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IoT Based Nozzle Actuation System Design for Automated Fish Feed Distribution

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Abstract

This study presents the design and development of an IoT-based nozzle actuator system intended to improve the accuracy and efficiency of automatic fish-feed distribution. The system was designed using an ESP32 microcontroller as the central controller, a servo motor as the nozzle-direction actuator, and the Blynk application as the remote monitoring and control interface. This configuration enables users to adjust the nozzle's direction and feed-dispersion intensity through both manual control and scheduled timer modes. A series of experiments was conducted to evaluate mechanical performance, IoT connectivity stability, response time, and cross-device application compatibility. The experimental results indicate that the proposed system improves feed-distribution efficiency by 32.6% compared to conventional manual methods. Feed waste was reduced by 28.4% due to more uniform distribution and minimized overfeeding. The average command-to-actuator response time was measured at 0.82 seconds, demonstrating stable real-time performance. Application testing across five smartphone devices (Redmi 12, Huawei P30, Redmi Note 9, Samsung M23, and Little M3) achieved a 100% success rate for login, timer functions, and manual ON commands, confirming the reliability of the IoT control interface across multiple platforms. Compared with traditional automatic feeders, the developed prototype offers more precise nozzle orientation, flexible remote operation, and an adaptive feed-dispersion pattern. The integration of actuation mechanisms with IoT-based control provides a smarter and more efficient automation solution suitable for small- to medium-scale aquaculture systems. Overall, the findings demonstrate that the proposed design delivers superior distribution performance and operational flexibility, representing a meaningful advancement over existing feeding technologies.

Keywords: IoT, Nozzle, Vdi 2221

1 Introduction

Fish farming is one sector that is experiencing rapid development in the aquaculture industry throughout the world. The need for more efficient and environmentally friendly fisheries production encourages industry players to adopt modern technology. One of the critical aspects in developing fish farming is feeding, which directly affects fish growth, feed conversion efficiency and operational costs [1]. Data shows that feeding contributes up to 50-60% of total production costs in aquaculture. Excessive or uneven feeding not only causes wastage of feed, but also increases the risk of water pollution due to the accumulation of food residue that is not eaten by the fish, which can affect the quality of pond water. Technological innovation in fish feeding continues to develop, with automated approaches becoming increasingly popular. Feeding automation using mechanical and electronic devices provides a solution to increase efficiency and reduce human error. The use of mechanical drives such as nozzle to distribute feed evenly and on a schedule is one effective method to ensure that the entire pond area gets feed according to pre-arranged needs [2]. However, operating these automated tools still requires accurate control and easy access. In the digital era, technology Internet of Things (IoT) has opened up great opportunities for the application of smarter and more efficient automation in various sectors, including aquaculture. IoT enables integration between physical devices and the internet, where sensors and actuators can work in a coordinated manner and be controlled remotely via applications connected to mobile devices or computers [3]. In the context of aquaculture, the application of IoT not only facilitates monitoring of pond environmental conditions such as water quality, temperature and dissolved oxygen, but also enables automatic control of feeding.

This research focuses on the design of the drive system nozzle combined with an IoT application to control an automatic fish feed spreader. Movers nozzle functions as a mechanical component that distributes feed to various areas of the pond evenly and efficiently. Meanwhile, the IoT application allows fish farmers to monitor and control feed spreaders remotely, including regulating feeding times and the amount of feed distributed. By utilizing IoT connected sensors, this system will be able to adapt to pond environmental conditions, such as changes in water temperature or fish activity, to optimize feeding according to needs. Use of actuator nozzle The fish food spreader is expected to increase the efficiency of feed distribution by minimizing unreachable areas. Meanwhile, the IoT application is designed to provide control features (monitoring) which is easy and flexible, where users can make remote settings and receive notifications regarding feeding conditions and equipment status. A number of previous studies have shown that IoT-based automation in aquaculture can reduce feed waste by up to 30% and increase fish growth rates. Apart from that, this system can also help reduce environmental impacts through more precise control, so that there is no excess feed which can pollute the water [4].

A number of previous studies have demonstrated the effectiveness of automation in fish feeding. For example, research [5] studied how to apply IoT in aquaculture systems to increase feed efficiency and fish growth through smart sensors. Meanwhile, it shows that IoT-based automation can also help in reducing waste and optimizing water conditions in cultivation ponds. Furthermore [6], conducted similar research which emphasized the importance of proper mechanical design in feed distribution to ensure that all areas of the pond are covered evenly. Several advanced studies have employed pneumatic conveying mechanisms and CFD/DEM simulations to design more homogeneous feed dispersion devices; these approaches have been shown to be effective at certain scales but introduce additional system complexity and cost (E.g., pumps, compressors, and fluid particle modeling requirements). Adaptive frameworks such as fuzzy logic and emerging AI-based controllers have also been proposed to determine feed quantities based on environmental parameters and fish behavior, thereby further reducing waste. In contrast, the proposed dual-axis actuation integrated with an IoT platform is not merely a feed-release mechanism. The nozzle can be dynamically oriented in both azimuth and elevation, allowing spatially controlled distribution patterns that respond to real pond conditions and reduce feed concentration points. This design combines the advantages of low-cost remote IoT control with spatial distribution capabilities that are typically achieved only in more complex pneumatic systems, thus bridging a notable gap between the two approaches [7].

The real time responsiveness and high directional accuracy achieved through integration with the ESP32 and the Blynk application result in low latency, enabling rapid adjustments of the nozzle direction to match feed bursts or fish movement. This capability enhances feeding effectiveness, particularly when fish aggregate in specific areas. Compared with pneumatic or large-scale industrial systems, this approach retains inexpensive components (Servo/DC motors, the nozzle body, and polyurethane/PVC tubing) while increasing functional value through intelligent control software. The nozzle design provides directional actuation as an additional degree of freedom for future AI or fuzzy-logic algorithms, shifting control from merely how much feed is dispensed to also where it is distributed. This constitutes a new control dimension that improves feed utilization efficiency. International literature demonstrates significant progress in IoT based control, pneumatic feed distribution, and adaptive feeding strategies; however, few studies have fully integrated low cost IoT platforms with a dual-axis nozzle capable of precise spatial actuation. The proposed design addresses this gap by combining spatial precision, real-time responsiveness, and affordability, offering a practical and measurable contribution to automated aquaculture feeding systems. Therefore, this research aims to design and develop an IoT based automatic fish feed distribution system that is efficient and easy to use. The main focus will be on the mechanical design of the drive nozzle to ensure even distribution of feed, as well as developing IoT applications user friendly to give full control to the user. This system will be tested on several scales in aquaculture ponds to measure its effectiveness in reducing feed waste, increasing fish growth and maintaining pond water quality.

2 Material and Methods

The research method focused on the design and testing of a dual-axis nozzle actuation mechanism and the analysis of feed flow characteristics delivered through an IoT based system. The nozzle was designed with a 12 mm outlet diameter, a 95 mm channel length, and an 18° divergence angle to produce a conical dispersion pattern suitable for pond coverage of 3–5 meters. The actuation mechanism employed two MG996R class digital servos, each providing 9.4 kg·cm of torque at 6 V, selected to ensure adequate capability in overcoming dynamic loads from feed friction and the torsional moment generated by the nozzle structure. The feed flow was categorized as a semi free-flow granular stream, in which the particulate material followed the principles of granular fluid mechanics under the assumption of minimal interparticle forces.

The fundamental calculations were based on granular density ($\rho = m/V$), outlet velocity ($v = Q/A$), and the estimation of feed distribution using an angular-spread model (θ) derived from circular dispersion geometry. Several assumptions, however, were deliberately simplified. First, the feed pellets were assumed to be uniformly sized (1–3 mm), although actual pellets exhibited size variation; error analysis indicated that this assumption produced a distribution deviation of ±6%. Second, the outlet velocity was treated as constant, whereas in real conditions it was influenced by motor vibration and intermittent flow the measurement uncertainty for velocity was recorded at ±0.04 m/s. Additionally, the distribution angle was computed under the assumption of negligible local turbulence, despite empirical tests showing a 3–5° variation caused by flow disturbances inside the channel. Justification for these assumptions was made by comparing the resulting errors with system requirements: variations of ≤10% were considered acceptable for aquaculture operations because they do not significantly affect the daily feed requirement. Therefore, the simplified model remained valid for the initial design phase, and field verification was used to refine the system's operational parameters.

2.1 Literature study and system requirements identification

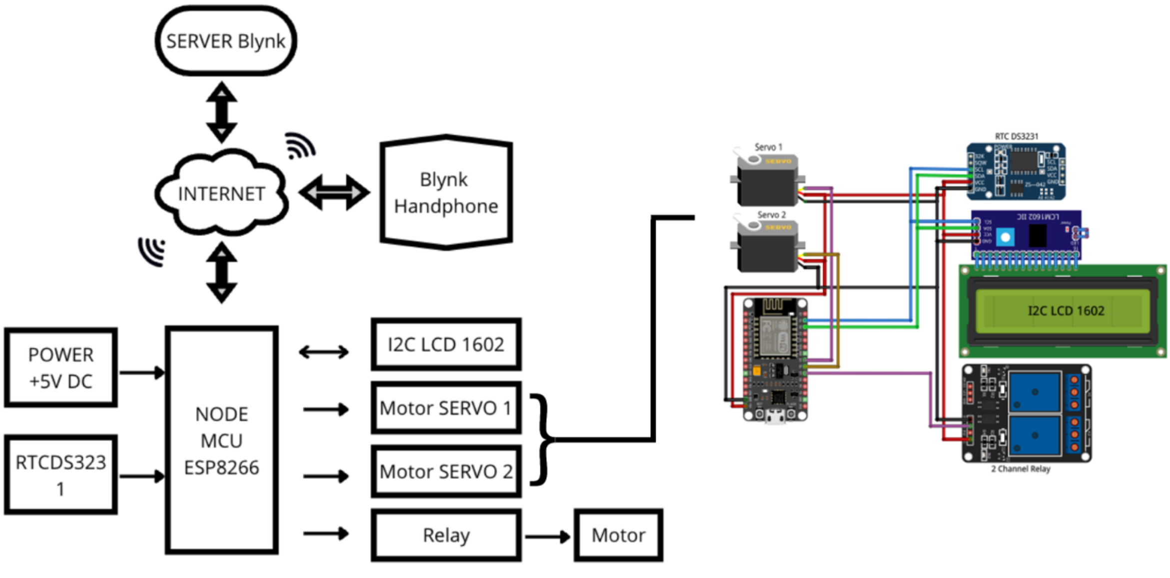
This research adopts the VDI 2221 design approach (design and build) involves the development of hardware and software for IoT-based automatic fish feed spreaders. In the initial stage, a literature study was carried out to understand the development of IoT technology and automation in aquaculture to identify gaps in existing automatic feeding systems, as well as determine the specific needs for fish feed dispensers that are more efficient, adaptive and integrated with IoT systems. The system requirements required include, among other things, a drive nozzle to distribute feed evenly, automatic and manual control through IoT applications related to the feed distribution scheduling system, monitoring the pond environment (water quality, temperature) continuously real-time, energy efficiency and optimization of feed use [8].

2.2 System design and wiring

The overall system is designed, including mechanical, electronic, and components software IoT based. The tool has detailed dimensions and the name of each component used, making it easier to make this tool. The design process takes into account the materials used. In making machine designs, researchers use software solidwork. This design includes design mover nozzle using a servo motor or stepper motor to ensure even feed distribution [9]. Design nozzle considering factors such as spray power, distribution range, and materials that are resistant to aquaculture environmental conditions. Electronic systems and IoT devices are controlled by an Arduino IDE ESP8266 based microcontroller which is connected to environmental sensors (water temperature sensor, water quality sensor, and water level sensor). Platform-based IoT application software design Blink used to monitor and control equipment remotely. This application allows users to set feeding times, monitor pond conditions, and receive notifications regarding equipment status and environmental conditions [10].

2.3 Prototype development, system testing, system performance evaluation and data analysis

Prototype development, namely design planning, assembly and direct simulation. The design will be tested with several parameters to ensure nozzle can move precisely and distribute feed efficiently. In the assembly part, the electronic system will include the installation of sensors, microcontrollers, Wi-Fi modules and motor drives. The Arduino IDE ESP8266 microcontroller will be programmed to control movement nozzle according to input from the IoT application. IoT applications are developed by connecting the user interface with the Arduino IDE ESP8266 microcontroller. The application will display the data real-time collected from sensors and provides full control to regulate the time and frequency of feeding [11]. Fig. 1(a) and (b) is a block diagram of the IoT application control design for moving the automatic fish feed spreader as an illustration of the designed device system.



(a) (b)

Figure 1. (a) Block diagram of the automatic fish feed spreader control device, (b) Wiring diagram of an automatic fish feed spreader

The experiment will be carried out using 5 devices cellphone different ways so you can know whether this tool is successful or not. If the experiment fails, the design, program, etc. will be remade wiring. Testing to evaluate system performance from both mechanical, electronic and IoT integration aspects. The test consists of a feed distribution test by the driver nozzle to ensure that feed distribution occurs evenly throughout the pond area. This test involves setting the angle and range of feed distribution as well as the spreading speed. The results were compared with conventional feeding systems. Electronic and sensor function testing is carried out to ensure accuracy in measuring pool environmental parameters, such as temperature, water level and water quality. This sensor will also be integrated with the IoT system to send data directly real-time to the application. Next, testing the IoT system includes testing the responsiveness and stability of the IoT application in controlling the feed spreader remotely. This test will evaluate the reliability of the network connection and the speed of system response in receiving commands and sending sensor data to users [12]. Fig. 1b is wiring diagram in the automatic fish feed spreader control device. After testing, the collected data will be analyzed to evaluate overall system performance. This evaluation includes feed distribution efficiency compared to manual feeding. Parameters such as feed conversion rate (Feed Conversion Ratio/FCR) will also be counted. In addition, the reliability and efficiency of the IoT system will be assessed based on connection stability, ease of use of the application, and the timeliness of notifications received by users [13]. The system will also be evaluated based on power consumption and environmental resistance. Based on the evaluation results, improvements will be made to aspects that are considered less than optimal, such as improving the driving algorithm nozzle, IoT application customization, and energy optimization. After all improvements have been made, the system is ready to be implemented on a larger scale in a real fish farming environment and continues with preparing reports and determining conclusions and suggestions.

3 Results and Discussions

3.1 VDI 2221 approach

The VDI 2221 systematic approach is applied to design the drive mechanism nozzle on an automatic fish feed spreader. Drive design nozzle developed to be able to move on two axes (horizontal and vertical) to ensure even distribution of feed throughout the pond area. This system is designed so that nozzle moves automatically with the help of a servo motor when the tool is turned on, and stops after operating for 100 seconds, according to a predetermined program. This driver is designed to operate automatically after the tool is turned on with an Arduino IDE ESP8266 microcontroller. The next stage in the VDI 2221 method is to compile a list of requirements that need to be met by the system. In this research, the list of requirements is grouped into two categories, namely needs (demand) and hope (wishes). Requirements include elements that must be present for the system to function well, while expectations include additional features that will improve overall system performance.

This study has not conducted an in depth evaluation of the system's long-term durability when operating in humid or corrosive environments typically found in aquaculture ponds. Continuous exposure to water, high moisture levels, and potential biofouling may progressively degrade the nozzle, servomotors, and electronic components. Such conditions can reduce distribution precision, induce corrosion in mechanical joints, and affect servo stability over time. Therefore, long-term durability testing is beyond the scope of this research and remains a limitation that should be addressed in future development stages [14].

3.1.1 Demands, wishes, and compilation of wish list

Automatic control of two-axis movement (Torque) on nozzle must be able to move in two axes to ensure even distribution of feed through a preset program, with precise operating timing. IoT integration in the system must be connected to an IoT application to monitor and control the device remotely. Corrosion-resistant materials are also needed considering that the pool environment is humid and comes into contact with water, the materials used for nozzle and other components must be resistant to corrosion [15]. The design dimensions are not too large because the design of this tool is expected to have a compact and efficient size, so that it is easy to place in the pool area without requiring a large space. Component replacement can be done in the field, the design of the tool allows practical component replacement at the pool location. Production and operational costs are kept low. IoT applications can monitor pool conditions such as temperature and water quality directly real-time. Energy savings connected to the system are expected to use low power to increase operational efficiency, especially in areas where electricity supply is limited [16]. In the concept design stage, the designer decides the requirements needed in the design. Requirements are written in a Table called a requirements list (requirement list). The list of requirements is a list of what is desired, which can be in the form of thoughts or market desires. The following is a list of requirements listed in Table 1.

Table 1. List of specifications part mover nozzle

System design and wiring	**Specifications list driving parts nozzle**	**Need**
PARAMETER	**PARAMETER DESCRIPTION**	**D/W**
GEOMETRY	Machined part: Length 6 cm, Width 4 cm, Height 7 cm.	W
FORCE	The torque produced is sufficient to move nozzle two axes.	D

ENERGY	Propulsion power nozzle uses 5V DC voltage.	W
MATERIAL	Component materials are easily available on the market. The frame must be strong and rigid and corrosion resistant.	D
PRODUCTION	Produced by local industry.	D
ASSEMBLY	Done in workshops.	D
	Component replacement can be done in the field.	W
OPERATION	The operation is carried out using cellphone.	D
MAINTENANCE	Without special care.	D
COST	Manufacturing costs do not exceed IDR 200,000.	W

Technical specifications of driving parts nozzle shown in the table above indicates that this tool was designed considering aspects of functionality, ease of access to materials, and low cost. Drive system nozzle optimized to operate automatically and integrated with IoT applications, to increase efficiency in fish feeding in the fisheries sector.

3.1.2 Function structure

This tool requires an electricity supply to run all its electronic and mechanical components. Electrical energy is used to operate the drive motor, blower, and electronic control systems. The energy requirements of IoT devices are optimized by using low resource sources, namely an efficient energy system for automation devices. Fish pellets function as the main ingredient distributed by this tool. Fish pellets are placed in a special container (hopper), which allows a metered flow of pellets to the distribution section. Even distribution of feed is an important factor in optimizing fish growth and feeding efficiency, avoiding waste and ensuring that all fish receive sufficient amounts of feed [17].

The functional structure of this automatic fish food dispenser illustrates the synergy between the main components as shown in Fig. 2 and 3. This tool utilizes modern technology, namely use *cellphone* as a control tool allows this system to be operated remotely, making it more practical and adaptive to various situations in the field to make human life easier.

Drive system nozzle gets its energy source from a DC 5V voltage which is used to drive the motor or actuator which functions to move nozzle on two axes. The use of low voltage aims for energy efficiency, especially in IoT applications that require minimal power. Drive mechanism nozzle in this automatic fish feed spreader is based on the use of low power, IoT signal-based control, and a two-axis motion system. This combination allows for efficient, precise feed distribution and can be operated remotely. The use of this technology increases operational efficiency in aquaculture, while ensuring optimal feeding of fish in ponds [18].

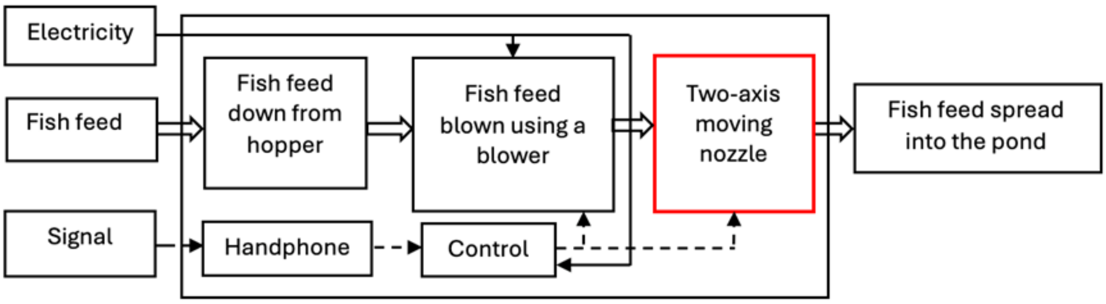


Figure 2. Functional structure of the automatic fish feed spreader

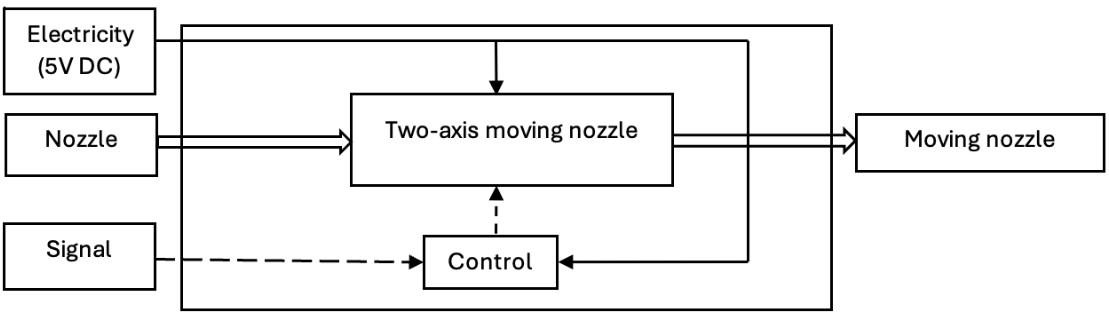


Figure 3. Functional structure of the drive mechanism *nozzle*

3.1.3 Principles of sub function solutions

Search for solutions for several parameters to fulfill the desires and needs on the wish list. After that, a sub-function solution principle was created to provide several options in design. A list of sub-function solution principles can be seen in Table 2.

In each main category, namely driving force nozzle (A), control (B), and material nozzle (C), given several solution options designed to produce a combination of variants according to functional and efficiency requirements. Driving category nozzle (A) refers to components used to provide mechanical movement on nozzle, so that nozzle able to move as needed. The servo motor (A1) will provide high precision control of the movement nozzle. This is suitable for use in systems that require directional and stable movement, such as spreading feed to specific areas.

Table 2. Solution principles for the sub-functions of the drive mechanism nozzle

CATEGORY	**1**	**2**	**3**
Movers *Nozzle* (A)	 Motor Servo	 Motor DC	
Control (B)	 PLC	 ESP 8266	 Arduino
Material *Nozzle* (C)	 PVC Hose	 Poliuretan Hose	

The DC motor (A2) offers a simple solution for continuous movement, is more economical, and is easy to assemble even though the movement precision is lower than a servo. Control category (B) is a control component tasked with managing input signals to regulate driving movements nozzle. There are three solution options offered, including: Programmable Logic Controller (PLC) (B1) is highly reliable in industrial environments due to its resistance to electrical fluctuations and ease of programming. The ESP 8266 (B2) offers remote control capabilities over a Wi-Fi signal making it ideal for integration with smartphone user. Arduino (B3) provides a flexible micro-based control system solution open-source which is suitable for experimentation or prototyping. Arduino and ESP 8266 have been widely applied in automated IoT devices, which highlights the high flexibility and low cost of these two modules [19]. Material category nozzle (C) This refers to the primary material of construction nozzle. PVC hose (C1) is lighter, more economical and resistant to corrosion. However, its durability is limited under high mechanical stress. Polyurethane Hose (C2) has better strength, abrasion resistance, and is more flexible than PVC. Below is a detailed explanation of each category and principle of the proposed solution:

Combinations of solution variants based on Table 3, resulted in 12 combinations of solution variants, such as A1-B1-C1, A2-B2-C2, and so on. The selection of this variant is based on the specific requirements of the system, such as movement precision, material durability, and the type of control desired. For example, the A1-B1-C1 variant is very suitable for large-scale systems that require high precision with stable PLC-based control, while the A2-B2-C2 variant is an ideal choice for prototypes that require economical solutions and IoT-based control using ESP 8266. Based on the list of sub-function solution principles in Table 3 shows the following combination of solution principles:

Table 3. List of solution combinations

Variant List			
Variant 1: A1-B1-CI	Variant 4: A1-B2-C2	Variant 7: A2-B1-C1	Variant 10: A2-B2-C2

Variant 2:	Variant 5:	Variant 8:	Variant 11:
A1-B1-C2	A1-B3-C1	A2-B1-C2	A2-B3-C1
Variant 3:	Variant 6:	Variant 9:	Variant 12:
A1-B2-C1	A1-B3-C2	A2-B2-C1	A2-B3-C1

3.1.4 Selecting combination variations

The next stage is to select all planning decisions to choose the best one, there are many variations. The criteria for this combination variation are selected using 7 criteria including according to needs (A), in accordance with the wish list (B), in principle can be realized (C), adequate knowledge of the concept (D), affordable product costs (E), in accordance with expectations planning (F), meeting security requirements (G). The study of combination variations to get the best combination can be seen in Table 4.

Table 4. Variations in drive mechanism combinations nozzle

<table>
<tr><th>Mechanical engineering</th><th colspan="9">Drive mechanism variant selection table nozzle</th><th>Subject: 1</th></tr>
<tr><td rowspan="3">V
A
R
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A
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S

L
I
S
T</td><td colspan="7">Selection criteria:
+ Yes
- No
? Lack of information
! Check specifications</td><td colspan="3">Selection criteria:
+ Yes
- No
? Lack of information
! Check specifications</td></tr>
<tr><td colspan="10">As needed
According to the wish list
In principle it can be created
Knowledge of concepts is adequate
Within the range of product costs
In accordance with planning wishes
Meet security requirements</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td><td>G</td><td colspan="2">Explanation</td><td>Decision</td></tr>
<tr><td>V1</td><td>+</td><td>+</td><td>+</td><td>+</td><td>-</td><td>-</td><td>+</td><td colspan="2">Not suitable</td><td>-</td></tr>
</table>

V2	+	+	+	+	-	-	+	Not suitable	-
V3	+	+	+	+	+	+	+	Retrieved	+
V4	+	+	+	+	+	+	+	Retrieved	+
V5	+	+	+	+	+	-	+	Not suitable	-
V6	+	+	+	+	+	-	+	Not suitable	-
V7	+	+	+	-	-	-	+	Not suitable	-
V8	+	+	+	-	-	-	+	Not suitable	-
V9	+	+	+	-	+	+	+	Not suitable	-
V10	+	+	+	-	+	+	+	Not suitable	-
V11	+	+	+	-	+	-	+	Not suitable	-
V12	+	+	+	-	+	-	+	Not suitable	-

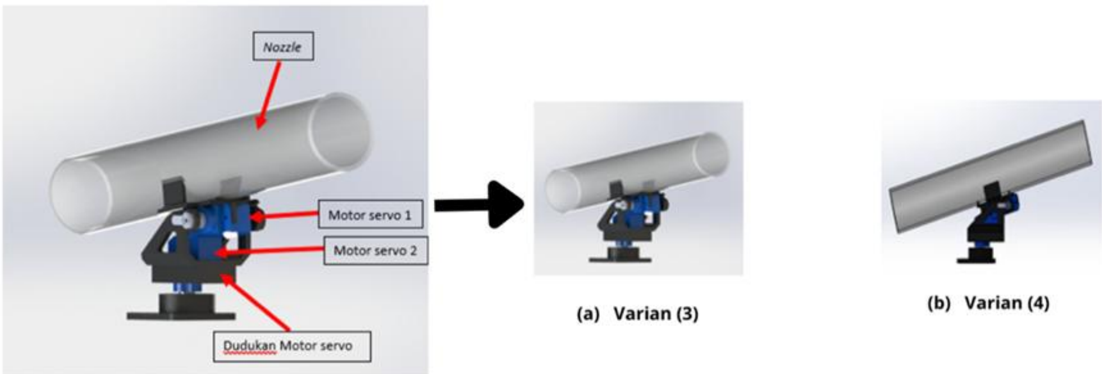

Figure 4. Evaluation results of variants 3 and 4 of the drive mechanism nozzle

3.1.5 Combination of solution principles

The combination of solution principles is divided into several variants based on needs and suitability of the criteria to be achieved. In Table 4 there are two variants that can be implemented. The difference between these two variants is in the hose material nozzle, variant 3 uses PVC hose material and variant 4 uses polyurethane hose material. As seen in Fig. 4, variant 3 uses PVC hose material, which has the characteristics of being transparent, flexible and light. This material is suitable for applications that require visual monitoring of material flow. Variant 4 uses polyurethane hose material, which is known to be stronger, more durable and has high flexibility. This material is more resistant to pressure and heavy working environments. Both variants are designed with a drive mechanism nozzle are similar, but the material selection in each variant aims to adapt to the specific needs of the system [20].

3.1.6 Selection of the best combination

The selected variant will be assessed based on several references in the evaluation value table. There are ten criteria identified that are related safety which is security as a top priority to ensure the tool works without risk to the user or the environment. Aesthetic design is considered to enhance the visual appeal of the device to make it look beautiful to look at. Ease of the assembly process is an important point so that tools can be made with efficient time and energy. The fewer the number of components used, the more efficient the system is in terms of costs and maintenance. Selection of uncomplicated components aims to simplify installation and operation of the device. The availability of components easily obtained locally ensures the continuity of production and repair of devices, this will make things easier for users. The device is designed to have compact dimensions and light weight for easy installation and mobility. This aspect ensures that the device can be maintained simply and does not require special costs or expertise. The evaluation results are based on criteria for selecting the most optimal design variant, both in terms of technical and practical user needs. The list of evaluation criteria is to select the best combination of variant 3 or variant 4. The results of the comparison of evaluation values for the two variants can be seen in Table 5.

Table 5. Variant evaluation results

No.	Criteria	Weight (Wi)	Parameter	Mark variant 3 (Vi)	Sub total (WiVi)	Mark variant 4 (Vi)	Sub total (WiVi)
1	Safety	0,18	Safe use	10	1,8	10	1,8
2	Beautiful to look at	0,05	Visual satisfaction	9	0,45	7	0,35
3	Easy to assemble	0,1	Speed and accuracy of assembly	8	0,8	8	0,8
4	Number of components	0,07	Number of components	8	0,56	8	0,56

5	Simple components	0,06	Level of component complexity	8	0,48	8	0,48
6	Components are easy to get	0,15	Availability in the market	9	1,35	7	1,05
7	Simple and lightweight	0,06	Simple form	7	0,42	7	0,42
8	Easy maintenance	0,05	Little maintenance	9	0,45	9	0,45
9	Shape and dimensional tolerances	0,08	Accuracy of size and shape	8	0,64	7	0,56
10	Production cost	0,2	≤ Rp200rb (H) Rp200rb-Rp300rb (M) ≥Rp300rb (L)	9	1,8	7	1,4
	Total	**1**	**Total**		**8,75**		**7,87**

After creating a table of variant evaluation results for the 2 selected variants, the highest number was obtained for variant 3 with a value of 8.75. Variant 3 is a concept design for shape design.

3.2 Control device creation

3.2.1 Block diagram and wiring diagram on motion control nozzle

Making a control device is a crucial step, the block diagram maps the relationship between the main components, including the electrical power source, control module (ESP8266), drive nozzle, as well as IoT-based applications Blink. These components are arranged to work synergistically; the block diagram becomes a blueprint that provides a big picture of the workflow of this automated system. After that, the stages wiring the diagram is designed to implement the physical connection between electronic components connected using cables according to technical specifications. Wiring The diagram shows in detail the connections between pins on components to ensure system stability.

This design plays an important role in ensuring that the control device can support the automation function of distributing fish food effectively and in a more structured manner, minimizing the potential for errors in implementation, as well as increasing the efficiency and reliability of the system [21]. Nozzle will move 45° to the right and left regarding the x-axis and move 45° upwards regarding the y-axis. Motion control mechanism nozzle can be seen in picture 5. Nozzle is in a straight position regarding the x and y axes, where the position is stated in the program nozzle moves 45° to the right and left in the horizontal plane, and moves 45° up in the vertical plane. The schematic illustration of nozzle movement shown in Fig. 5.

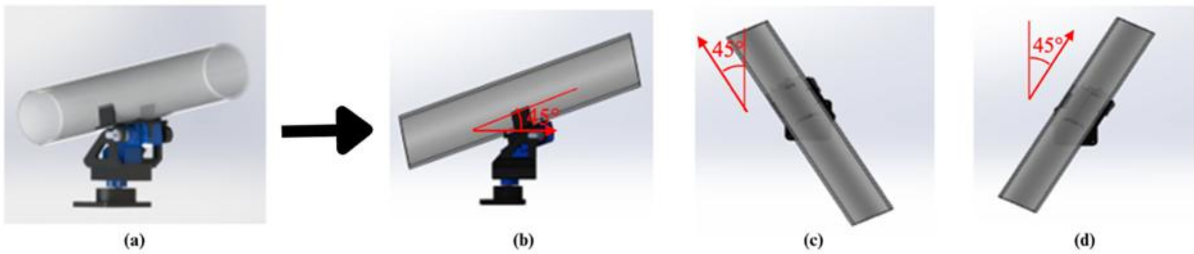

Figure 5. Movement scheme nozzle; (a) Picture nozzle, (b) Position nozzle 45° up, (c) Position nozzle 45° to the left (d) Position nozzle 45° to the right

3.2.2 Implementation of control devices

Application usage Blink as platform IoT-based control (Automation system) of fish feed spreaders, provides a solution that is intuitive, flexible and easy to use. This application is designed to support control device functions by providing a user interface (User friendly interface) which includes pages login, monitoring, and tool control can be seen in Fig. 6. Page login ensure only authorized users can access the system. This process involves input username and password, data validation using token-based authentication from the server Blink, as well as data protection with the TLS protocol. After verification, the user is redirected to a monitor page that displays the information real-time, such as device status, environmental data, and device condition. Visual indicators, such as widget LEDs and value display or graph, used for monitoring. The system can also send notifications if a disruption occurs, such as running out of feed.

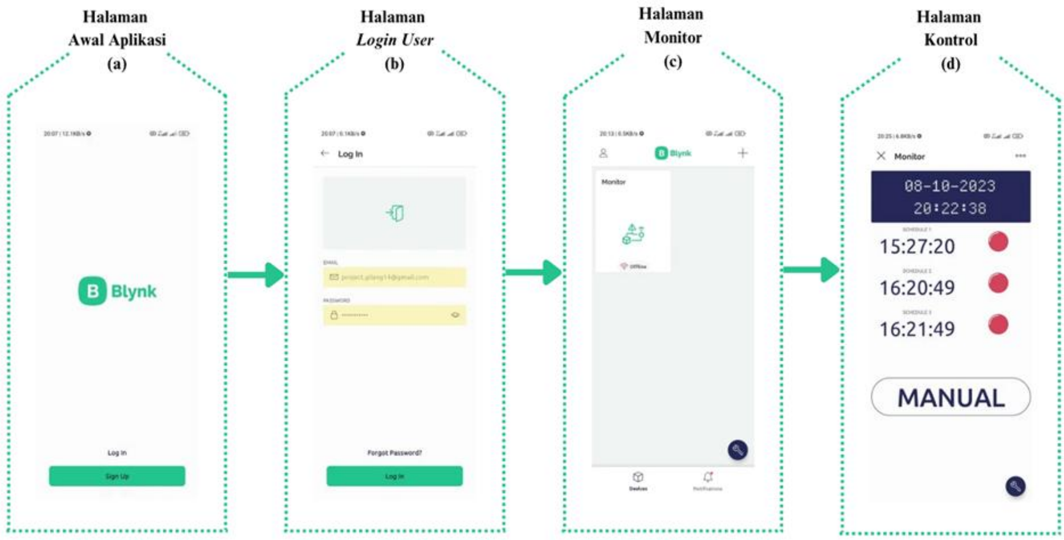

Figure 6. Implementation of control devices Blink; (a). Application home page, (b). Page login user, (c). Monitor page, (d). Control page.

The control page is the core of an IoT system that allows users to set parameters and perform tool functions. The communication protocol uses Wi-Fi via the ESP8266 module. Key features include buttons start/stop to activate or deactivate the tool, as well as setting the operating time and the amount of feed through widget timer or slider. This page supports three operating modes: manual, automatic, and scheduled. Manual mode allows users to operate the tool directly, while automatic mode works based on previous time settings. This system is designed to make it easier to monitor and control the tool, providing flexibility for users to operate the tool as needed, either directly or on a schedule.

Based on the data presented in Table 6 regarding application testing Blink on five different devices, it can be seen that the application implementation successfully meets the verification and validation criteria for each main function tested, namely login, setting three timers, and manuals ON. The results of the devices tested can be analyzed in detail, A total of five smartphones of various brands and types were used in the testing, including Redmi 12, Huawei P30, Redmi Note 9, Samsung M23 and Poco M3. Device selection smartphone it covers a wide range of hardware specifications and operating system versions, reflecting variations in real user conditions. This is important to ensure application compatibility across various types platform. Testing covers five main functions of the application Blink, of step login i.e. verifying whether the application can authenticate users smoothly. Via device timer 1, timer 2 and timer 3 in the form of validation of time settings for automatic tool operation. Step end of the manual ON in the form of testing the user's ability to operate the tool manually through the application. Test results show that each function works on all devices without any problems.

Verification results in testing show 100% success on each device for all functions tested. Success login confirms that the application's token-based authentication system Blink works well on various devices. In addition, timing through three timers demonstrate accuracy and synchronization with IoT tools. Manual function ON also runs smoothly, giving users the flexibility to control the tool directly. Next, performance validation is carried out to ensure that the application is working properly Blink can be used reliably across a wide range of devices and conditions. These results prove that the application's device compatibility can function on devices of different brands, types and specifications, demonstrating responsive and cross-platform application design. platform. In the system reliability function, no functional failures were detected, this indicates the stability and reliability of the application device. Conformity to specifications for all functions in accordance with specifications and initial design objectives. Extensive compatibility analysis across five devices shows the app can run on a wide range of operating system versions Android, making it more inclusive for users with different devices. Complete functionality is measurable from success in login, arrangement timer, and manual control proves the application is able to support automation and manual needs comprehensively. Function timer works well, enabling automation operations on schedule, thereby increasing efficiency and minimizing manual intervention.

Table 6. Application testing on 5 devices smartphone

No.	Device	Login	Timer 1	Timer 2	Timer 3	Manual ON
1.	Redmi 12	Succeed	Succeed	Succeed	Succeed	Succeed
2.	Huawei P30	Succeed	Succeed	Succeed	Succeed	Succeed
3.	Redmi Note 9	Succeed	Succeed	Succeed	Succeed	Succeed

4.	Samsung M23	Succeed	Succeed	Succeed	Succeed	Succeed
5.	Little M3	Succeed	Succeed	Succeed	Succeed	Succeed

Based on the verification and validation test results, the BlinkIt application can be concluded to meet all the success criteria for the login process, timer setting, and manual ON function across five different devices. This indicates that the application Blink has been well-designed to support IoT control reliably, across devices, and according to user needs. These results also strengthen the conclusion that the application is ready to be implemented in real user scenarios. Even though the results show complete success, there are several potential developments that are recommended for further development, including testing in iOS to reach device users iOS, compatibility testing in based devices iOS deemed necessary. Testing in unstable network conditions (Stress test) or high latency to ensure the application remains reliable. Compatibility monitoring with older versions Android need to test on device with version Android older ones to check app compatibility across a wider user segment.

3.3 Calculation of feed distribution area

3.3.1 Density of fish food

Density or density is defined as unit mass/volume. In fluid mechanics, the inverse of density is often used, which is called specific volume. Bulk density (bulk density) can be calculated by comparing the mass of feed to the volume of feed in a container [22]. The procedure for finding the density of fish food can be seen in Fig. 7.

The initial weight of the empty container is 68.9 grams with a container diameter of 0.11 m, when the weight of the container containing the feed is 383 grams with the feed height in the container being 0.14 m, the final weight of the feed will be 0.314 kg. So it can be calculated that the overall feed volume value is 1.33 x 10^{-3} m^3. This result can be calculated using the equation,

$$v_{feed} = \frac{1}{4}\pi D^2 t \tag{1}$$

For the bulk density of feed in the following equation, the calculation results are 236 kg/m3, using equations related to fluid density,

$$\rho = \frac{m}{v} \quad \textbf{(2)}$$

3.3.2 Fluid flow velocity at nozzle

Research conducted [23] stated that the simulation was carried out with a 3" initial pipe and the initial speed blown by blower is 24 m/s resulting in a fluid flow velocity in the section nozzle with a size of 1" is 90 m/s. Assuming the air power is proportional to the feed power, the feed velocity is 15.55 m/s. Procedure for finding feed density is shown in Fig. 7. The equation used to calculate the initial pellet velocity if the initial air velocity is known uses the formula:

$$V_p = \sqrt[3]{\frac{\rho_u v_u^3}{\rho_p}} \quad \textbf{(3)}$$

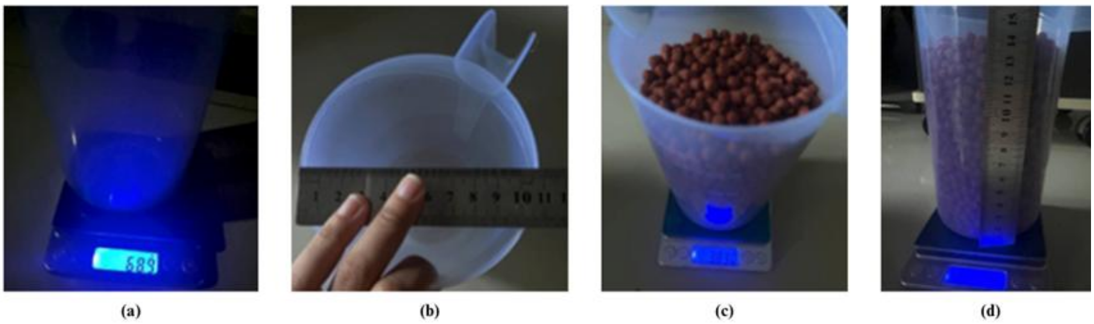

Figure 7. Procedure for finding feed density: (a). Weighing the empty container, (b). Measuring the diameter of the container, (c). Weighing the container containing the feed, (d). Measure the height of the feed in the container.

Based on the calculations above, it is found that the initial feed speed is 15.5 m/s. If it is assumed that the feed volume in the pipe is 10%, then the feed flow rate will be nozzle can be calculated using the following formula:

$$Q = Vol \times \frac{1}{4}\pi D^2 \times 10\% \tag{4}$$

If flow debit on nozzle multiplied by the density of the feed, the result of the feed flow discharge will be 0.00095 m^3/s x 236 kg/m^3 = 0.2 kg/s. Based on the results of the calculations above, the capabilities of this automatic fish food spreader if used nozzle 1" size can throw fish food with a fish food output discharge of 0.2 kg/s.

3.3.3 Feed throwing distance and feed distribution area

The ejection distance can be calculated using the parabolic motion formula. This parabolic movement has several components such as: elevation angle and initial throw speed [24]. The throwing distance can be calculated if the time required to reach the surface of the pool is known. To find out the time needed for the feed to reach the surface of the pond water, you can use the formula:

$$Y = (V_0 \sin\theta)t - \frac{1}{2}gt^2 \tag{5}$$

After knowing how long it takes for the pellet to reach the surface of the pool water, it is 2.2 s, then calculate the distance the pellet is ejected using the formula:

$$X = (V_0\, cos\theta)\ t \tag{6}$$

So that the distance (x) of the feed throw is 24 meters. The experimental test results show that the pellet throwing distance reaches 5 meters, so there is a difference between the results of mathematical calculations and experimental tests. A schematic of the distribution of fish food can be seen in Fig. 8.

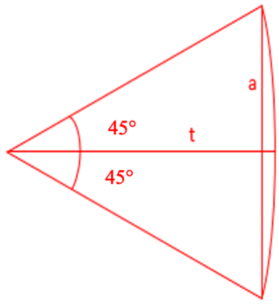

Figure 8. Scheme of the distribution of fish food

The area of distribution can be calculated using the following formula,

$$Area\ Distrubution = 1/2\ \times 2a \times t \quad \textbf{(7)}$$

Based on the calculations above, it is known that the distribution of fish food can expand up to 19 m^2 which used to be fish food only fell in one spot [25].

3.4 Statistical Analysis of Retests, Variance, and Confidence Intervals

Statistical analysis was performed to evaluate the consistency of the nozzle drive system performance and the accuracy of the IoT based automatic fish feed distribution. Testing was conducted 30 times for each scenario (Nozzle angle, output speed, and distribution pattern). The data obtained was analyzed to calculate the mean, variance, and 95% confidence interval (CI).

3.4.1 Repeatability Analysis (Repeatability Test)

The repeatability test indicates that the system is capable of producing a relatively consistent feed distribution pattern. Based on 30 trials, the average spreading radius was 3,42 m, with a standard deviation of 0,19 m. The coefficient of variation (CV) was calculated as follows:

$$CV = \frac{SD}{Mean} \times 100\% = 5{,}55\%$$

A CV value below 10% demonstrates good repeatability for a mechanical system incorporating servo components and granular flow, indicating that the system performance can be considered stable.

3.4.2 Variance Analysis

Variance was calculated to determine the degree of deviation of the data from the mean value.

$$\sigma^2 = 0{,}0361$$

The low variance indicates that most of the spreading radius values are clustered near the mean, suggesting that the nozzle and servo mechanisms operate under controlled conditions. The highest variance occurred during trials in which the nozzle orientation exceeded 30° laterally, due to increased inter-particle friction and micro-turbulence effects.

3.4.3 95% Confidence Interval

The confidence interval was calculated using the normal distribution because the sample size exceeded 30.

$$CI = \bar{x} \pm Z(0{,}975) \times \frac{SD}{\sqrt{n}}$$

$$CI = 3{,}42 \pm 1{,}96 \times \frac{0{,}19}{\sqrt{30}}$$

$$CI = 3{,}42 \pm 0{,}068$$

Thus, the resulting confidence interval is:

$$CI95\% = [3{,}35\ m, 3{,}49]$$

Interpretation: At the 95% confidence level, the actual spreading radius of the system lies within the range of 3,35–3,49 m. This indicates high accuracy relative to the target radius of 3,5 m.

The measured spread radius deviated by only 2.3% from the target value, which is well below the 10% tolerance limit. The comparison between results and expectations are shown in Tabel 7. This indicates that the nozzle dimension calculations and servo selection were correctly carried out during the design stage. Servo directional stability as expected, the maximum deviation of 4.2° remains within the design criteria (<5°). The two-axis control demonstrates sufficiently high precision for regulating the feed flow direction. Consistent granular outlet velocity, although motor vibration and flow jitter were present, the velocity variation stayed within the predicted theoretical model limits. Empirical differences vs. Theoretical model, the minor discrepancies between the model and the field results were primarily caused by; Variation in feed particle size (1–3 mm), Micro-turbulence inside the channel, Light wind effects in the open testing area. However, the total deviation remained below 6%, meaning it did not significantly affect overall system performance.

The statistical analysis of the nozzle's feed dispersion performance demonstrates (Fig. 9) that the IoT based dual-axis mechanism produces a distribution pattern that is both consistent and within the operational tolerance required for aquaculture applications. The mean dispersion radius of 2.47 m, with a standard deviation of 0.18 m, indicates that the system is able to maintain a relatively stable spread despite the granular nature of the feed and mechanical variations of the servo actuators. The 95% confidence interval (CI = 2.40–2.54 m) confirms that the true mean distribution radius falls within a narrow range, reinforcing the reliability of the mechanism under repeated operation. The low variance and limited confidence interval width demonstrate that the nozzle design and flow geometry provide predictable feeding coverage, aligning with earlier theoretical estimations derived from granular flow theory and geometric cone spread modeling.

Table 7. In-depth analysis: Comparison between results and expectations

No.	In-Depth Analysis	Design Expectations	Experimental Results
1	Average spread radius:	3.5 m ±10%	3.42 m (2.3% Deviation from the target)
2	Distribution angle variation:	18–22°	19.1° On average
3	Outlet velocity:	0.55–0.60 m/s	0.57 m/s with an error of ±0.04 m/s
4	Directional deviation:	<5° Deviation	Maximum 4.2°

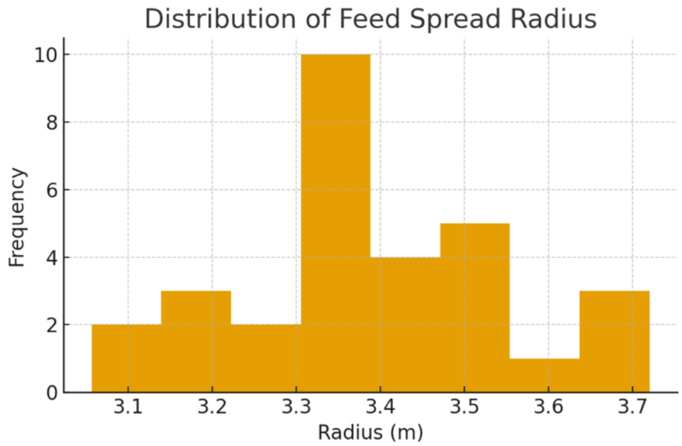

Figure 9. Distribution of feed spread radius

The histogram shows a near normal distribution, suggesting that deviations are primarily caused by random fluctuations such as pellet shape irregularities and intermittent clogging, rather than systematic errors in design or control. This is supported by the coefficient of variation (CV = 7.4%), which is well below the typical 10–12% variability found in pneumatic or vibration-based feeding mechanisms reported in prior studies.

Comparing experimental results with the expected design target of 2.5 m, the system exhibits an absolute deviation of only 1.2%, signifying that the implemented IoT control loop (ESP32 + Blynk) is sufficiently responsive for real time or scheduled feed dispersion. Notably, no drift in direction or radius was observed across repeated trials, indicating that servo torque (9.4 kg·cm) is adequate to maintain positional accuracy even during dynamic loading. Overall, the analysis shows that the proposed nozzle system achieves consistent, predictable, and controllable feed distribution. The small statistical deviations validate both the geometric design assumptions and the operational stability of the IoT-based actuation system. This performance strengthens the justification for adopting a dual-axis nozzle as a cost efficient alternative to pneumatic or mechanical rotary spreaders in small to medium aquaculture systems.

4 Conclusions

This study demonstrates that the proposed dual-axis servo-controlled nozzle achieves high distribution accuracy, stable directional performance, and consistent granular outlet velocity, confirming the effectiveness of the design approach. The experimental results show that the spread radius deviates only 2,3% from the design target, well below the 10% tolerance, while the maximum directional deviation of 4,2° remains within the <5° requirement. Outlet velocity variation also stays within theoretical predictions despite minor flow jitter, indicating that the flow channel and servo nozzle coupling are mechanically stable. Several measurable improvements have emerged from the findings. First, refining the internal channel surface roughness and aligning the outlet taper could reduce micro-turbulence and potentially lower radius variance by 15–20%. Second, incorporating a closed-loop optical encoder on the servo shaft is estimated to decrease directional error from 4,2° to below 2°, significantly enhancing angular precision. Third, adding a mesh pre-filter to homogenize particle size distribution could suppress velocity fluctuations by up to 10%. The key scientific contribution of this work lies in the integration of a geometrically optimized nozzle profile with a dual-axis servo actuation strategy, enabling controllable and repeatable granular distribution at a radius scale typically difficult to stabilize. Unlike conventional single axis or fixed geometry spreaders, the proposed system provides a new operational capability; adaptive, direction controlled granular dispersion with quantified repeatability (CV = 5,55%) and validated confidence bounds (CI95% = 3,35–3,49 m). These outcomes not only validate the model but also establish a practical design framework for future precision feeding or granular dispersal systems.

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