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Design of a mobile aquatic feeder for Oreochromis niloticus
Diseño de un alimentador acuático móvil para Oreochromis niloticus

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Resumen

Hoy en día, el cultivo de tilapia es un proceso estandarizado y bien definido, sin embargo, los acuicultores no cuentan con las herramientas necesarias para asegurar que el proceso se esté llevando a cabo de manera correcta en cuanto a las porciones, sobre todo cuando se trata de estanques grandes, alimentar al cardumen de peces que se encuentran en ellos se convierte en una tarea que requiere tiempo y esfuerzo. En este trabajo se ha desarrollado una propuesta de proyecto para ayudar a los acuicultores con el diseño y construcción de un prototipo de alimentador automático móvil acuático que, como su nombre indica, permita alimentar a los peces desplazándose por el estanque y con la proporción correcta. Además, se desarrolló el diseño de una interfaz hombre-máquina para que el operario pudiera controlar el prototipo, incluida la capacidad de decidir cuándo soltar el alimento. Con este proyecto se pretende facilitar al piscicultor la tarea de alimentar al banco de peces utilizando la metodología del diseño mecatrónico.

Palabras Clave: Acuicultura, alimentador, dispensador móvil, robot acuático, tilapia.

Abstract

Today, tilapia farming is a standardized and well-defined process, however, fish farmers do not have the necessary tools to ensure that the process is being carried out properly in terms of portions, especially when it comes to large ponds, feeding the school of fish in them becomes a task that requires time and effort. In this work, a project proposal was developed to help fish farmers with the design and construction of a prototype aquatic mobile automatic feeder that, as its name says, allows feeding the fish by moving around the pond and with the correct ratio. In addition, the design of a human-machine interface was developed so that the operator could control the prototype, including the ability to decide when to release the feed. This project is intended to help facilitate the fish farmer's task of feeding the school of fish using the mechatronic design methodology.

Keywords: Aquaculture, feeder, mobile dispenser, aquatic robot, tilapia.

1. Introduction

Worldwide, Mexico ranks ninth as a tilapia producer, so 94.3% of the national fishery is focused on this species. Tilapia farming is one of the most widespread, as it is highly productive due to the attributes of this species. Although tilapia is a species that can survive adverse conditions, good production requires monitoring and control of various parameters. Feeding in particular is a factor that affects batch efficiency per culture (INAPESCA, 2021).

Tilapia is a freshwater fish from 10 to 30 cm in length, its culture has become popular because it is highly productive and profitable due to the attributes of the species such as rapid growth, disease resistance, high productivity, tolerance to high-density conditions, ability to survive different salinities, in addition to accepting a wide range of feed types (INAPESCA, 2021). However, in the process of feeding tilapia, fish farmers must ensure that a correct ration is given otherwise the fish can experience weight loss but can also be overfed which causes diseases such as irritability of the nervous system, growth inhibition, gill destruction among others (Rodriguez-Leal *et al.*, 2021).

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Currently, tilapia feeding techniques in aquaculture farms are manual, so the process of feeding the species becomes a task that requires skilled labor that knows the ratio to disperse consequently, often this technique poorly performed can lead to loss of food, which generates a monetary cost and can also represent a danger to the health of the fish because both a deficit of food and overfeeding can cause diseases and insufficiencies in the specimens. In addition, feeding for tilapia farmers is a laborious task because this activity must be done with a certain frequency so it has to be carried out several times a day, which is time-consuming (Hernández Pizano, 2022).

The manual feeding of tilapia also involves risks for the distribution personnel, as there are testimonies of accidents with wild animals that enter the ponds and may attack the personnel that enter the ponds. In part, also referring to the feeding of tilapia, it affects their growth, since they do not have access to food (Hernández Pizano, 2022). This will help the personnel in charge of feeding to ensure that the right portion of food is delivered for the breeding stage and thus the product remains healthy and reaches the right weight and size for its subsequent distribution and sale.

The traditional way of raising tilapia is fattening ponds, whose dimensions are around 50x50 meters with a depth of 1.2 to 1.5 meters. Therefore, this work proposes the design and construction of a prototype that can go around the pond (based on mobile robotics (Marco Andres Meza Calderon, 2015)), dispersing food along the pond so that the operator can disperse it through the interface, which will help to make the feeding process less laborious and ensure that most of the population within the pond receives a dose of food, which will help to have an equitable growth for the entire school.

2. Methodology

The mechatronic design methodology has proven to be a powerful tool to address interdisciplinary challenges that require a combination of mechanical, electronic, and control engineering (Kotlyarov *et al.*, 2022; Sotelo-De la Cruz *et al.*, 2022). In this work, this methodology was applied to develop an efficient and reliable solution that addresses the specific needs related as reported by aquaculturists in the municipality of Armeria and Manzanillo in the state of Colima, Mexico (Hernández Pizano, 2022), establishing three challenges to be addressed.

- Ensuring uniform feeding in tilapia farming is a very present need in the work of aquaculturists in Mexico. Due to the little or no tecnification of this kind of process, the activities are carried out in a completely handmade way, which leads to a bad use of the feed and a different growth among the specimens.

- Either due to the lack of trained personnel, since, at the moment of distributing feed manually, as mentioned, it is necessary to have personnel available at the moment of distribution, and also to have the correct data at the moment of supplying the feed.

- To solve the dispersion of the feed, generally, the automated feed dispensers only have modes that allow controlling the time and amount of feed to be dispensed, and they do not have what is required for the needs of the specimen.

The mechatronic design methodology begins with the identification of the needs and objectives of the project. At this stage, a thorough investigation and analysis of the problem was conducted to thoroughly understand the system requirements and constraints. This allowed the basis for the design to be established and the success criteria to be clearly defined. Next, a complete analysis of the problem was carried out using the IDEF-0 methodology (Pacori-Palomino *et al.*, 2022; Suarez-Paz *et al.*, 2022), taking into account technical, economic and social aspects. Relevant data were collected and analyzed, and feasibility studies and risk assessments were carried out. This stage was fundamental to understanding the complexity of the problem and establishing the key parameters for the design of the solution.

The design specifications were established based on the problem analysis and identified needs. These specifications defined the technical and functional requirements that the solution had to meet. Aspects such as performance, durability, energy efficiency and safety, among others, were considered to ensure that the proposed solution is adequate and viable. Subsequently, 5 conceptual designs were defined based on brainstorming in order to cover all the specifications and solve the main need. The generation of possible solutions was a crucial step in the mechatronic design methodology. Various alternatives were explored and creative and innovative concepts were developed. Tools such as brainstorming techniques, rapid prototyping and simulations were used to evaluate and compare different options. This stage allowed for a broad exploration of ideas and approaches, leading to an informed selection of the most promising solution.

Finally, the selection of the appropriate solution was carried out through membership and selection tables. The different alternatives were evaluated against the criteria set out in the design specifications. At this stage, the proposed solution had to meet the requirements and provide the expected results.

The mechatronic design methodology was applied in this work to address the specific needs of fish farmers in the state of Colima. Through the identification of needs, analysis of the problem, definition of design specifications, generation of possible solutions and selection of the appropriate solution, an innovative and efficient solution was developed that satisfies the established requirements.

2.1. Mechanical design

In the mechanical design, it was necessary to determine the minimum dimensions required for the prototype to float (Mott y Untener, 2015). With this information, we proceeded to a more detailed design of the prototype hulls, considering aspects such as material, commercial sizes, weight and other relevant parameters. Subsequently, the design of the paddle wheels, which will be responsible for propelling the prototype over the water surface, was carried out.

Figure 1 shows the complete design of the base structure of the prototype, which was planned as a rectangle for the raft and two cylinders for the hulls, inspired by a catamaran. This shape was chosen because it is a structure that due to its characteristics is more stable than other structures for boats.

For ease of fabrication and to reduce weight, it was decided to use PVC pipes for the hulls. A length of 1.7 meters was arbitrarily chosen for the prototype, and a standard diameter of 6 inches was used for the PVC pipes. After the hull dimensions were chosen, a buoyancy calculation was performed to verify that the chosen dimensions were adequate. The result of the calculations determined that the prototype will be able to support a mass of up to 54.59 kilograms without sinking when the hulls are submerged.

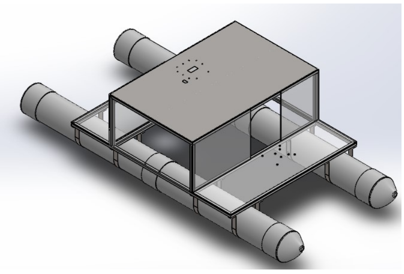
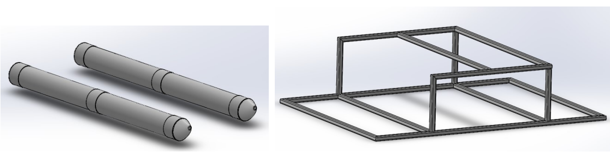


Figure 1: Final structure.

Once the necessary measurements were defined, we proceeded to design the hulls in SolidWorks®, as well as to create a pair of caps to be placed on the front of the prototype. These caps, which will be manufactured by additive manufacturing using acrylonitrile styrene acrylate (ASA), have a conical shape in order to reduce friction with the water. At the back of the pipes, standard PVC pipe caps will simply be added. The union of the pipes and the respective caps will be made with Oatey blue PVC cement, as this is used even in pipes carrying drinking water, thus ensuring that the pond where the prototype will be located will not be contaminated.

The design of the hulls is shown in figure 2a, in addition, the incorporation of a tube structure was considered to support the acrylic rafts and prevent buckling. In order to achieve a lighter prototype, square PVC pipes were used. The resulting structure can be seen in the Figure 2b.



(a) PVC hulls. (b) PVC square tube structure.

Figure 2: Automatic feeder main structure.

Subsequently, it was necessary to determine the dimensions of the paddle wheel and its location. For this, calculations were made considering the target speed of the prototype of 0.5 m/s and the surface of the wheels, which was established with the same area as that of a propeller capable of supporting the required weight and speed. After calculations, the result is a wheel with 7 paddles spaced 51.42 centimeters apart. Each paddle has a height of 10 centimeters, and the total diameter of the wheel is 40 centimeters.

The final design result for the prototype was two equal paddle wheels, for which, it was considered to make them of acrylic with a laser cutter, for that reason, it was designed in such a way that it was assemblable with slots and had two supports for the paddles. Figure 3 shows the isometric view of the final wheel design.

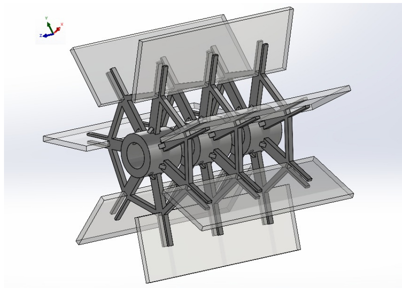


Figure 3: Paddlewheel isometric view.

Considering the maximum speed required for the prototype, the calculations performed indicated that the main motor requires a power of 275 W, an angular velocity of 34.1 rpm and a torque of 71.968 Nm, therefore a MY1016ZL gearmotor was chosen (Fig. 4), with a power of 250 W, a torque of 36 Nm and an output speed of 75 revolutions per minute.

Figure 4: Motor MY1016ZL.

In the doser mechanism (León Quenguan y Rueda Almario, 2013), it was considered that the best option is to use a worm screw to empty the feed kibbles into the water, therefore a motor for the doser is necessary. A series of calculations were made, so, taking into account the results and the type of material to be transported through the auger, the required speed for the auger is 120 rpm. Then, based on the price, maximum torque and nominal speed, the model 5840-31ZY geared motor was selected (Fig. 5), which provides a speed similar to the required one, with a high torque for the concrete application.

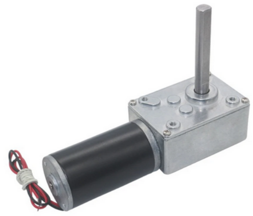


Figure 5: Germotor model 5840-31ZY.

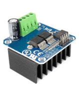
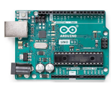
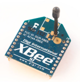
The prototype will require a rudder to steer the ship. The torque required to move the rudder blade as calculated is very little, approximately 0.0044 kg/m. In addition to the calculated torque, the rudder is limited to moving 35° to the left and 35° to the right so it requires an accurate motor. The MG995 servo motor (Fig. 6) offers a torque of 15 Kg/cm which is significantly higher than required, however, the motor also has the advantage of precise movements.

Figure 6: Servo motor MG995.

2.2. *Components*

In addition to the motors mentioned above, the components shown in Table 1 are necessary for the correct operation of the prototype, including wireless communication (Mayné, 2005) and energy autonomy (Bermudez, 2002).

Table 1: Components selected

Component	Image	Component	Image
Velocity controller		Main controller	
Battery		Wireless module	
Magnetic sensor		LCD display	
I2C module conversion		Ultrasonic sensor	
Joystick			

2.3. *Electronic circuits*

The components of Table 1 will be combined according to the electronic diagrams for each of the systems and mechanisms used for the operation of the prototype. The schematic shown in Figure 7 represents how the selected components that make up the drive system will be connected. When the Arduino receives the instructions through the wireless communication system, it will move the prototype forward or backward, the motor will be powered by an external source that is able to provide the necessary energy.

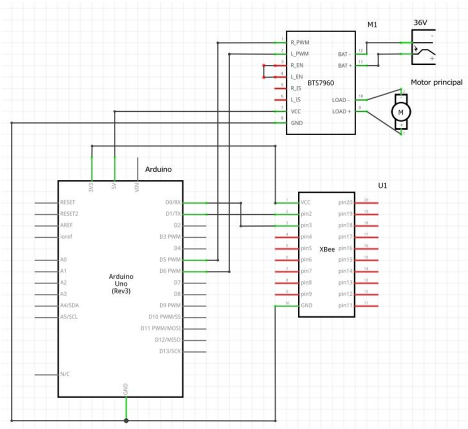


Figure 7: Feed system circuit.

Another fundamental mechanism is the steering system, which is represented in Figure 8, and its purpose is to give direction to the prototype. and its purpose is to give direction to the prototype. When the Arduino receives the turning instructions from the operator control, the servomotor, through PWM signals, will move to the direction sent by the operator. Since the Arduino has a low output current, the servomotor will be powered by an external supply, so as not to compromise the integrity of the microcontroller.

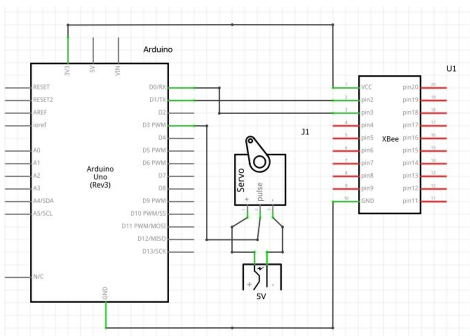


Figure 8: Steering system circuit.

The dosing system also needs a circuit for control, which can be reviewed in Figure 9, this will be responsible for driving the screw to dose the food coupled to a motor. By means of wireless communication, when the operator sends the instruction to dose, the motor will start, it is powered by an external source, since the Arduino does not provide enough energy to power it.

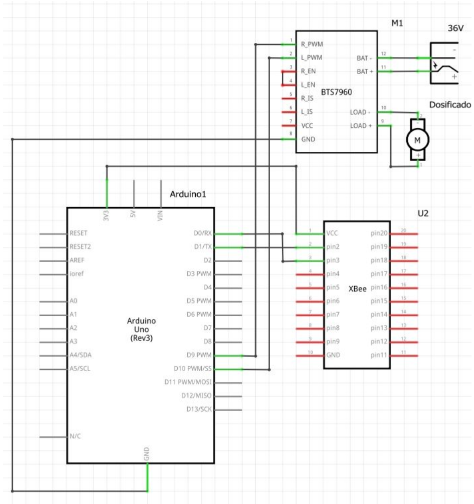


Figure 9: Circuit for dosing system.

A circuit was designed to measure the amount of food remaining, as well as to verify if the lid is closed, consisting of two sensors, one in charge of measuring and the other in charge of closing. In case the container has run out of food, the wireless communication system will send a signal of this state, and for the verification of closed, an actuator in the control for the operator will give the signal that the lid is open, and at the same time the prototype will give a warning by activating an audible alarm, warning that the lid is open. The schematic is shown in Figure 10.

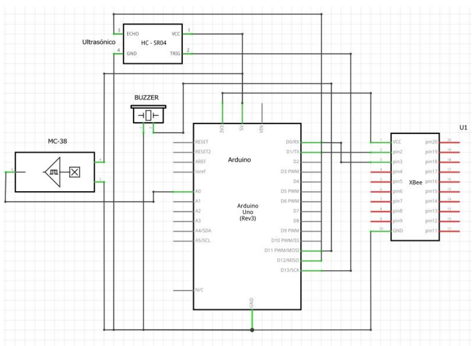


Figure 10: Meal measuring circuit and verification of closure.

In Figure 11 the general circuit of the prototype is represented, the same as all the connections between the selected components, here are the 4 circuits presented previously.

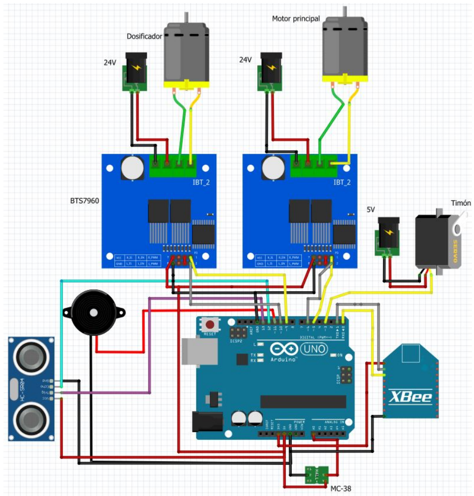


Figure 11: General circuit of the prototype.

In Figure 12, the schematic shows the connections and the components selected for the control. This has 3 circuits: the control for the directions, the wireless communication system, and the system in charge of giving information on the prototype status.

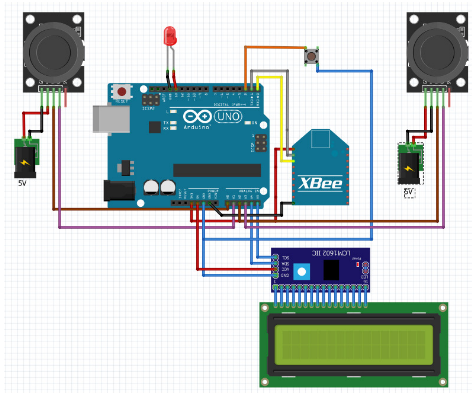


Figure 12: General circuitry for human-machine interface.

2.4. HMI proposal

For the human-machine interface, a control was designed to manipulate the prototype, taking into account the measurements of the components that will go inside the housings and trying to ensure that the antenna of the radio frequency module does not have any interference. A special section for the battery compartment was also designed. The control design can be found from Figure 13 to Figure 16.

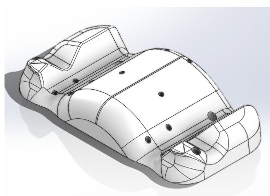


Figure 13: Rear view assembly of the control to manipulate the prototype.

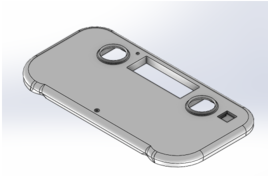


Figure 14: Assembly inside view of the control to manipulate the prototype.

Figure 15: Isometric view of control assembly.

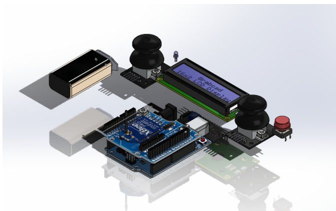


Figure 16: Internal view of control assembly with components.

3. Analysis and results validation

The final design of the prototype with all its electronic components and other elements can be seen in Figure 17.

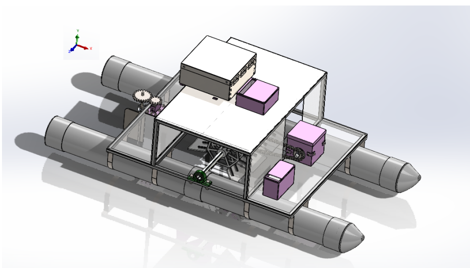


Figure 17: Isometric view of the prototype.

A static study was performed to check where the structure may fail due to the weight of components or feed load. Figure 18 shows that the highest stress is $6.876 \times 10^5\ N/m^2$ but this is not large enough to pose any risk to the integrity of the structure. Figure 19 shows the results of the deformation that the prototype structure will have, a maximum deformation of $1.905 \times 10^{-2}\ mm$ was obtained, this means that no part of the structure will deform even a millimeter, being a favorable result.

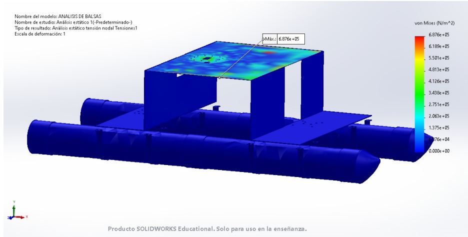


Figure 18: Results (Von Mises) of the static study.

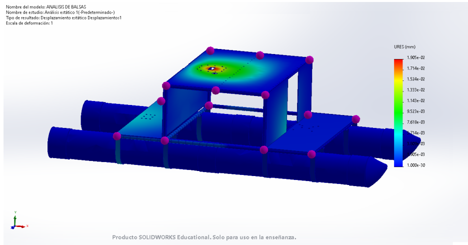


Figure 19: Static study results (displacements).

4. Conclusions

According to the results of the simulations and calculations performed, it is concluded that the final design achieved by applying the mechatronic design methodology meets the proposed objectives since the prototype is capable of loading and dosing more than 4 kilograms of food (up to 7 kilograms) and a system was designed to control the device wirelessly with the necessary range, since the prototype can be efficiently controlled even at a distance of more than 50 meters. At the same time, the human-machine interface was designed to be easy to understand for operators with no previous experience with technical interfaces and aiming at marketable interfaces, thus ensuring that anyone can operate the prototype.

In order to evaluate if the final design was adequate, it was decided to use CAD validation tools, in which several simulations were performed and measurement tools were used to approximate the final mass of the prototype, and its resistance, among other characteristics. In addition, several calculations were performed and specifications were added. The selection of components, both electronic and mechanical, was made by comparing with other options in order to shape the prototype, and thus ensure its operation as proposed in the objectives.

At this point, six of the nine steps of the mechatronic design methodology were performed, leading to a final detailed design, the three stages remaining are undergoing to implement the results here exposed and obtain a functional prototype of a mobile aquatic feeder.

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