Development of a local unmanned aerial vehicle (UAV) pesticide sprayer for rice production system in the Philippines

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Abstract. Currently, commercially available UAV Pesticide Sprayers in the Philippines are very expensive. Therefore, this study aimed to develop a locally made automated UAV Pesticide Sprayer for rice production system that is much cheaper than the current price in the market. Moreover, the One-liter Capacity UAV Pesticide Sprayer has an autopilot flight control system allowing the pilot to fly the UAV without directly maneuvering the controls. Pixhawk 2 Cube and Arduino Uno were used as flight and spray controllers, respectively, while Mission Planner 1.3.68 was used as the UAV sprayer's ground control station. The result from the UAV sprayer's field performance test revealed that its effective field capacity was 750 m² per 10 minutes, and its application rate was 3.2 liters per 1,000 m² of the field. Meanwhile, it was observed that its battery's life was too short to cover at least a tenth of a hectare. Nonetheless, it was found that relative to the tank capacity and field capacity of the UAV Pesticide Sprayer, the one that was developed in this study was the cheapest, compared to the current price of UAV Sprayers in the market.

1. Introduction

Aerial robotics is one of the most anticipated research areas in agriculture today [1]. It is considered a breakthrough technology with very high potential in precision agriculture [2]. It has even attracted a great deal of scientific interest due to sensor electronics' advances and the emergence of fast and compact microcontrollers and lightweight high-capacity batteries [3]. Particularly, Unmanned Aerial Vehicles (UAVs) have become popular in the field of agriculture (i.e., seeding, spraying, and mapping) due to their high capability [4]. In pesticide spraying, the use of UAV is promising. It keeps the operators safe from possible crash accidents [5] and even protects them from direct exposure to pesticides [6], which is a major concern in agricultural practice [7]. However, despite its potential benefits, the current market price of UAV sprayers is quite expensive.

In the Philippines, the use of UAV sprayer is quite challenging. Aside from the fact that the country's level of mechanization is low, particularly in crop care and cultivation for rice and corn [8], the commercially available UAV Pesticide Sprayers in the country are very expensive. Thus, this study aimed to develop a local version of UAV Pesticide Sprayer for rice production systems, which is much cheaper than the commercially available ones.
2. Methodology

2.1. Design Concept

The schematic diagram shown in figure 1 generalizes the mechanism of the entire UAV Pesticide Sprayer system. The designed and assembled UAV Pesticide Sprayer has an autopilot flight control system, which allowed the pilot to fly the UAV without directly maneuvering the controls. Besides, Mission Planner 1.3.68 was used as the ground control station of the UAV sprayer. The UAV can be triggered to turn on/off, takeoff or land, change UAV’s flight mode (i.e., Autopilot, Position Hold, Altitude Hold), and return to launch turn on/off the sprayer's pump through the Radio Transceiver (Remote Control). Meanwhile, a liquid level sensor was installed on the pesticide sprayer assembly of the UAV to monitor the tank capacity. When the sensor detects during the spraying operation that the tank has no more fluid, it would automatically stop, and a buzzer would automatically make a long beep sound. The long beep sound serves as a signal to the operator to trigger the UAV Pesticide Sprayer to "return to launch" for a refill.

![Figure 1. The UAV Pesticide Sprayer’s Schematic Diagram showing how the sprayer is activated or inactivated.](image)

2.2. Field Performance Test

2.2.1. General Field Performance Test Parameters. The field performance test of the UAV Pesticide Sprayer was based on PAES 113:2000. However, in testing the swath, some modifications in the test method were done so it would be appropriate with the mechanism of the UAV sprayer. Meanwhile, a mission in the Mission Planner was prepared for each trial. The mission was set to 2.5 m/s forward speed, 3 m operating altitude, 5 m altitude during the takeoff and landing, 2 m spacing between lines (rows), and a working area that measures approximately 500 m². The mission was implemented three times with the UAV pesticide sprayer at full tank capacity. Subsequently, the following field performance test parameters were gathered: actual operating time, unproductive time (refilling time,
adjustment time, time to takeoff, travel time to the first waypoint, and time to return to launch), effective field capacity, effective working width, forward speed, and application rate of the UAV pesticide sprayer. Moreover, effective field capacity and application rate of the UAV Pesticide Sprayer were computed using the following formulae:

2.2.1.1. Effective Field Capacity (EFC). The UAV Pesticide Sprayer's actual capacity to cover a specific working area per total time (that it is committed to doing the field operation).

\[ EFC = \frac{SW \cdot E_{ff}}{t_e + t_u} \]  

Where EFC is the effective field capacity (ha/h), S is the UAV's forward speed, W is the swath, \( E_{ff} \) is the UAV’s field efficiency, A is the actual area covered (ha), \( t_e \) is the effective UAV sprayer operating time, performing its full width of action (h), \( t_u \) is the unproductive time including refilling time, adjustment time, takeoff time, travel time to first waypoint, and return time to launched point (h).

2.2.1.2. Application Rate (AR). The amount/volume of pesticide solution applied to a particular working area.

\[ AR = \frac{Q \cdot t_{actual}}{A} \]

Where AR is the application rate (L/ha), Q is the nozzle discharge (L/h), A is the actual area covered (ha), \( t_e \) is the effective UAV sprayer operating time, performing its full width of action (h).

2.2.2. Swath at Hover. The UAV Pesticide Sprayer’s swath was determined by hovering the UAV two meters above the dry concrete pavement (nozzle tip to ground). The UAV Pesticide Sprayer position was held, and the sprayer was turned on until the wetted area of the spray became visible on the concrete pavement. The longest diameter of the wetted area (the length perpendicular to the forward direction of the UAV Pesticide Sprayer) was recorded as swath. This method was done three times for validation.

2.2.3. Statistical Method for Data Analysis. Descriptive statistics was used in the analysis of data. Specifically, the standard deviation, z-score, and coefficient of variation were determined to test the dispersion and precision of the gathered data.

2.2.4. Software Development. The algorithm used to activate the spraying activity of the UAV Pesticide Sprayer is presented in figure 2. The algorithm determines when the user should start refilling the tank or turning off the pump and when the spraying would start or end. This algorithm was materialized using a liquid level sensor, a pump, and a radio transceiver (RC Controller). The algorithm was adopted during the laboratory and actual field testing of the UAV Pesticide Sprayer.

2.2.5. Simple Cost Analysis. The most commonly used and commercially available imported UAV Pesticide Sprayers in the Philippine market were compared to the developed local UAV Pesticide Sprayer. Each UAV sprayer's cost was scaled-down relative to its tank capacity and field capacity, respectively, to compare their costs. Moreover, the following assumptions and considerations were observed: (1) Other things being equal, only UAV Sprayer’s tank capacity and field capacity affect its cost, (2) UAV sprayer’s cost is proportional to its tank capacity and field capacity, (3) UAV Sprayers must have undergone AMTEC Test or have been used for research activities, and (4) Information about UAV Sprayer’s cost must be from an authorized distributor or the end-user.
3. Results and Discussion

3.2. General Specifications
The locally designed UAV Pesticide Sprayer (figure 3) has a dimension of 60 cm X 60 cm X 48 cm with props. It weighed 3.815 kg with no load and 4.875 kg with a load of one liter of fluid.
Figure 3. The locally developed Unmanned Aerial Vehicle (UAV) pesticide sprayer

The tank was designed for a one-liter capacity with a working pressure of 414 kPa. Furthermore, a single head single hole nozzle with a solid cone spray pattern was used.

3.3. Field Performance Test

3.3.1. Swath. The actual swath (swath when the propellers were working) was determined before the UAV pesticide sprayer was sent to do the spraying mission. Table 1 presents the obtained values of the different parameters used in the study. The average swath of 2.27 m was obtained as the UAV Pesticide Sprayer hovered 2.46 m above the ground. A minimal dispersion of data for the swath was observed as it only had a 1.17% coefficient of variation. Also, a wider swath was observed in the actual field test (2.27 m) in comparison to the swath obtained in the laboratory test (1.94 m). The propeller's air blown effect and the increase in altitude of the UAV sprayer while hovering during the test caused the spreading out of the spray as it hit the ground. Further investigation on this observation should be done to know the effect of the propeller's air blown on the swath of spray. Also, no extreme value in swath was observed during the test.

| Trial | Altitude (m) | Swath (m) |
|-------|-------------|-----------|
| 1     | 2.44        | 2.30 (1.13) |
| 2     | 2.49        | 2.26 (-0.38) |
| 3     | 2.46        | 2.25 (-0.76) |
| Average | 2.46     | 2.27    |
| CV    | -           | 1.17%    |

Note: Values in parentheses are the standard deviations of each data from the mean (z-score).

3.3.2. UAV Pesticide Sprayer Field Performance Test Results. In evaluating the UAV Pesticide Sprayer's field performance, the mission was prepared in the Mission Planner and was used in three flights. Each flight was considered a trial; hence, three trials were conducted for the actual field testing. Also, the actual sampling area was 527 m². This area was used to solve for the effective field capacity. The summary of the gathered data is presented in Table 2. In general, the UAV Pesticide Sprayer performed its spraying operation for 107.10 seconds (1 minute and 47.10 seconds).

Moreover, the UAV sprayer's computed effective field capacity was 0.45 ha/h or 750 m² per 10 minutes. The small value obtained for the effective field capacity was basically due to the battery's short life- it barely covered at least a tenth of a hectare. Perhaps, the option to use a battery with a higher milliAmp-hour (mAh) rating could help resolve the problem. However, replacing the current battery with a higher mAh-rating would mean additional weight to UAV's payload, thus resizing and re-
matching the corresponding UAV components, i.e., DC motors propellers. Further analysis and optimization of the UAV sprayer's battery will be conducted.

The decrease in speed was also assumed to affect the UAV sprayer's effective field capacity since field capacity is also a function of UAV's forward speed (see equation 1). The slightly unstable altitude of the UAV as it completed the mission was suspected of causing the fluctuation in UAV's forward speed. Nevertheless, the UAV sprayer's unstable altitude needs to be investigated further since the researchers hypothesized that the fluctuation was mainly due to the gradually decreasing payload of the drone as it sprayed out the fluid inside the tank and the excessive vibration of the DC pump used. The calibration of the flight controller's barometer might also be a contributor; however, it was assumed that the flight controller used was in good condition, and its sensors are working well since it was new.

Furthermore, a huge dispersion of data was observed in the recorded actual operating time of the UAV Pesticide Sprayer. During the second trial of the sprayer, the UAV Pesticide Sprayer was interrupted during its mission because the pump stopped spraying due to loosened wires. The sprayer was then triggered to "Return to Launch" to fix the loosened connections. After then, the UAV sprayer was resumed to its last waypoint (the point where it last sprayed). However, due to human error, the UAV sprayer was resumed to a different waypoint. Instead of resuming the mission at point 25, the mission was resumed at point 35 (the mission had 45 overall waypoints). As a result, two rows were missed, and the operating time of the UAV sprayer was shortened. Despite this error, the mission was still considered a trial since the two important parameters to compute the UAV sprayer's effective field capacity were attained – the Covered Area and Total Time (productive time and unproductive time).

Table 2. Field performance test result based on PAES 113:2000.

| Particulars                  | Test Number | Average |           |
|-----------------------------|-------------|---------|-----------|
|                             | 1           | 2       | 3         |            |
| Actual operating time, s    | 100.49      | 77.72   | 143.10    | 107.10 (30.99%) |
| Unproductive time, s        | 334.62      | 329.03  | 290.64    | 318.10 (7.53%)  |
| Effective field capacity, ha/h | 0.44        | 0.47    | 0.44      | 0.45 (3.84%)    |
| Effective working width, m  | 2.27        | 2.27    | 2.27      | 2.27          |
| Forward speed, m/s          | 1.95        | 2.18    | 2.41      | 2.18 (10.51%)  |
| Application rate, L/ha      | 35.70       | 32.07   | 28.92     | 32.23 (10.52%) |

Note: Values in parentheses are the coefficient of variation of each parameter.

On the other hand, a similar error happened during the third trial except that the UAV sprayer was resumed to point 17 instead of point 27. Consequently, two rows overlapped, causing a longer operating time and extended covered area. Notwithstanding, the mission was considered since it would offset the missed rows' equivalent field capacity from the previous error. Subsequently, small variation was found in the effective field capacity, forward speed, and unproductive time of the sprayer. Meanwhile, the UAV sprayer's application rate was 32.23 L/ha or 3.2 L per 1,000 m².

3.3.3. Simple Cost Analysis. Table 3 shows the costs of the different UAV Pesticide Sprayer models from foreign manufacturers and the cost of the locally developed UAV Pesticide Sprayer. For this study's purpose, only the cost of each UAV Sprayer relative to its tank capacity and field capacity were determined to compare the cost of each unit and to know whether the developed UAV Pesticide Sprayer in the study is cheaper or not. AGILA Drone D10 and AGILA Drone M12 of Eagle Brothers were used as the basis for comparison on this study since only these UAV sprayers have undergone AMTEC (Agricultural Machinery Testing and Evaluation Center) Testing as of June 2020. AMTEC is the premiere and reference testing center of agricultural and fisheries machinery in the Philippines.
Moreover, DJI Agras MG-1 was also included since it has been used by the Philippine Rice Research Institute (PhilRice) and International Rice Research Institute (IRRI) in their research and extension activities [9]. The tabulated costs of commercialized UAV sprayers are their approximated values based on personal interviews with UAV sprayer operators/evaluators from AMTEC and IRRI and personal interviews with drone sprayer distributors in the country. After considering the above-mentioned factors and assumptions, the result showed that as the UAV Pesticide Sprayers work with the same tank capacity and field capacity, the locally developed is the cheapest among the drone sprayers being compared.

Table 3. Cost analysis for the local UAV Pesticide Sprayer versus imported UAV Sprayer models.

| Model                     | Tank Capacity (L) | Field Capacity (ha/hr) | Cost (PHP)     | Cost per Liter (Php/L) | Cost per ha/hr, (Php/ha/hr) |
|---------------------------|-------------------|------------------------|----------------|------------------------|-----------------------------|
| Local UAV Pesticide Sprayer | 1                 | 0.45                   | 63,143.64      | 63,143.64              | 140,319.20                   |
| DJI Agras MG-1            | 10                | 3.6                    | 1,000,000.00   | 100,000.00             | 277,777.78                   |
| AGILA Drone D10           | 10                | 4                      | 720,000.00     | 72,000.00              | 180,000.00                   |
| AGILA Drone M12           | 12                | 5                      | 980,000.00     | 98,000.00              | 196,000.00                   |

4. Summary and Conclusion

In summary, the UAV Pesticide Sprayer weighs 3.815 kg and has a one-liter tank capacity. The performance test results showed that the local UAV pesticide sprayer's computed effective field capacity was 750 m² per 10 minutes, and its application rate was 32.23 liters per hectare or 3.2 liters per 1,000 m² field. It was also found that relative to the tank capacity and field capacity of the UAV Pesticide Sprayer, the locally developed was the cheapest. Hence, the study's objective to develop a local and cheap version of UAV Pesticide Sprayer for rice production in the Philippines was achieved.

5. Recommendation

Further studies regarding the optimization of the UAV sprayer's design must be done to ensure its safety, durability, and reliability. Subsequently, cost analysis relative to UAV Pesticide Sprayer's other capabilities should be done.

References

[1] Mogili U M and Deepak B B V L 2018 Review on application of drone systems in precision agriculture. *Proc. Computer Science* (Elsevier) (133) 502–503

[2] Abdullahi H, Mahieddine F and Sheriff R 2015 Technology impact on agricultural productivity: A review of precision agriculture using unmanned aerial vehicles *Wireless and Satellite Systems 2015* (USA: Springer International Publishing) 388–400

[3] Boursianis A, Papadopoulou M, Diamantoulakis P, Liopa-Tsakalidi A, Barouchas P, Salahas G, Karagiannidis G, Wan S and Goudos S 2020 Internet of things (IoT) and agricultural unmanned aerial vehicles (UAVs) in smart farming: A comprehensive review *Internet of Things* 9 p 2

[4] Gaponov I and Razinkova A 2012 Quadcopter design and implementation as a multidisciplinary engineering course. *Proc. of IEEE Int. Conf. on Teaching, Assessment, and Learning for Engineering 2012* (USA: IEEE/Curan Associates, Inc.) p 1

[5] Kim J, Kim S, Ju C and Son H 2019 Unmanned aerial vehicles in agriculture: A review of perspective of platform, control, and applications *IEEE Access* 17 (105) 100-112

[6] Faical B, Freitas H, Gomes P, Mano L, Pessin G, De Carvalho A, Krishnamachari B and Ueyama J 2017 An adaptive approach for UAV-based pesticide spraying in dynamic environments *Computers and Electronics in Agriculture* 138 210-23

[7] Wang A, Han Y, Li X, Andaloro J, Chen P, Hoffmann W, Han X, Chen S and Lana Y 2020 Field evaluation of spray drift and environmental impact using an agricultural unmanned aerial vehicle (UAV) sprayer *Science of the Total Environment* 737 2
[8] Desale R, Chougule A, Choudhari M, Borhade V and Teli S 2019 Unmanned aerial vehicle for pesticides spraying. *Int. J. for Sci. and Adv. Rsch. in Tech.* 5 79-82

[9] Cao L, Cao C, Wang Y, Li X, Zhou Z, Li F, Yan X and Huang Q 2017 Visual determination of potential dermal and inhalation exposure using Allura Red as an environmentally friendly pesticide surrogate. *ACS Sustain. Chem. Eng.* 5 3882

[10] Suministrado D 2013 Status of agricultural mechanization in the philippines. *Reg. For. on Sus. Agr. Mech. in Asia and the Pacific* Quingdao, China

[11] Adriano L 2019 Autopilot agricultural drone sprayer tested in Ilocos Norte *Philippine News Agency* 14 March 2019

[12] Arcalas J 2019 PHL farms to take flight in the future as government supports drone use *BusinessMirror* 14 February 2019