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PangaVax: A computer vision–based automated vaccination system for Pangasius fingerlings

Nguyen Phuc Truong [1, 2], Luong Vinh Quoc Danh [1, *], Nguyen Thanh Tung [1] and Nguyen Chanh Nghiem [1]

[1] *College of Engineering, Can Tho University, Can Tho City, Vietnam.*
[2] *Faculty of Electrical and Electronic Engineering, Vinh Long University of Technology Education, Vinh Long, Vietnam.*

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Abstract

Pangasius is a key freshwater aquaculture product in the Mekong Delta, Vietnam, with the country accounting for over 90% of the global supply of frozen Pangasius fillets. Vaccination of Pangasius fingerlings is an effective approach to promoting sustainable aquaculture by preventing infectious diseases, reducing antibiotic use, and improving survival, product quality, and profitability. However, vaccination is currently performed manually, resulting in low productivity and high labor demand. In contrast, automated injection offers higher throughput, lower stress, and faster recovery, leading to superior physiological outcomes in fish. Therefore, accurate automated vaccination for Pangasius fingerlings is urgently needed. This paper presents PangaVax, the first automated vaccination system for Pangasius fingerlings. The proposed system integrates computer vision and mechatronic control to enable accurate, size-adaptive vaccine injection. Experimental results demonstrate a throughput of up to 3,600 fish per hour with an average accuracy of 99.59%. Furthermore, the use of open-source, low-cost components enhances practical feasibility and enables broader deployment in commercial hatcheries.

Keywords: Computer vision; Injection; Pangasius; Vaccination

1. Introduction

Pangasius is one of the major freshwater aquaculture products in the Mekong Delta, Vietnam, generating approximately USD 2 billion in export revenue in 2024, while accounting for more than 90% of the global supply of frozen Pangasius fillets [1]. During the grow-out phase from fingerlings to market-size fish, the mortality rate ranges from 30% to 50% [2]. This mortality is primarily attributed to three factors: disease (bacterial and parasitic), water quality degradation (pollution and low dissolved oxygen), and suboptimal management practices (poor-quality fingerlings, excessive stocking density, and inadequate feed) [3]. Therefore, vaccination of Pangasius fingerlings is considered an effective solution to prevent infectious bacterial diseases, reduce antibiotic usage, improve survival rate and product quality, and enhance farmers' profitability, thereby promoting sustainable aquaculture practices [4]. Despite the significant benefits of vaccination, the vaccination rate of Pangasius fingerlings remains low (approximately 6%) due to several factors, including limited availability of high-quality vaccines, financial constraints, and technical limitations in vaccine administration [5].

Currently, fish vaccination is performed manually, resulting in low productivity and high labor demand. Moreover, vaccine injection in Pangasius fingerlings is particularly challenging due to their small size and morphological variability, which hinder consistent and accurate injection. The large number of fish requiring vaccination compels well-trained operators to work at high intensity for extended periods, leading to physical fatigue and reduced injection accuracy and efficiency. Consequently, improper injection may damage internal organs and increase post-injection

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[*] Corresponding author: Luong Vinh Quoc Danh

mortality, thereby limiting the scalability and efficiency of vaccination in commercial hatcheries. In contrast, automated injection offers higher throughput, induces lower stress and enables faster recovery than manual injection, demonstrating superior physiological outcomes in fish [6]. Therefore, there is an urgent need to develop an automated system for accurate vaccination of Pangasius fingerlings.

Motivated by these limitations, this paper proposes, for the first time, the design and implementation of an automated vaccination system for Pangasius fingerlings, termed PangaVax. The proposed system integrates a computer vision–based approach with mechatronic control to enable accurate and size-adaptive vaccine injection.

This study makes the following key contributions:

- Introduces a computer vision–based method for accurate determination of the vaccine injection position in Pangasius fingerlings.
- Presents the first experimentally validated automated vaccination system for Pangasius fingerlings.
- Provides a low-cost, automated vaccination solution for aquaculture farms using open-source software and commercial off-the-shelf hardware.

2. Related Works

Several companies have developed automatic vaccination machines for round fish, which are commonly used to vaccinate farmed salmon in Nordic countries. The NFT series of automated vaccination systems [7], developed by Pharmaq Fishteq, are designed for salmon, rainbow trout, and seabass, with a throughput of 8,500–17,000 fish per hour, depending on the system configuration. In addition, Maskon AS also offers the Skala Maskon VX series of automated vaccination systems [8], specifically designed for salmon, with a throughput of 10,000–40,000 fish per hour depending on the model. These systems employ computer vision techniques to estimate the appropriate injection position for round fish. The equipment is primarily designed for salmon and features a high level of automation; however, its high cost and complex structure and operation limit its adoption in small and medium-scale fish farms. In addition, researchers in South Korea have developed an automated vaccination system specifically for flatfish based on a computer vision–based algorithm for fish shape analysis, with a throughput of up to 2,800 fish per hour [9]. In China, the authors in [10] introduced an automatic injection device for grass carp having a throughput of 900 fish per hour. Recently, with the advancement of artificial intelligence algorithms, deep learning–based methods have been applied to estimate injection positions for turbot and grass carp [11],[12]. However, these systems are primarily designed for salmon, spindle-shaped fish, and flatfish, and are not directly applicable to Pangasius due to its distinct morphology, characterized by an elongated, laterally compressed body, scaleless mucus-covered skin, a high dorsal fin with a rigid spine, and pectoral fins with sharp spines. In addition, deep learning–based approaches require substantial computational resources, limiting their use in cost-sensitive aquaculture settings. Therefore, a low-cost automated vaccination system for Pangasius fingerlings is needed to enable broader deployment in aquaculture farms.

3. Methodology

3.1. Architecture of the Proposed Vaccination System

Fig. 1 illustrates the structural layout of the proposed automated vaccination system. The system comprises six main components: imaging chamber, conveyor belt, fish chute, fish holder, injection controller, and image processor. Fig. 2 shows the interconnection diagram of the system components. A Basler acA1300-200uc 1.3-megapixel camera [13] is installed in the imaging chamber to capture images of fish moving along the conveyor belt. The images captured by the camera are transmitted to the image processor, a Raspberry Pi 4 kit [14], via a USB 3.0 interface for subsequent processing. The fish on the conveyor belt are then conveyed to the fish chute and guided toward the fish holder. In parallel, the image processor transmits the coordinates of the vaccine injection point to the injection controller via a serial UART interface. Upon detecting a fish at the fish holder, the injection controller drives the vaccine needle to the predetermined injection site for vaccination. The system adopts a modular architecture, which enables easy disassembly for convenient transportation to fish farms.

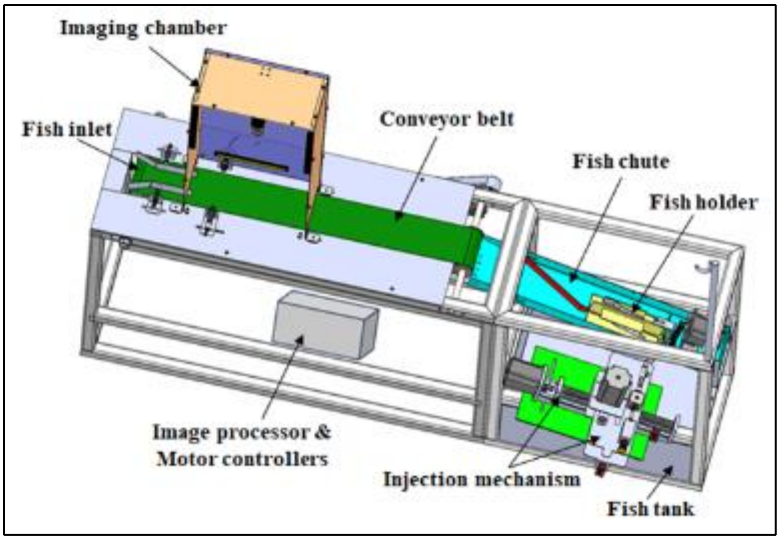

Figure 1 Configuration of the automated vaccination system for Pangasius fingerlings

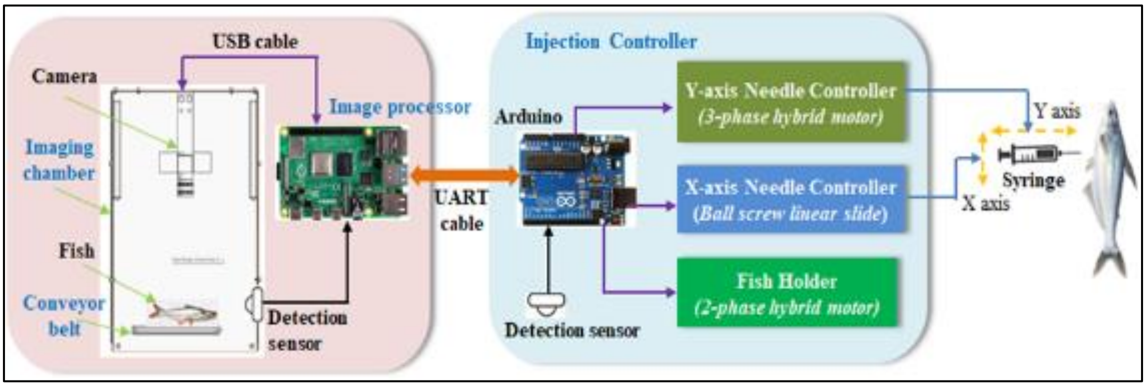

Figure 2 Interconnection diagram of the components in the automated vaccination system

3.2. Operating Principle of the System

Fig. 3 shows the operational flow of a single vaccination cycle of the proposed system. First, the anesthetized fish are fed into the system via the conveyor belt. As the fish move along the conveyor, they pass a detection sensor. Once a fish is detected, the sensor signals the image processor to trigger the camera to capture and store the fish image. Next, the image processor retrieves the stored fish image and processes it to determine the vaccine injection position. The injection coordinates are then transmitted to the injection controller, which actuates the needle to the designated position to perform vaccination and subsequently releases the fish into the fish tank.

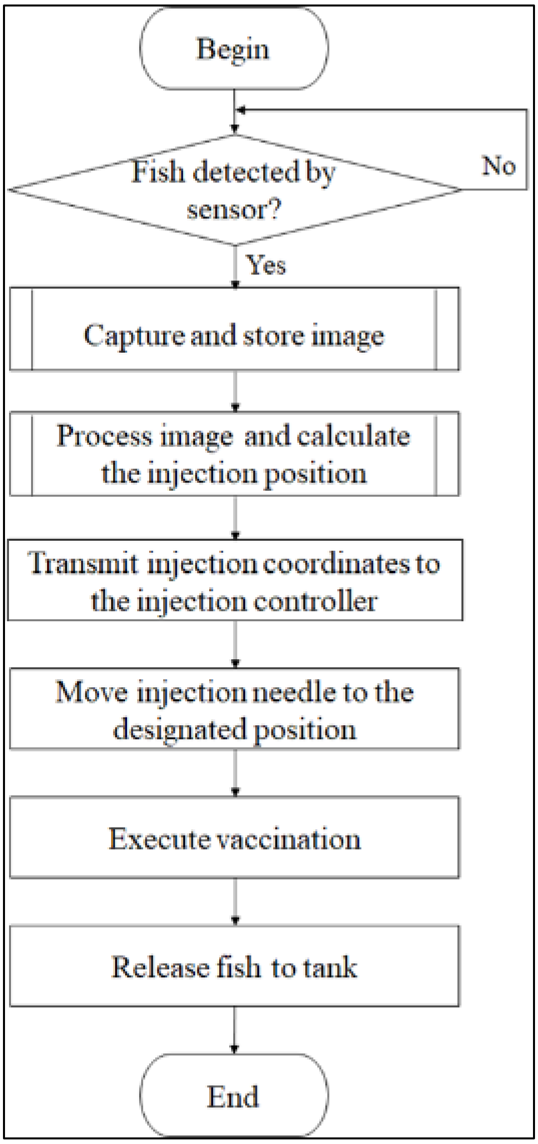

Figure 3 Flowchart of a single vaccination cycle

3.3. Vision-Based Injection Site Determination

According to the technical guidelines for Pangasius vaccination, the optimal injection site is located at 0.5÷0.75 of the pelvic length, anterior to the base of the pelvic fin [15]. Accordingly, the needle insertion position is defined as point P, as illustrated in Fig. 4. The distance from the fish head tip to the injection point P, referred to as L_3, can be determined as follows [16]:

$$L_3 = L_1 - 0.625 * L_2 \qquad (1)$$

Where,

L_1: the prepectoral length.

L_2: the pelvic length.

A computer vision–based method for automatically determining the vaccine injection point in Pangasius fingerlings was proposed by the authors [16]. The approach integrates OpenCV-based image processing with the statistical morphological characteristics of Pangasius fingerlings to estimate the injection site. The image-processing algorithms are developed using the Python programming language and implemented on the image processor. Fig. 5 summarizes the algorithm used to estimate the injection location. The procedure consists of five primary processing steps: convert image to grayscale one, convert image to binary one, extract the region of interest, find the position of fish's caudal peduncle, and estimate the vaccine injection point. The vaccine injection site on the fish P is defined by the distance from the fish head tip to P, denoted as $L_{injection}$, which is computed as follows [16]:

$$L_{injection} = 0.41 * (0.8907 * L + 6.975) \quad (2)$$

Here, L represents the distance from the snout to the caudal peduncle, which is computed using the image-processing algorithm. The value of L is transmitted to the injection controller to compute the coordinates of the vaccine injection point.

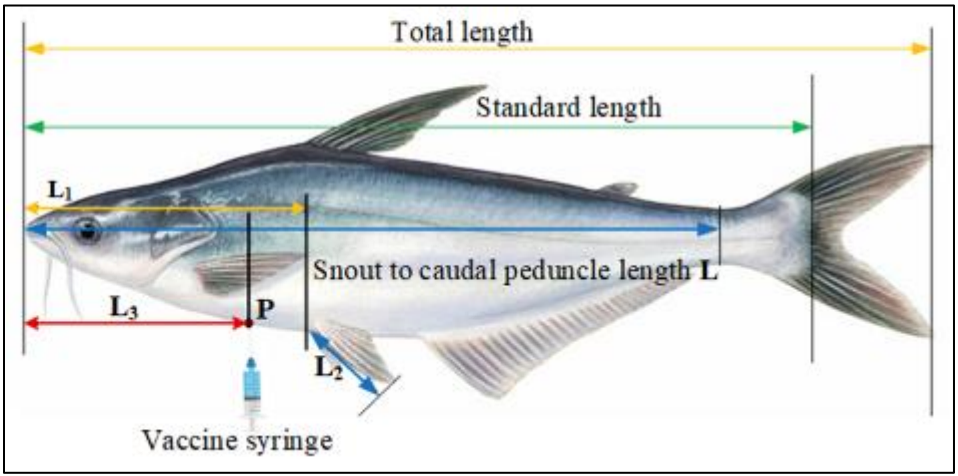

Figure 4 Vaccine injection site on the fish body [16]

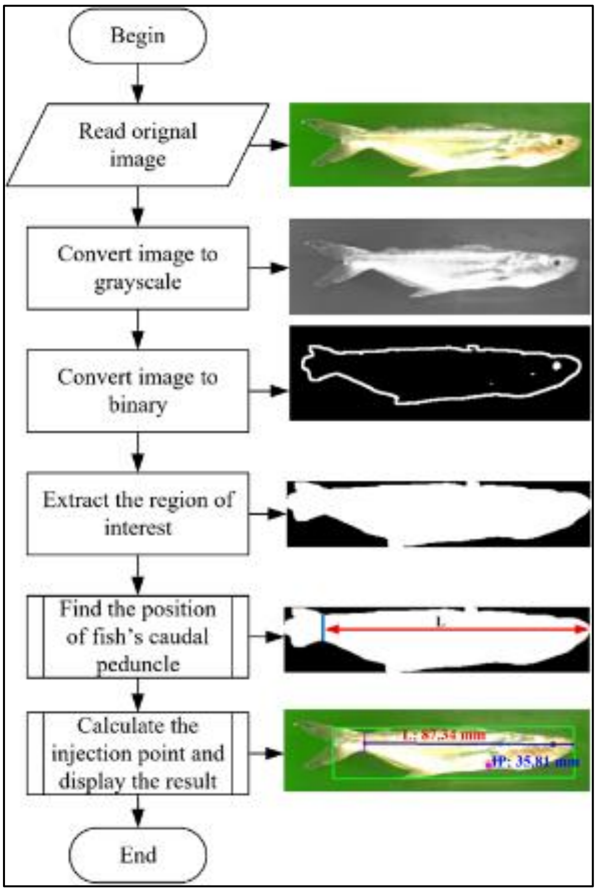

Figure 5 Image-processing algorithm flowchart for vaccine injection site estimation

3.4. Injection Controller Design

As shown in Fig. 2, the injection controller is responsible for controlling the movement of the vaccine needle to the injection site. This unit consists of six main components: an Arduino Mega 2560 kit [17], the X-axis needle controller, the Y-axis needle controller, self-refilling syringe [18], the fish holder, and the detection sensor. When the detection sensor (reflective optical sensor) detects the presence of a fish in the fish holder, the Arduino kit controls the movement of the vaccine injection needle via the needle controllers.

The X-axis needle controller, responsible for moving the vaccine needle in the horizontal direction, comprises a SGX-1605 ball screw linear slide [19], an HBS57 hybrid servo driver [20], and a three-phase hybrid servo motor 573HBM20 [21], as shown in Fig. 6. The ball screw linear slide has a shaft diameter of 16 mm and a thread pitch of 5 mm, with an accuracy of ±50 µm. The HBS57 driver provides a microstep resolution of 4000 pulses per revolution and operates at a control frequency of 39.6 kHz, achieving a linear speed of 49.5 mm/s. Fig. 7 presents the flowchart of the control algorithm for the X-axis needle controller. After receiving the injection position data from the image processor, the needle controller determines the injection location by comparing the received position data with the current position in order to determine the motor rotation direction. Subsequently, the injection control unit compares the difference between the received injection position data and the current position to calculate the travel distance required to move from the current position to the desired position. The number of pulses required to trigger the driver is determined based on the calculated travel distance, combined with the driver resolution and the thread pitch of the ball screw. Finally, the system checks the number of pulses generated. If the number of generated pulses reaches the calculated value, the pulse generation is stopped to halt the motor, and the system waits for the next injection position data.

The Y-axis needle controller drives and retracts the syringe during the vaccination process. It includes a driver and a motor similar to those of the X-axis needle controller, along with a cam mechanism, as depicted in Fig. 6. To ensure stable and accurate needle insertion, the driver and motor are programmed to operate at three speed levels, gradually increasing from 213.4 mm/s and 416.6 mm/s to 6,656.1 mm/s. After the injection is completed, the needle is retracted to its initial position at a constant speed of 213.4 mm/s and stops when it reaches the longitudinal limit sensor position. In addition, a push–pull electromagnetic actuator [22] is employed to control the syringe plunger, enabling the vaccine to be injected into the fish body. At the fish holder, a two-phase hybrid servo motor [23] is used to control the release of the fish into the fish tank after the vaccination process is completed.

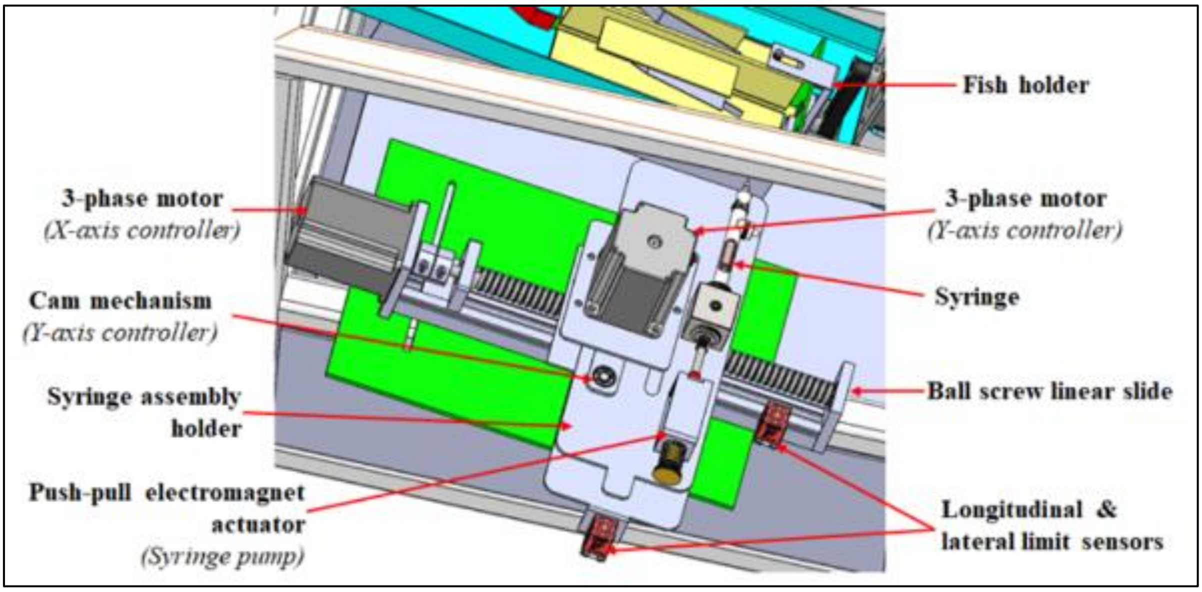

Figure 6 Structure of the injection needle position controllers

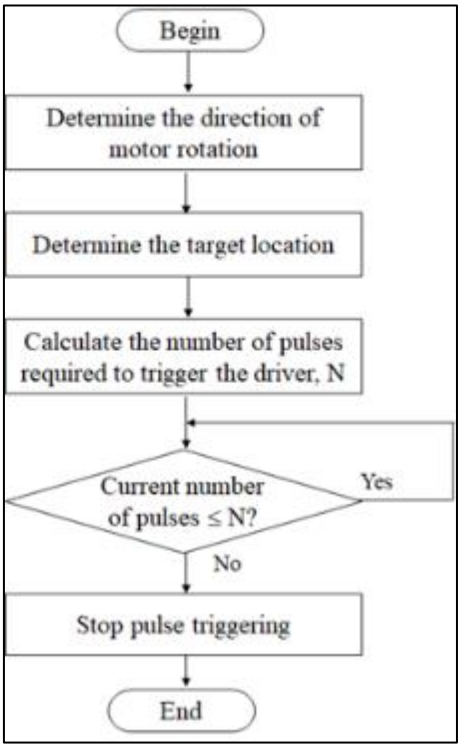

Figure 7 Flowchart of the control algorithm for the X-axis needle controller

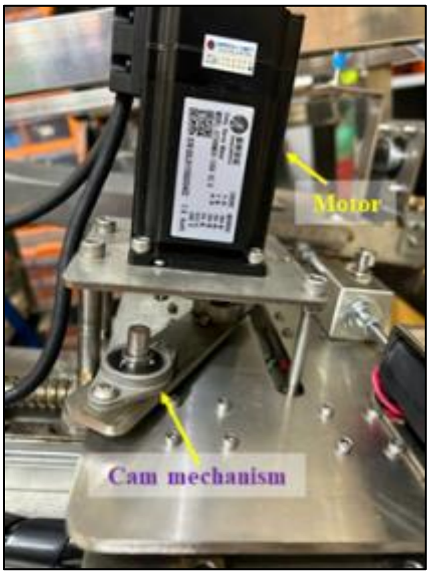

Figure 8 Photograph of the Y-axis needle controller

3.5. Design of the Vaccine Injection Control Algorithm

Fig. 9 illustrates the main control program flowchart of the injection controller. The needle controllers are first initialized by returning the needle to its initial home position. This helps prevent cases where the needle is in an incorrect position, which may lead to needle damage and incorrect determination of the injection position. After initialization, the injection controller enters a state ready to receive injection position data from the image processor via the UART communication interface. If the injection position data value is less than or equal to zero, this indicates that no injection data has been received. In addition, if injection position data is missing while a fish still enters the fish holder due to errors from the fish detection sensor in the imaging chamber or image processing errors, the system skips the injection process and releases the fish into the fish tank, as indicated in the 'fault detection' block in Fig. 9. When the injection position value is received, the X-axis needle controller moves the needle to the desired injection position and waits for confirmation from the fish detection sensor that the fish has reached the fish holder. When a fish is detected at the fish holder, the injection controller initiates the vaccination process, as illustrated in the flowchart in Fig. 10. Meanwhile, the injection controller receives the next fish injection data to prepare for the subsequent vaccination process.

Fig. 10 presents a vaccine injection cycle. When the injection position data are received, the injection controller compares the received data with the current position of the X-axis needle controller to adjust the needle to the desired injection position. When a fish is detected in the fish holder, the Y-axis needle controller advances the needle into the abdominal cavity of the fish. When the needle reaches the preset depth, the system activates the motor to push the syringe plunger, injecting the vaccine into the fish body. After the injection is completed, the Y-axis needle motor retracts the needle to its initial position. Subsequently, the fish holder releases the fish into the fish tank by controlling a two-phase hybrid servo motor. Subsequently, the fish holder releases the fish into the fish tank by controlling a two-phase hybrid servo motor. At this point, the vaccine injection cycle is completed, and the system waits for the next cycle.

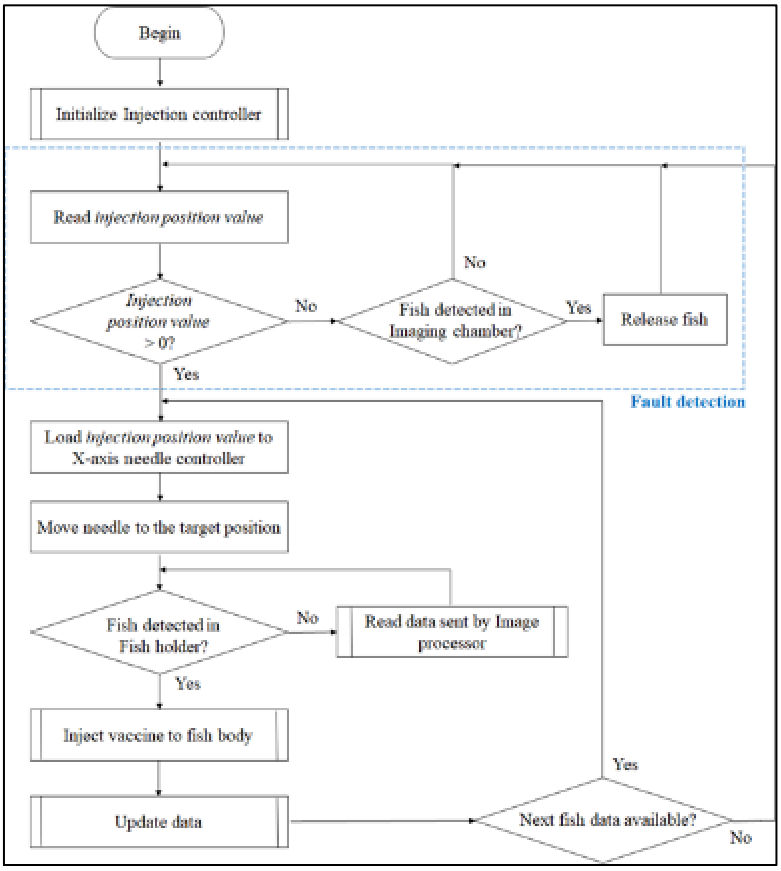

Figure 9 Control algorithm flowchart of the injection controller

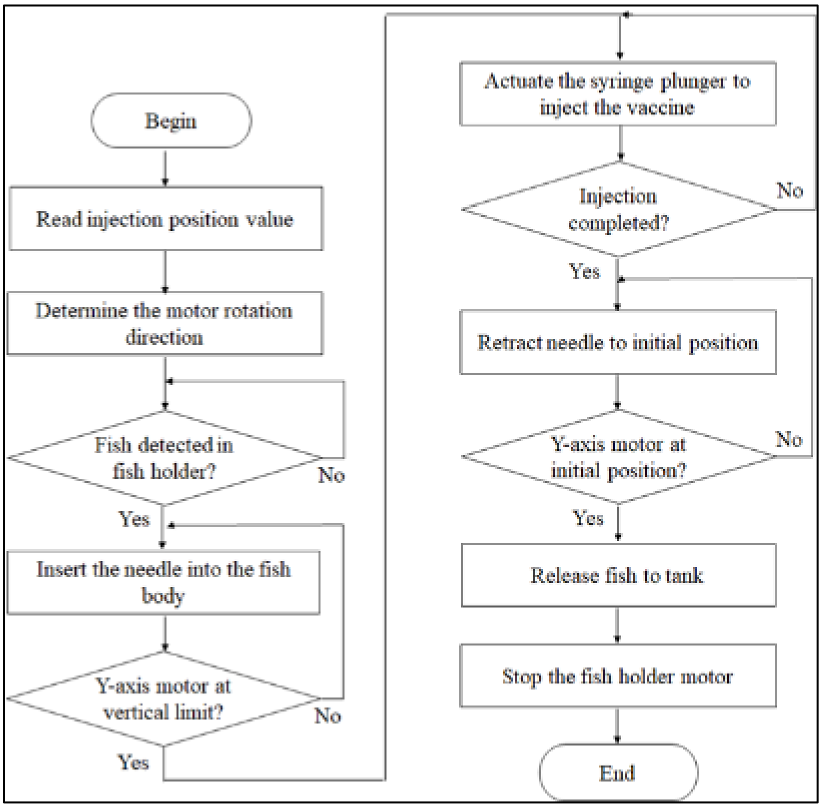

Figure 10 Control flowchart of a vaccine injection cycle

4. Experimental Results

A prototype of the automated vaccine injection system was designed and experimentally implemented, as shown in Fig. 11. The system frame is constructed from SUS304 stainless steel, ensuring reliable operation in humid environments. To verify the effectiveness and accuracy of the proposed method, 125 Pangasius fingerlings with weights ranging from 15.21 g to 51.35 g were purchased from a fish farm for validation. The fingerlings were reared in tanks and anesthetized prior to vaccination. Fig. 12 illustrates several images captured during the automatic fish vaccination process at four stages: manual placement of fish at the fish inlet, fish entering the imaging chamber, fish moving on the conveyor, and fish being injected with the vaccine.

Table 1 presents a comparison of the vaccine injection positions obtained using the automated injection method and manual measurements with a digital caliper. The experimental results show that the automated injection system achieves a minimum accuracy of 98.89% and an average accuracy of 99.59%. The results also indicate that the actual injection position deviates by 0–0.54 mm from the position determined using the image-based method, as shown in Fig. 13.

Table 1 Experimental Measurement Results

No.	Weight (g)	Calculated injection position (mm)	Actual injection position (mm)	Accuracy (%)	No.	Weight (g)	Calculated injection position (mm)	Actual injection position (mm)	Accuracy (%)
1	39.29	49.17	49.36	99.61	64	25.90	44.61	44.72	99.75
2	31.04	47.31	47.44	99.73	65	19.99	42.22	42.25	99.93
3	38.52	49.76	49.77	99.98	66	24.86	44.34	44.56	99.50
4	30.36	46.73	46.93	99.57	67	30.61	48.41	48.63	99.55

5	21.40	41.12	41.35	99.44	68	41.21	52.33	52.61	99.46
6	18.99	39.11	39.53	98.93	69	23.04	44.16	44.3	99.68
7	20.48	42.30	42.75	98.94	70	15.21	37.29	37.61	99.14
8	25.5	44.62	44.84	99.51	71	21.95	43.30	43.78	98.89
9	29.37	47.04	47.13	99.81	72	25.72	46.34	46.63	99.37
10	25.88	45.34	45.44	99.78	73	22.24	43.94	44.09	99.66
11	25.66	45.78	45.94	99.65	74	33.63	49.93	50.26	99.34
12	22.58	42.57	42.73	99.62	75	35.72	49.39	49.74	99.29
13	18.77	41.61	41.71	99.76	76	45.64	54.4	54.71	99.43
14	24.07	44.35	44.53	99.59	77	19.43	40.97	41.09	99.71
15	22.30	43.07	43.24	99.61	78	21.88	43.35	43.51	99.63
16	30.2	47.65	47.54	99.77	79	19.19	40.77	41.11	99.17
17	18.42	41.97	42.14	99.59	80	26.75	44.32	44.44	99.73
18	26.47	43.51	43.71	99.54	81	29.11	47.83	47.86	99.94
19	33.46	48.52	48.71	99.61	82	20.16	41.42	41.35	99.83
20	30.61	47.36	47.52	99.66	83	34.77	49.2	49.58	99.23
21	39.2	50.89	51.04	99.71	84	21.52	42.73	42.85	99.72
22	21.30	42.50	42.61	99.74	85	23.98	43.92	44.17	99.43
23	23.19	44.03	44.37	99.23	86	32.38	48.47	48.98	98.95
24	30.34	49.49	50.03	98.91	87	15.22	38.44	38.66	99.43
25	20.08	41.63	41.71	99.81	88	25.38	45.38	45.53	99.67
26	18.86	40.96	41.04	99.80	89	23.12	44.53	44.65	99.73
27	35.41	50.61	50.61	100.00	90	23.92	44.31	44.37	99.86
28	27.05	45.72	45.86	99.69	91	24.89	43.33	43.74	99.05
29	15.62	40.66	40.82	99.61	92	20.91	41.28	41.52	99.42
30	34.79	49.82	49.92	99.80	93	15.85	38.23	38.57	99.11
31	27.40	46.30	46.37	99.85	94	27.60	46.79	47.00	99.55
32	17.49	40.25	40.38	99.68	95	23.80	43.54	43.91	99.15
33	20.90	42.35	42.40	99.88	96	31.63	49.12	49.22	99.80
34	21.32	41.27	41.40	99.69	97	18.43	39.93	40.03	99.75
35	26.61	46.55	46.61	99.87	98	33.44	50.34	50.59	99.50
36	43.06	53.97	54.12	99.72	99	30.27	47.64	48.03	99.18
37	22.16	42.04	42.05	99.98	100	29.51	48.13	48.32	99.61
38	17.13	39.67	39.81	99.65	101	32.74	47.24	47.64	99.15
39	37.72	52.94	53.02	99.85	102	30.04	45.10	45.31	99.53
40	27.77	46.04	46.06	99.96	103	44.23	55.16	55.62	99.17
41	26.88	46.46	46.41	99.89	104	24.31	43.06	43.38	99.26
42	25.16	43.15	43.15	100.00	105	42.03	52.39	52.7	99.41

43	31.57	47.50	47.59	99.81	106	27.32	46.05	46.23	99.61
44	33.34	50.20	50.34	99.72	107	35.48	49.20	49.21	99.98
45	22.75	44.72	44.83	99.75	108	46.67	55.74	55.9	99.71
46	24.01	43.57	43.71	99.68	109	40.27	52.04	52.25	99.60
47	30.78	47.32	47.43	99.77	110	25.70	45.57	45.74	99.63
48	17.57	39.20	39.39	99.52	111	29.78	47.89	48.14	99.48
49	20.77	41.81	41.93	99.71	112	39.49	50.12	50.23	99.78
50	40.22	51.97	52.18	99.60	113	26.63	45.02	45.38	99.20
51	27.43	50.69	50.82	99.74	114	47.52	53.40	53.53	99.76
52	26.46	45.26	45.32	99.87	115	37.09	51.40	51.63	99.55
53	32.37	48.31	48.52	99.57	116	24.32	44.33	44.70	99.17
54	21.96	43.44	43.46	99.95	117	50.44	55.42	55.50	99.86
55	31.82	48.74	48.91	99.65	118	30.97	49.65	49.88	99.54
56	18.82	40.40	40.64	99.41	119	43.14	53.49	53.69	99.63
57	20.79	42.83	43.02	99.56	120	23.77	43.58	43.88	99.31
58	21.15	42.61	42.75	99.67	121	23.50	44.79	44.55	99.46
59	25.69	45.90	45.44	99.00	122	26.51	45.61	45.56	99.89
60	39.84	51.85	51.97	99.77	123	42.70	52.64	52.81	99.68
61	46.35	54.44	54.57	99.76	124	21.64	42.45	42.53	99.81
62	22.04	43.71	43.75	99.91	125	51.35	55.19	55.08	99.80
63	25.02	45.31	45.38	99.85					

The accuracy of injection position, and absolute error is computed as given in Eq. (3), and Eq. (4), respectively:

$$Accuracy\ (\%) = 100 - \frac{|Calculated - Measured|}{Measured} x100 \quad (3)$$

$$Abs.\ error\ (mm) = |\,Calculated - Measured| \quad (4)$$

Figure 11 Photograph of the designed vaccination system

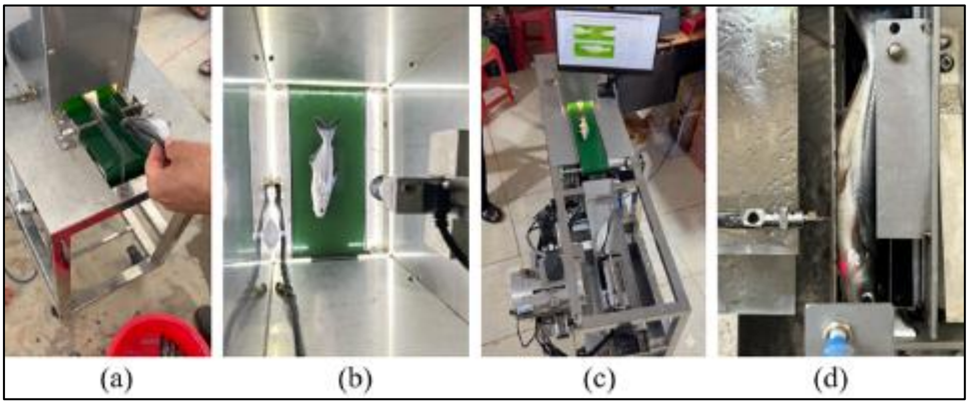

Figure 12 Representative images of the vaccine injection process: (a) Fish placed on the conveyor, (b) Inside the imaging chamber, (c) Fish on the conveyor, (d) Fish being injected with the vaccine at the fish holder

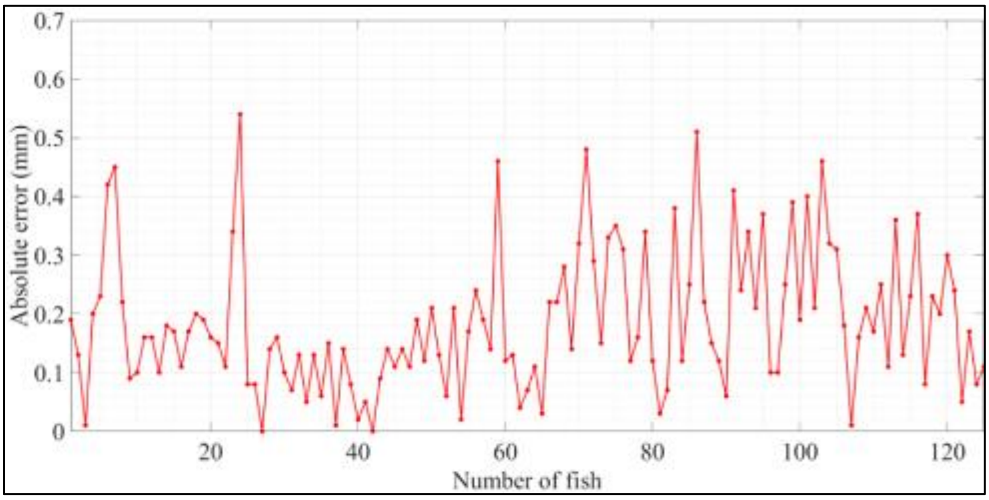

Figure 13 Absolute error between the actual and calculated injection positions

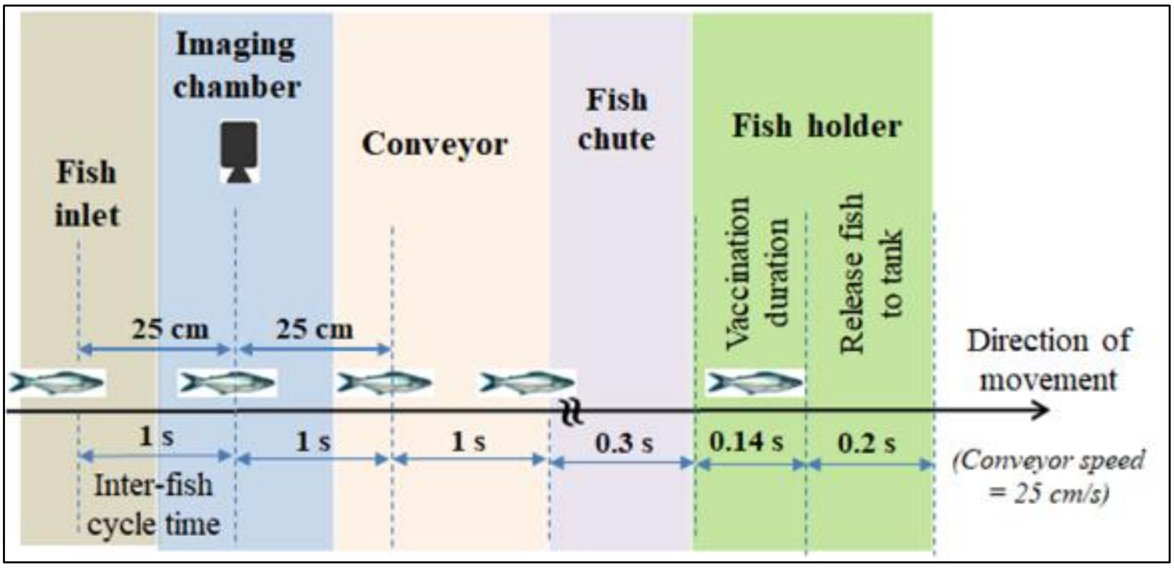

Figure 14 Processing time of the stages in the vaccine injection process.

Fig. 14 illustrates the average processing time of the stages in the fish vaccine injection process. Fish are fed onto the conveyor through the fish inlet at a rate of one fish per second. The conveyor is set to move at a speed of 25 cm/s. The average fish image processing time is 0.25 s. The average time for the fish to move from the end of the conveyor to the fish holder is 0.3 s. In parallel with the fish movement from the imaging chamber to the fish holder, the injection needle is controlled to move to the ready position for vaccine injection, which takes 0.4 s. Once the fish reaches the injection position at the fish holder, the vaccine injection process is completed in 0.14 s. Subsequently, the fish is released into the fish tank in about 0.2 s. Accordingly, the proposed automated vaccine injection system can achieve a vaccination throughput of 3,600 fish per hour. Although fish must be manually placed at the conveyor inlet, the subsequent process is fully automated and requires no additional human input. The automated system significantly enhances accuracy, stability, and vaccination rate compared with the manual injection, which achieves approximately 1,000 fish/h per operator [24].

5. Conclusion and Future Work

This paper presented PangaVax, a prototype of an automated vaccine injection system for Pangasius fingerlings that was designed and experimentally validated. To the best of our knowledge, this work represents the first computer-vision–based automated vaccination system developed for Pangasius fingerlings. The proposed system integrates computer vision and mechatronic control to accurately determine injection positions for fish of varying sizes and perform automated vaccination with an average accuracy of 99.59%. Experimental results demonstrate that the system is capable of achieving a vaccination throughput of up to 3,600 fish per hour, significantly improving the accuracy, stability, and productivity compared with the manual injection method. Moreover, the use of open-source Python software and widely available hardware platforms, including Raspberry Pi and Arduino kits, facilitates practical implementation. The automated vaccination system reduces labor costs and processing time while minimizing physical injuries and environmental stress, thereby improving post-injection survival rates. Future work will focus on fully automating the process of introducing fish into the vaccination system and further improving system robustness and throughput for large-scale applications.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there are no financial or non-financial conflicts of interest related to the research presented in this manuscript.

A Declaration on Generative AI

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References

[1] Vietnamnet Global. Vietnam’s pangasius industry eyes high-value transformation, https://vietnamnet.vn/en/vietnam-s-pangasius-industry-eyes-high-value-transformation-2421566.html.

[2] Nguyen Van Kien, “Commercial pangasius fish suffer losses of 30-50% during the farming period,”. Agriculture and Environment Newspaper, https://nongnghiepmoitruong.vn/ca-tra-thuong-pham-bi-hao-hut-toi-30--50-trong-giai-doan-nuoi-trong-d401670.html (in Vietnamese)

[3] Trong Nam, “”Reduce losses when raising Pangasius fingerlings,”. Vietnam Fisheries Magazine, https://bit.ly/4lBb45h (in Vietnamese)

[4] Sau Nghe, “The issue of vaccinating Pangasius fingerlings against diseases”. Tep Bac JSC., https://bit.ly/415aeUK (in Vietnamese)

[5] Sau Nghe, “Requirements and challenges in vaccinating Pangasius fingerlings”. Vietnam Fisheries Magazine, https://thuysanvietnam.com.vn/yeu-cau-va-vuong-mac-tiem-vaccine-ca-tra-giong/ (in Vietnamese).

[6] Cameron S Sharpe, “Physiological stress responses to automated and hand vaccine injection procedures in Yearling Coho salmon,” North American Journal of Aquaculture, Volume 69, Issue 2, April 2007, Pages 180–184, https://doi.org/10.1577/A06-004.1.

[7] Pharmaq Fishteq, "NFT20, NFT25, NFT30 Precision vaccination-Advancing care for fish," 2021, https://www.pharmaq.com/media/0lclhgr3/nft-brochure_2022.pdf.

[8] Maskon AS. "Maskon vaccination system-Revolutionizes and streamlines fish vaccination!" Maskon AS, https://maskon.no/en/produkt/vaccination/

[9] D.-G. Lee, Y.-S. Yang, and J.-G. Kang, "Conveyor belt automatic vaccine injection system (AVIS) for flatfish based on computer vision analysis of fish shape," Aquacultural Engineering, vol. 57, pp. 54-62, 2013/11/01/ 2013, doi: https://doi.org/10.1016/j.aquaeng.2013.08.004

[10] Yang Hong, Ye Zhu, Meng Yang, et al. “Design and experiment of continuous automatic injection device for grass carp vaccine,” [J]. Fishery Modernization, 2024, 51 (6): 2024-12-12. https://www.sciengine.com/doi/10.3969/j.issn.1007-9580.2024.06.002.

[11] Luo, W.; Li, C.; Wu, K.; Zhu, S.; Ye, Z.; Li, J. “A method for estimating the injection position of Turbot (Scophthalmus maximus) using semantic segmentation,”. Fishes 2022, 7, 385. https://doi.org/10.3390/ f ishes7060385

[12] Li, C., Danhassan, U.A., Luo, L. et al. “Design and research of a grass carp vaccination machine based on enhanced YOLOv8s,”. Aquacult Int 34, 24 (2026). https://doi.org/10.1007/s10499-025-02428-4

[13] Basler ace. acA1300-200uc. https://www.baslerweb.com/en/shop/aca1300-200uc/

[14] Raspberry Pi 4. https://www.raspberrypi.com/products/raspberry-pi-4-model-b/

[15] Pharmaq. Vaccine Package Insert. (2018). https://pharmaq-cdn-e9g8bdeng6hhcsee.z01.azurefd.net/media/njgph0sn/pil-ajpanga2-vn-v3-english.pdf

[16] Nguyen Phuc Truong, Luong Vinh Quoc Danh and Nguyen Chanh Nghiem. “A Computer Vision–Based Method for Determining the Vaccine Injection Position in Pangasius Fingerlings”. International Journal of Advanced Computer Science and Applications (IJACSA), 17.2 (2026). http://dx.doi.org/10.14569/IJACSA.2026.0170216

[17] Arduino Mega 2560. https://docs.arduino.cc/hardware/mega-2560/

[18] Socorex. Self-refilling syringes. https://socorex.com/images/Documents/VET/Catalogues/classic/Socorex_classic_Syringes_Catalogue_-_EN.pdf

[19] Handsontec. SFU1605 Ball Screw Kit, https://www.handsontec.com/dataspecs/linear%20motion/Ball%20Screw-Kit-1605.pdf

[20] Thunder Laser USA. HBS57 hybrid servo driver, https://support.thunderlaserusa.com/portal/en/kb/articles/leadshine-hbs57

[21] Thunder Laser USA Support. "Leadshine 573HBM20 Series EZ Servo". https://support.thunderlaserusa.com/portal/en/kb/articles/leadshine-573hbm20-series-ez-servo

[22] Dongguan Dason Electric. Push–pull electromagnetic actuator. https://www.dc-solenoid.com/sale-13805401-push-pull-single-holding-linear-electromagnetic-solenoid-actuator.html

[23] Bulk Man 3D. “57HSE2.2N 2.2N.M Stepper Motor with HBS57 Closed-loop Stepper Motor Driver”. https://bit.ly/4bma9SH

[24] Vietnam Fisheries Magazine. Vaccination procedure. https://thuysanvietnam.com.vn/quy-trinh-tiem-vaccine/ (in Vietnamese)