming the symbolic packages procedures and commands. This state of affairs motivated the development of a computer program highlighting the fundamentals of robot mechanics and control. The project leads to the *SIRB - Simulation and Implementation of a Robotic Bird* - program which was adopted as an educational tool in a flying robotics birds. This section introduces the package and discusses both basics and advanced aspects. The simulation platform was developed in *MatLab* (Matrix Laboratory) being a software for numerical computation and high performance visualizations. It allows to efficiently implement and solve mathematical problems faster than other languages such as *C*, *BASIC*, *PASCAL* or *FORTRAN*. The *SIRB* educational package (Fig. 7) was designed to take full advantage of the Windows environment. All the commands and the required parameters are entered through pull-down menus and dialog boxes. The software is intended to be self-explanatory to the extent possible to encourage students exploring the program. For the same purpose, help menus are available throughout the different windows. Several dialog boxes include figures to clarify context-dependent definitions.



Parameters

Wing Area 1000 [cm^2]

Tail Area 60 [cm^2]

Mass 400 [grams]

Inertia x= 6.91 y= 1.49 z= 8.08 [grams/m^2]

Data Acquisition

GPS: x= 0 [cm] y= 0 [cm]; Accuracy 100 [cm]

Altimeter: Elevation= 0 [cm]; Accuracy 50 [cm]

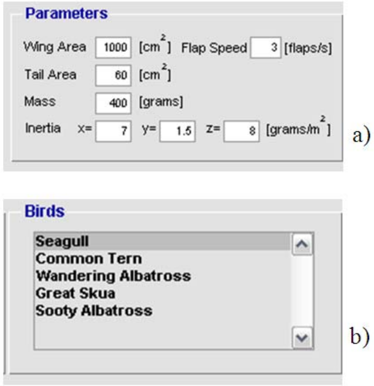
Fig. 7. *SIRB* Educational Package.

In order to demonstrate the capabilities of the package the paper shall now follow a typical classroom session. The tour begins with the definition of the type of the robotic bird and the numerical parameters, namely the wing and tail area, total mass of the bird, maximum flapping speed and the inertia of the bird (Fig. 8a). Later on, these numerical parameters can be viewed/changed and saved. As it can be seen in Fig. 8b, it will be possible to choose parameterized birds based in previous studies [7]. The primarily advantage inherent to the existence of a list birds, is to help users to setup the different parameters. Some bird parameters, like the inertia and the wing area, may be a little bit hard to choose. Therefore, selecting a bird with similar characteristics of the one desired can prove to be useful.

The parameters can easily be configured by the user. Even so, we will give some emphasis to the determination of the wing area and its inertia. To easily calculate the wing area based on the size of the wings (Fig. 9) we can use the following approximated method.

$$S = L_2\,(H_1 + H_2) + L_1\,(H_2 + H_3) \tag{2}$$

The easiest way is to approximate the body of the bird to a rectangular parallelepiped as shown in Fig. 10.



Parameters

Wing Area 1000 [cm^2] Flap Speed 3 [flaps/s]

Tail Area 60 [cm^2]

Mass 400 [grams]

Inertia x= 7 y= 1.5 z= 8 [grams/m^2]

a)

Birds

- Seagull
- Common Tern
- Wandering Albatross
- Great Skua
- Sooty Albatross

b)

Fig. 8. Setup parameters for the robotic bird.

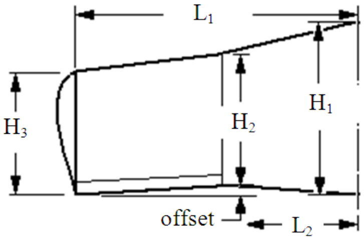


Fig. 9. Approximated method to calculate the wing area.

The inertia moment *I* in (*x*,*y*,*z*) axis, acting in the center of gravity of the rectangular parallelepiped, can then be calculated by the following equations:

$$I_x = m\frac{b^2 + c^2}{12}; I_y = m\frac{a^2 + b^2}{12}; I_z = m\frac{a^2 + c^2}{12} \tag{3}$$

After choosing the desired parameters, the user can choose the action that will be realized by the bird. After choosing the desired action some options will appear. Those options may vary depending on the action. For example, if the desired action is to go in a straight line then the bird initial velocity will be requested (Fig. 11). But, if the desired action it to go up or down, besides the initial velocity, the vertical distance to travel will also be requested (Fig. 12).

While the simulation is running the user will have the opportunity to see the charts of the velocities in *x*,*y* and *z* axis being constructed (Fig. 13) as well as the 3D animation of the bird.

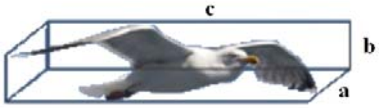
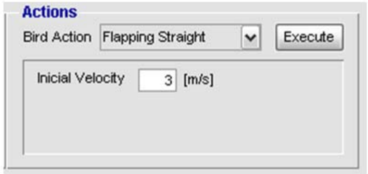


Fig. 10. Approximation of body for rotation.

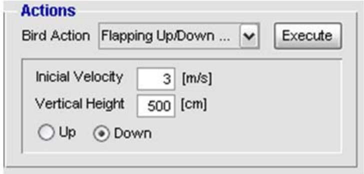


Actions

Bird Action Flapping Straight

Inicial Velocity 3 [m/s]

Fig. 11. Setup action to fly in a straight line with an initial velocity of 3 m/s.



Actions

Bird Action: Flapping Up/Down ...

Inicial Velocity: 3 [m/s]

Vertical Height: 500 [cm]

○ Up ● Down

Fig. 12. Setup action to fly down a vertical distance of 5 m with an initial velocity of 3m/s.

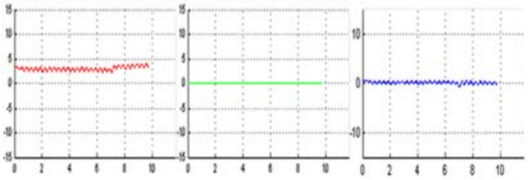


Fig. 13. Charts of the velocities in (*x*, *y*, *z*) axis.

To better watch the 3D animation the user can change the camera and can rotate and zoom while the simulation is running. Some actions, like flying up or down, will stop if the objectives are completed; others will never stop until the user wants to do so. After the action is realized the simulation can be saved to load it later in order to compare to other simulations. A grid line corresponding to the previously loaded simulation will appear in the charts of the velocities and the trajectory of the bird in the 3D animation (Fig. 14).

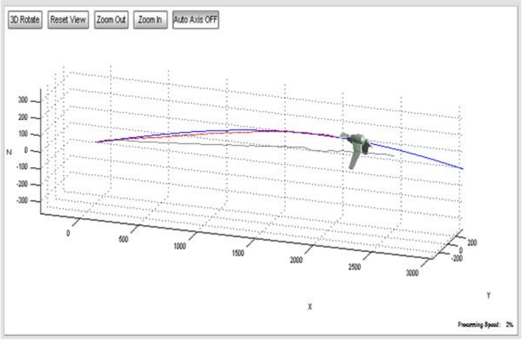


Fig. 14. Comparing trajectories made by different birds.

V. ELECTRONIC SYSTEM

Fig. 15 shows the electronic system implemented in the robotic bird. Basically the system consists on a electronic board with a *PIC18F258* microcontroller, a *LM2576-ADJ* chopper voltage regulator, an *ER400TRS* radio frequency module and the six servomotors corresponding to the six controlled joints.

A. Electric Actuators

The actuators used in the robot are servomotors. A servo is a small device that has an output shaft that can be positioned to specific angular positions by sending the servo a PWM signal. As long as the coded signal exists in the input line, the servo will maintain the angular position of the shaft. As the duty cycle changes, the angular position of the shaft varies. In practice, servos are used in radio controlled airplanes to position control surfaces like the elevators and rudders. They are also used in radio controlled cars, puppets, and of course, robots.

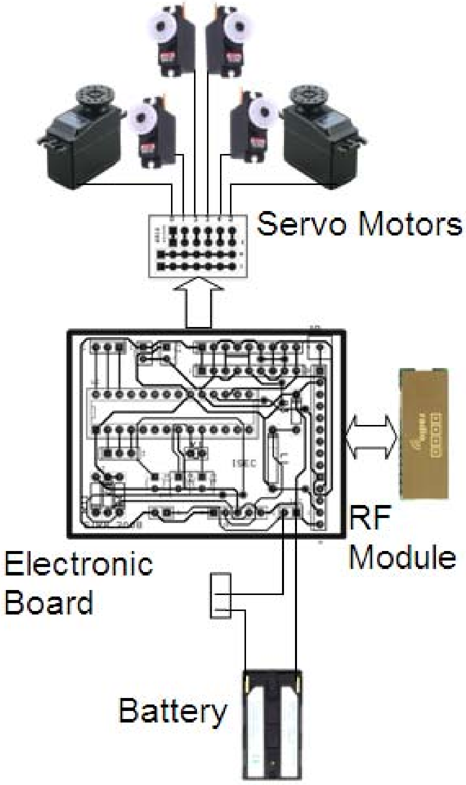


Fig. 15. Electronic System of the Robot.

Servos are extremely useful in robotics. The motors are small with built in control circuitry and are extremely powerful for thier size. A standard servo such as the *HS-81MG* from *Hitec* has 2.6 Kg/cm of torque with a speed of 0.11 sec/60 with a small weight of 19 grams and measuring just 29.8x12x1.00 mm. Those were the servos used to control the tail and the angle of attack of both wings independently (Fig. 16a).

Fig. 16. Servo a) *HS-81MG* from *Hitec* b) *S9254* from *Futaba*.

A regular standard servo couldn't be used to control the flapping wings. Even having a great relation torque-speed it would not be enough. We then used digital servos. Digital servos are controlled no differently than analog servos. The difference is in how the servo motor is controlled via the circuit board. The motor of an analog servo receives a signal from the amplifier 30 times a second. This signal allows the amplifier to update the motor position. Digital servos use a high frequency amplifier that updates the servo motor position 300 times a second. By updating the motor position more often, the digital servo can deliver full torque from the beginning of movement and increases the holding power of the servo. The quick refresh also allows the digital servo to have a tighter deadband. With the exception of a higher cost, there are only advantages for digital servos over analog servos. The digital micro processor is 10 times faster than an analog servo. This results in a much quicker response from the beginning with the servo developing all the rated torque 1 degree off of the center point. The standing torque of a digital servo is 3 times that of its analog counterpart. This means digital servos are typically smaller and have more torque. The digital servo used on the wings is the *S9254* from *Futaba*, with a speed of 0.06 sec/60, a torque of approximately 3.4 Kg/cm, a small weight of 49 grams and 41x20x36mm (Fig. 16b). This servo is very fast and commonly used in helicopters as well as other kind of applications that needs a very fast output speed.

B. *Power Supply*

To feed the whole system we need a battery with high durability, little, light and small costs. Lithium ion batteries are commonly used in consumer electronics. They are currently one of the most popular types of battery for portable electronics, with one of the best energy-to-weight ratios, no memory effect, and a slow loss of charge when not in use. In addition to uses for consumer electronics, lithium-ion batteries are growing in popularity for defense, automotive, and aerospace applications due to their high energy density. However certain kinds of mistreatment may cause Li-ion batteries to explode.

We used a Li-Ion 7.2V/1850mAh battery from Duracell commonly used in digital movie cameras. One of the primary advantages of using this battery is its weight being approximately 90 grams and its dimensions (70x38x20.5mm). Those batteries require periodically attention. They have a specific charging time with a specific battery recharger. In order to supply the regular 5V to the electronic system we used the step down switch voltage regulator *LM2576-ADJ* showing a great improvement in current consumption when comparing to the regular *LM7805* or other similar regulator.

VI. PHYSICAL STRUCTURE

A. *Robot Construction*

The construction of flying models should follow the principles of simplicity, slightness and robustness. Thus, the wooden raft, given to its low density and the enormous easiness which it can be worked out, is one of the basic materials in the construction of flying models. A main part of the bird is the wing. It is responsible for generating the forces that will raise the bird of the ground. It's in the construction of the wing, therefore, that becomes necessary to deposit a well-taken care and special attention. The wings had been made with wooden raft and carbon rods giving a good resistance and low weight. To give form to the wings, we connected the various airfoils made in raft with laths of raft and carbon tubes to strengthen the structure (Fig. 17).

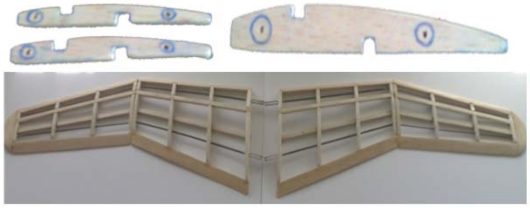


Fig. 17. Wings made with wooden raft and carbon rods.

Fig. 18. Mechanical spring mechanism in the wrist joint.

To be able to have a wing movement similar to the one of real birds we used a set of springs and hinges in order to construct a mechanical spring mechanism in the wrist joint (Fig. 18). A thermal adhesive isolator was used to cover the structure of the wings.

To connect the servomotor that will define the angle of attack of the wings, we used pine wood. Although is heavier than the raft, it was the indicated option to resist to the coupling between the engine and the wings (Fig. 19).

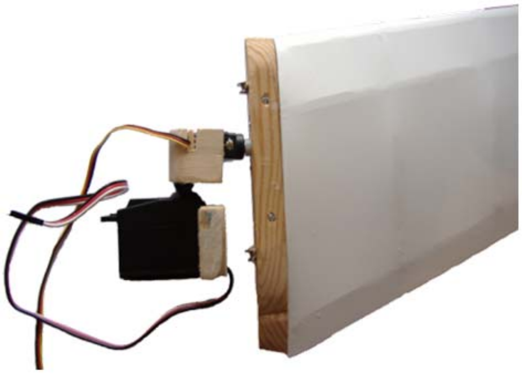


Fig. 19. Coupling between the servomotor and the wing.

Similarly to the wings, the tail was made in raft and afterward isolated with the same thermal adhesive material. The coupling between the tail and the servomotors was also similar to the one made in the wings using pine (Fig. 20).

The fuselage of the bird was made in fiberglass being a very resistant material and easy to be molded. Isolating everything with lycra and adding feathers made with a flexible plastic film to achieve a greater wing area we obtain the following result (Fig. 21).

B. *Experimental Results*

After the construction of the robot, we accomplished some experiences. We started with isolated tests for each motor to obtain the position and velocity limits. An initial position, the start position, is initially fixed for each one of

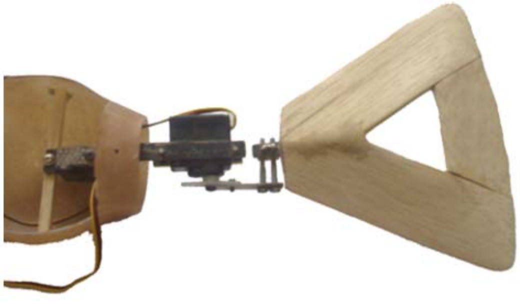


Fig. 20. Coupling between the servomotor and the tail.

Fig. 21. Robotic bird.

them. After receiving the start signal, all the motors will go to this position. As said before, contrarily to the standard servos used in the other joints, for the wing beat we used digital servos allowing a better relation force/speed. These servos can make, without any load, a rotation of 60 in 0.06 seconds. In the first test, we didn't use the flexible plastic film to simulate the effect of feathers. We made a great wing beat speed of approximately 640 ms per cycle. Fig. 22 illustrates an image sequence of one wing beat cycle.

Fig. 22. Image sequence showing one wing beat cycle.

However, the area of the wings was not enough when compared to the weight of the robot. In the second test we used the flexible plastic film to simulate the feathers getting a greater wing area. The application of the film took us to another problem. We used glue to adhere the film to the Lycra increasing the weight of each wing in 70 grams. The engine speed had then considerably decreased making it impossible to oppose the weight of the bird. Other solutions are still being implemented.

VII. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

Some satisfatory results were obtained with the simulation platform proving that the development of the kinematical and dynamic model can show us the behavior of the bird. It is possible to simulate all kind of closed loop actions like gliding, flapping wings, taking off, landing, following trajectories and others. Information relative to the physical nature of the flapping flight proved to be important to analyze solutions. The results had been evaluated using an intuitive analysis, and equally validated by other preceding analysis in this area. The robotic platform gave us some problems that could easily be avoided if the construction was implemented after all the dynamical analysis. Two servos where used in order to control the wing beat of each wing independently. However, such would not be necessary. To achieve identical movements, we can simply change the angle of attack of each wing and the tail rotations.

B. Future Works

We could change a lot of different characteristics in the physical structure of the bird such as using another kind of material instead of fiberglass to construct the body. The fiberglass, although relatively light, it still corresponds to almost one-third of the global weight of the robot. The body could be constructed using raft or another kind of light material as carbon fiber.

Relatively to the digital servomotors used in the wings, they could be substituted by a different system. Using only one DC engine connected to a V-system making both wings to flap simultaneously we could benefit of bigger force and speed.

REFERENCES

[1] Micael S. Couceiro, Carlos M. Figueiredo, N. M. Fonseca Ferreira, J. A. Tenreiro Machado, *Simulation of a Robotic Bird*, 3rd IFAC Workshop on Fractional Differentiation and its Applications, Ankara, Turkey, 05-07 November 2008.

[2] R. Zbikowski, *Fly Like a Fly*, IEEE Spectrum, 42(11), 46-51, 2005.

[3] J. Grasmeyer and M. Keennon, *Development of the Black Widow Micro Air Vehicle*, Proc. of the 39th AIAA Aerospace Sciences Meeting and Exhibit, NV, USA, AIAA Paper No. AIAA-2001-0127, 2001.

[4] A. Colozza, *Fly Like a Bird*, IEEE Spectrum, 44(5), 38-43, 2007.

[5] H. Rbinger *How Ornithopters Fly*, 2006.

[6] N. M. Fonseca Ferreira, J. A. Tenreiro Machado, *RobLib: An Educational Program for Robotics* , SYROCO'00, IFAC Symposium on Robot Control, vol.1 pg. 163-168, Vienna, Austria, 2000.

[7] Charles H. Blake *More Data on the Wing Flapping Rates of Birds*, 1948.