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QR-Code Based Visual Servoing and Target Recognition to Improve Payload Release Accuracy in Air Delivery Missions using Fully Autonomous Quad-Copter UAV

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Abstract. Unmanned Aerial Vehicles (UAVs) are increasingly utilized for package delivery due to their efficiency and automation capabilities. UAVs can execute autonomous flight missions using Global Positioning System (GPS)-based navigation. However, challenges arise in the final stage of delivery, known as the last-mile delivery problem. The limitations of GPS-based navigation, the absence of recipient authentication, and shifting drop-off points create reliability and safety concerns. External factors such as varied environmental topography further contribute to delivery inaccuracies, highlighting the need for a more precise approach.
Purpose: Many studies have explored UAV navigation and delivery systems, but challenges in last-mile delivery remain unresolved. This research introduces an improved UAV delivery system using computer vision (CV) and image-based visual servoing (IBVS) with QR Codes as location markers. The aim is to enhance UAV navigation accuracy and recipient verification, ensuring more reliable package deliveries.
Methods/Study design/approach: The study implements a CV-based navigation system where QR Codes serve as landing markers for UAVs. Image processing is conducted using a companion computer linked to the UAV's flight control system. The IBVS method enables UAVs to adjust their position in real-time, minimizing GPS errors. Recipient verification is performed through QR Code scanning before releasing the package. The system is tested through computer simulations and real flight experiments to assess accuracy and effectiveness.
Result/Findings: Experimental results demonstrate that UAVs equipped with the IBVS method can successfully complete package delivery missions with improved accuracy. GPS errors are corrected by aligning the UAV's position with QR Code markers, and recipient authentication is verified before package release. Real-flight tests confirm that this approach significantly enhances UAV delivery reliability compared to conventional GPS-based navigation.
Novelty/Originality/Value: This research presents a novel integration of computer vision and UAV navigation for addressing last-mile delivery challenges. By leveraging IBVS and QR Code-based authentication, UAVs can perform fully autonomous, precise, and secure package deliveries. This method offers a viable solution to improve UAV-based logistics, reducing delivery errors and enhancing operational safety.

Keywords: Computer Vision (CV), Image Based Visual Servoing (IBVS), Delivery Drones.
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INTRODUCTION

The increasing demand for logistics delivery to fulfill personal needs and trading activities post-Covid-19 pandemic has spurred rapid growth in digital transactions, becoming a lifestyle in the modern era. The logistics industry has certainly been a positively impacted element due to the growth of the digital economy in Indonesia. Amid the Covid-19 pandemic, the logistics industry grew by 40% due to circumstances requiring people to transact digitally and utilize logistics expedition services for their needs [1]. The opportunity for future development of UAV parcel delivery is wide open due to the convincing trend of increasing market revenue in logistics. In 2020, the Indonesian logistics market recorded revenue of USD 220.9 billion and is projected to continue growing to USD 300.3 billion by 2024 [2].

Unmanned Aerial Vehicles (UAVs) also known as drones are unmanned flying vehicles capable of full autonomous flight or partially controlled by operators on the ground for specific purposes. According to a survey conducted by Boysen, et al. [3], parcel delivery via UAV is one convincing option for direct delivery

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to customers in the future. Various commercial delivery companies in the United States are currently developing aerial parcel delivery programs using UAVs, such as Amazon [4], DHL [5], Google [6], and UPS [7]. One of the challenging tasks for UAVs in aerial delivery missions is their reliability in navigation, especially the accuracy of payload release at the destination location. The Global Positioning System (GPS) is one of the most widely used technologies for navigation on land, sea, or air. However, the high error rate and low consistency of consumer-grade GPS make GPS-based navigation for such missions quite dangerous to implement in real-life scenarios [8].

Generally, UAVs have several basic navigation sensors for flight, consisting of an Inertia Measuring Unit (IMU), which is a combination of accelerometers and gyroscopes to obtain attitude information, and GPS to report the UAV's position through coordinates on the Earth's surface based on satellites. This navigation system is referred to as the active navigation approach [9, 10]. However, the combination of these two sensors has weaknesses that can affect UAV performance. The IMU sensor can easily be disturbed by vibrations occurring on the UAV, resulting in unexpected shifts. On the other hand, GPS does not guarantee the accuracy of the positions it obtains because it depends on the number of satellites and the quality of signals which vary in different locations [11, 12].

Computer vision (CV) is one of the image processing methods that can be utilized to address this issue. CV can detect marker features present in images of the recipient's location through a camera. In addition to accommodating the limitations of GPS, CV can recognize the identity of the package recipient for verification purposes. Verified markers can be acquired and aligned with the UAV using Visual Servoing methods so that payload release can be accurately performed at the desired point. QR-Code Based Visual Servoing is a visual servoing method that uses QR-Codes as reference features in images used by UAVs to perform specific movements. This approach falls under the category of passive navigation where position estimation can be autonomously conducted through visual sensing [9].

Visual-based sensing methods play a crucial role in improving the accuracy of sensing that cannot be guaranteed by the combination of IMU and GPS [10]. Target recognition methods involving humans proposed by Safadinho, et al. [13] require heavy computation and necessitate the use of high-specification computers such as cloud computing. However, cloud computing methods require good response speed for the system to operate efficiently. In addition to serving as visual servoing reference markers, the use of QR-Codes in this mission can act as data storage that is complex yet requires low computational resources.

METHODS

This research will prioritize experimental approach and testing with the aim of obtaining a prototype that is ready for application. The research will focus on the development of UAV systems, implementation of computer vision on UAVs, and testing in non-restricted flying areas. Testing will be conducted on the functionality of control systems and computer vision applications without considering flight efficiency.

Hardware Design

The UAV design phase is carried out to obtain specifications that meet the research requirements. The developed UAV is a rotary-wing UAV with a 4-rotor configuration, also known as a Quadcopter, with a maximum airframe weight of 2 kg and a payload capacity of up to 500 g. This UAV falls into the Micro UAV category [14]. The weight and size of the UAV are adjusted in accordance with local regulations. In Indonesia, the UAV design is regulated by Permenhub No. 34 of 2021 concerning Civil Aviation Safety Regulation Part 22 on Airworthiness Standards for Remotely Piloted Aircraft Systems (the regulation governing the airworthiness standards for remotely piloted aircraft in Indonesia).

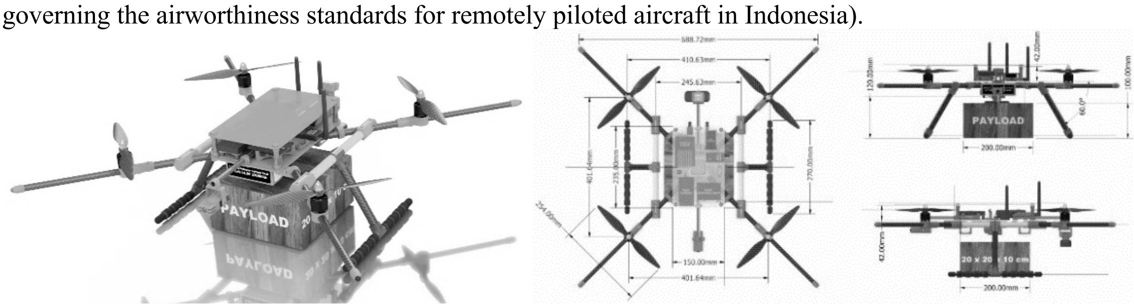

Figure 1. Design and dimensions

Figure 1 shows the UAV design. The UAV is designed with dimensions of length × width × height measuring 688.2 × 688.2 × 275.0 mm. Carbon fibre material is used as the main material to produce a rigid and lightweight airframe. Some parts such as joiners and electronic device mountings are fabricated using Fused Deposition Modelling (FDM). Polyethylene Terephthalate Glycol (PETG) will be used as the main material printed with a 3D printer. This material is chosen because it requires a relatively low forming temperature, is resistant to chemical changes, and is easy to fabricate with FDM compared to other materials [15].

Software Architecture
To support autonomous systems, integrated flight control is required to operate within the UAV system.

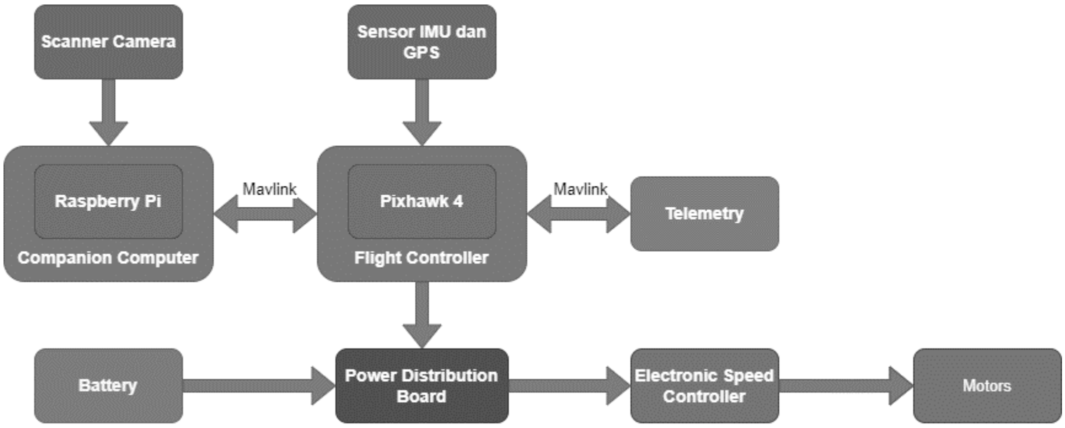

Figure 2. Software architecture

The diagram in Figure 2. illustrates the first computer, the FC Pixhawk4, which is responsible for handling flight control with an active navigation system. Essentially, an FC with Ardupilot software can effectively execute autonomous vehicle missions, but this system is limited to specific missions such as 3D mapping, crop spraying, search and rescue, underwater mapping, *etc,* and does not support the image processing that will be conducted in this research. To perform image processing, a second computer is added as a companion computer that shares tasks with the FC as the flight controller. The Mission Planner software provided by Ardupilot is no longer used for mission planning but only for monitoring and flight risk mitigation. The entire mission planning process up to flight is done automatically through the companion computer. With two computers installed on the UAV, it allows the UAV to continue executing autopilot-based GPS flight missions normally but with additional computer vision sensing features.

QR-Code
QR-Code (Quick Response Code) is a 2D matrix symbol code capable of storing data and can be quickly decoded [16]. QR-Codes have the advantage of being readable from all directions and can correct errors such as dirt or damage in certain parts and still be successfully decoded. Its ability to remain readable even when not fully intact allows QR-Codes to be applied in open areas with many external interference factors that can alter their shape. If widely developed, the use of QR-Codes as recipient address markers can also be utilized as navigation tools in areas with weak GPS signal coverage [17].

Figure 3. QR-Code

As can be seen in Figure 3, the QR-Code contains data consisting of an identification code ('id') and GPS location coordinates ('lat', 'lon') of the delivery destination. This data provides information to the UAV's autonomous system for flight execution and route determination. The identification code 'id' will be used during target verification before payload release.

Image Based Visual Servoing (IBVS)

In general, visual servo methods are divided into two techniques: PBVS and IBVS. PBVS involves estimating or reconstructing the 3D position of the UAV relative to the object and then applying motion control algorithms. In IBVS, features in the image are directly used to control the relative pose of the UAV with respect to the reference object [18]. The goal of all visual-based control methods is to minimize the error €, which is commonly defined in Equation 1.

$$e(t) = s[m(t), a] - s* \tag{1}$$

The IBVS scheme utilizes coordinates on the image plane from a set of points to define visual features (s). Image measurements (m) are expressed in the form of pixel coordinates. Measurements in pixel form require camera parameters (a) to define visual features. 3D points with coordinates x = (X, Y, Z) in the image are projected onto 2D points with coordinates $x = (x, y)$ as shown in Equation 2.

$$x = (x, y) \begin{cases} x = X/Z = (u - u_0)/p_x \\ y = Y/Z = (v - v_0)/p_y \end{cases} \tag{2}$$

Where $m = (u, v)$ represents the coordinates of the point in the image expressed in pixel form, and the set $a = (u_0, v_0, p_x, p_y)$ represents the camera parameters where u_0 and v_0 are the principal point coordinates, while p_x and p_y are the ratios between the focal length and pixel size.

Let's denote the spatial velocity of the camera as $v_c = (v_c, \omega_c)$, where v_c is the instantaneous linear velocity of the origin point in the frame and ω_c is the instantaneous angular velocity of the frame. The relationship between x, the time variation of feature $s = x$, and the camera velocity v_c is expressed by $s = L_x v_c$, where L_x is the interaction matrix is (see Equation 3).

$$L_x = \begin{bmatrix} -1/Z & 0 & x/Z & xy & -(1+x^2) & y \\ 0 & -1/Z & y/Z & 1+y^2 & -xy & -x \end{bmatrix} \tag{3}$$

Considering v_c as the control input for the UAV, to ensure exponential error reduction, we obtain $v_c = -\lambda L_x^+ e$.This method is implemented on the UAV using QR-Code as the reference feature in the image. The output value is a Pulse Width Modulation (PWM) signal sent to the flight controller to position the UAV directly above the QR-Code and ensure that the payload is released at the correct point.

Mission Algorithm

The execution of autonomous flight missions must be based on systematic mission algorithms. The autonomous mission algorithm is prepared in the form of an autonomous mission flowchart to facilitate software development and code writing. The autonomous mission flowchart can be seen in Figure 4.

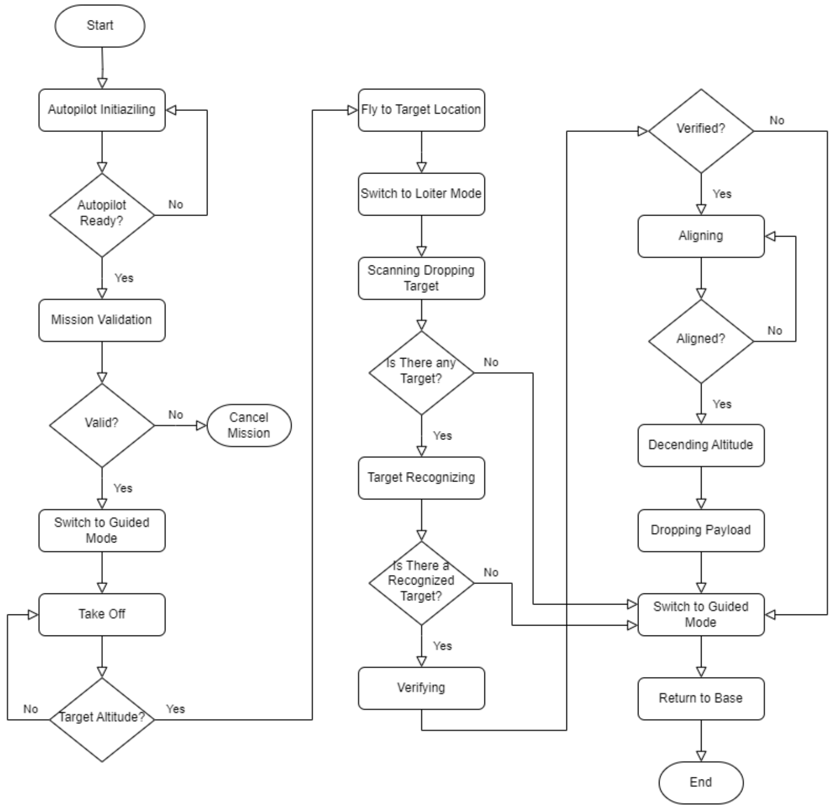

Figure 4. Mission Algorithm Flowchart

In broad terms, there are three main stages in the designed flight mission, including preparation, flight, and payload release. All mission stages are designed to run fully autonomously and do not require any human interference whatsoever. The biggest challenge is to develop application software that can efficiently handle any errors that may occur during the flight process. Here are some key points of the mission algorithm to be developed.

1. Pre-Flight
   During the preparation stage, the UAV will initiate the autopilot system and perform mission validation. Mission validation includes checking the availability of target location data, verifying coordinate validity, estimating distances, and ensuring the readiness of the autonomous system. If there are any errors or failures in the autonomous system, the entire mission will be canceled.
2. Flight
   After the preparation stage, the UAV determines the flight route towards the coordinates of the target location. Starting from the takeoff phase until reaching a certain altitude, it then flies towards the payload release location following the predetermined route guided by GPS.
3. Payload Release
   After reaching the target location, the UAV activates the computer vision system and scans the target area from the air. Once the target is detected, the computer vision system will recognize the object using a specific identifier contained within a QR-Code. If the target is deemed valid and has been verified, the UAV will descend in altitude to minimize external variables such as weather disturbances that could affect the accuracy of payload release. Once the target altitude is reached, the payload is released from the UAV's altitude, and the UAV flies back to the takeoff location or performs a Return to Launch (RTL) maneuver.

The autonomous mission algorithm is written in a software application program using the Python programming language.

RESULTS AND DISCUSSION

The Autonomous Payload Dropper Quad-Copter UAV which has been designed is implemented in the form of a prototype presented in Figure 5.

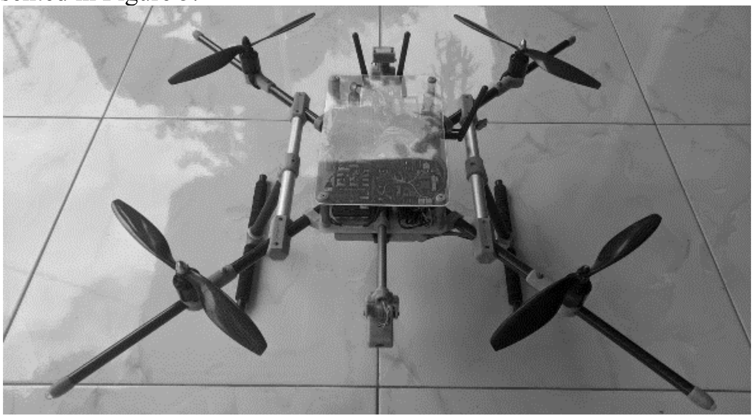

Figure 5. Autonomous Payload Dropper Quad-Copter UAV Prototype

The results of the Autonomous Quad-Copter UAV research include the UAV Airframe, Autonomous System, and Computer Vision application.

Target Acquisition

Assuming that more than one QR-Code will be detected from the altitude, during the target recognition stage, the application will record each detected QR-Code. The QR-Codes used in this research have a unique data format in the Python Dictionary data type, which is converted into String format. The QR-Code will be recognized if it meets the criteria, which are that the data available on the decoded QR-Code is in the form of a Dictionary data type with the id, lat, and lon data lines. Target recognition is carried out by the image processing application by obtaining visual images through the camera on the UAV. The results of target recognition can be seen in Figure 6.

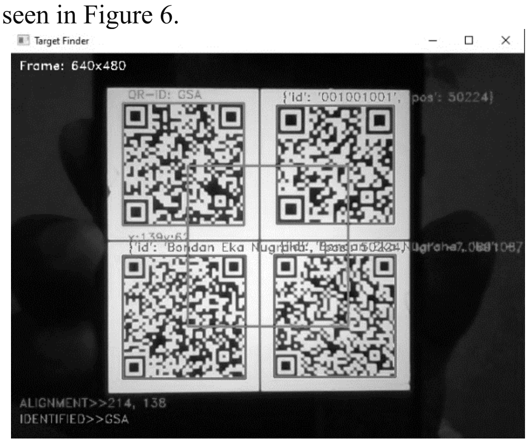

Figure 6. Target Acquisition

The "Target Finder" window displays features on the image obtained from the camera as well as the decoded data from each QR-Code feature available in the image. In addition to reading data from QR-Codes, this Computer Vision application will also recognize the location of QR-Codes relative to the UAV in the form of coordinates (x, y). The target verification stage ensures that the destination address is correct and matches the identity of the intended recipient. From the recognized QR-Code data, the application will ensure the data in the QR-Code matches the data that was previously initialized before the flight mission was conducted. Verified QR-Codes will be marked with a green square marker on the edge of the QR-Code (See Figure 6). The coordinates of the verified QR-Code location relative to the UAV in the visual image will be used in the alignment stage to improve the UAV's position relative to the QR-Code using visual servoing methods so that payload release can be done precisely.

Target Alignment

The limited landing area for the package and the varying environmental topography factors at each coordinate location point require the alignment process to be conducted.

Figure 7. UAV Position Alignment

Before releasing the payload, the UAV is aligned with the verified target QR-Code using visual servoing methods.

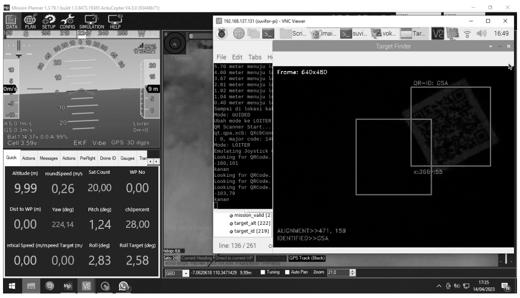

Figure 8. Ground Control Station

Figure 8 presents the Ground Control Station (GCS) screen displaying the Mission Planner application as the GCS software. Next to it is a live streaming screen from the on-board companion computer, showing the image processing application for control and mission flight control.

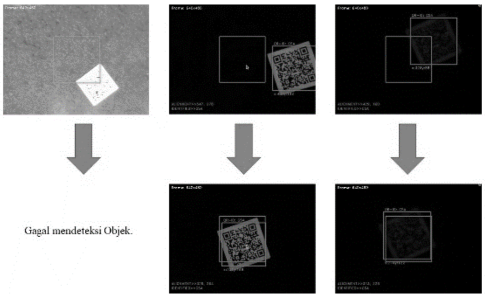

Figure 9. Visual servoing alignment

Figure 9 displays the results of tests 2, 3, and 4 sequentially. The UAV aligns with the verified QR-Code according to the designed algorithm and adjusts its position relative to the QR-Code to achieve accurate payload release at the target. In the second experiment, the UAV failed to detect the QR-Code marker due to overly bright lighting conditions. This occurred because the camera used did not have good light adjustment capabilities. In the third experiment, an ND16 lens filter was added to reduce the light intensity entering the camera sensor without altering the image color. In the third and fourth tests, the UAV successfully aligned with the QR-Code and accurately released the payload at the marker point. The graph of UAV position error correction relative to the payload release target is presented in Figure 10.

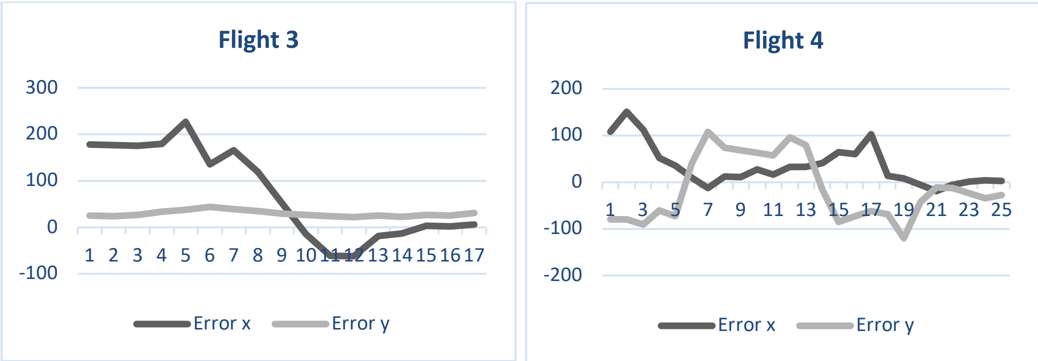

Figure 10. Error graph (e)

Figure 10. displays the flight data results of flights 3 and 4 visualized in the form of a line graph. Each graph shows two lines representing the error level on the x and y axis. These lines are obtained by connecting points of error levels arranged over time. The diagram represents the correction of UAV error points relative to the center point of the QR-Code in the image. Error on the x and y axis represents the difference (Δ) between the translated distances x and y relative to the reference point in the image. The closer the value is to 0, the UAV is defined to be closer to the payload release target.

CONCLUSION

The addition of computer vision capabilities to UAVs can significantly reduce the accuracy weaknesses of GPS in the final phase of air package delivery. The designed system can autonomously execute flight missions effectively and in accordance with the predefined mission algorithms. The QR-Code Based Visual Servoing method implemented through computer vision software application can effectively align the UAV with the target marker in the form of a QR-Code, enabling precise payload release on the target. The image processing program successfully decodes QR-Codes from a height of 15 meters above ground and verifies the data contained within. The application performs adequately during UAV flights. The results of this research indicate that the QR-Code Based Visual Servoing method offered can provide a solution to the last-mile delivery problem in UAV package delivery missions.

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