ICIC Express Letters
Part B: Applications
Volume **11**, Number **12**, December **2020**

ICIC International ©2020 ISSN 2185-2766
pp. 1125–1132

GNSS-BASED NAVIGATION SYSTEMS OF AUTONOMOUS DRONE FOR PESTICIDE SPRAYER IN AGRICULTURE

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Received March 2020; accepted June 2020

Abstract. *This paper presents the development of navigation systems of autonomous drone that uses a GNSS (Global Navigation Satellite System) and a compass as the main tools in drone as a pesticide Sprayer. The grand purpose of our research is to develop drones with implementation in smart farming in Indonesia. In the sending process, the drone must be able to detect objects and reach a goal position and go back safely using GNSS. We proposed the usage of course-over-ground information to help drone in doing autonomous navigation. In the experiment that we did, the average of positional deviation of landing position between the actual landing position and the desired landing position in the flight tests of flying from start to goal is 1.1125 meters and for the tests that use the algorithm which uses course-over-ground, the positional deviation has an average of 2.39 meters. Navigation using the course-over-ground algorithm is not more reliable than the navigation algorithm with GNSS and compass at a navigation distance of less than 1 meter.*

Keywords: Drone, GNSS, Navigation systems, Sprayer pesticide, ROS, Autonomous spraying drone

1. **Introduction.** Worldwide media and scientist attention have put Unmanned Aerial Vehicles (UAVs) in the spotlight. UAV or known as a drone is an unmanned aerial vehicle that has the main functions for intelligence, reconnaissance, and surveillance [4]. The recent developments of drone for sprayer pesticide applications are used for delivering items, for instance, the Amazon Prime Air, where Amazon used an octocopter to deliver items with weights less than 5 pounds or around 2.3 kilograms [5]. UAVs can be operated more economically than manned helicopters; they are less limited by weather conditions (although this varies by model) and easier to deploy. Deep learning is a fast-growing domain of machine learning, mainly for solving problems in computer vision. It is a class of machine learning algorithms that use a cascade of many layers of nonlinear processing. One of the implementations of deep learning is object localization and detection based on a video stream. Object localization and detection are crucial in computer vision. In this research, we use Erle Drone [6], and as the heart of our drone system, it uses Erle-Brain 3

DOI: 10.24507/icicelb.11.12.1125

hardware autopilot and the APM flight stack. Erle-Brain 3 consists of an Ubuntu Linux based embedded computer with full support for ROS (the Robot Operating System) and ROS 2.0 that integrated the sensors, camera, power electronics, and abstractions necessary to easily create autonomous vehicles.

The state of the art for this research has many approaches such as using a horizontal track to make the drone fly precisely by (Berner & Chojnacki, 2017) [15]. There is also another approach by using GPS navigation by pinpointing the coordinates and pre-programmed spray system by (Huang et al. 2015) [16]. The last one, there is an approach by using GPS and camera sensor to track the drone and distinguish the target crop from other plants (de Rijk et al. 2018) [17]. The result of this research proves that the positional deviation is below 1.2 meter. This research will become part of the beginning of drone research in Indonesia, as drone technology will play a major role in Society 5.0, and the eventual demands of drone fleet traffic control which deals with a large amount of data and came from multiple sources. The paper is organized as follows: We provide the problem statements in the introduction section that we answer with this paper in the proposed methods in Section 3. We provide experimental results and discussion in Section 4. We provide our conclusion in Section 5. Our prototype of a drone is shown in Figure 1.

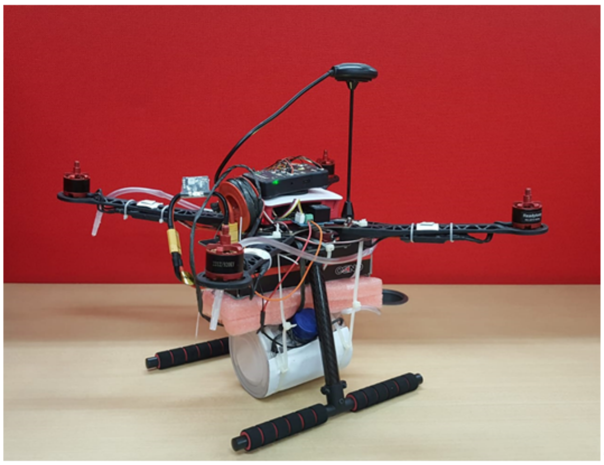

Figure 1. Our prototype of drone uses water pump and drone from Erle Robotics [6] based on the ROS for sprayer application. Erle-copter's flight time is around 20 minutes with a 5000 mAh battery, and the drone is built to support a payload of up to 1 kg.

2. Navigation System.

2.1. Geodetic coordinate system. A geodetic coordinate system is a coordinate system which a position is defined by 3 numbers, a latitude, longitude, and altitude. A position defined by a geodetic coordinate system is a position on a globe. Latitude is a line that intersects the defined position and a line which is parallel to an equator line. Longitude is a line that intersects the defined position and a line which is parallel to a prime meridian line. Altitude is a distance between a defined position and the ellipsoid reference [7] as described in Figure 2.

2.2. Body coordinate system. Body coordinate system is a coordinate system in which the origins of 3 axes (x, y and z) are the center of mass of the vehicle. In a NED (North, East, Down) system, x-axis points towards the head of the vehicle, y-axis points towards the right side of the vehicle, and z-axis points towards the downside of the vehicle [7]. Figure 2 describes the body coordinate system.

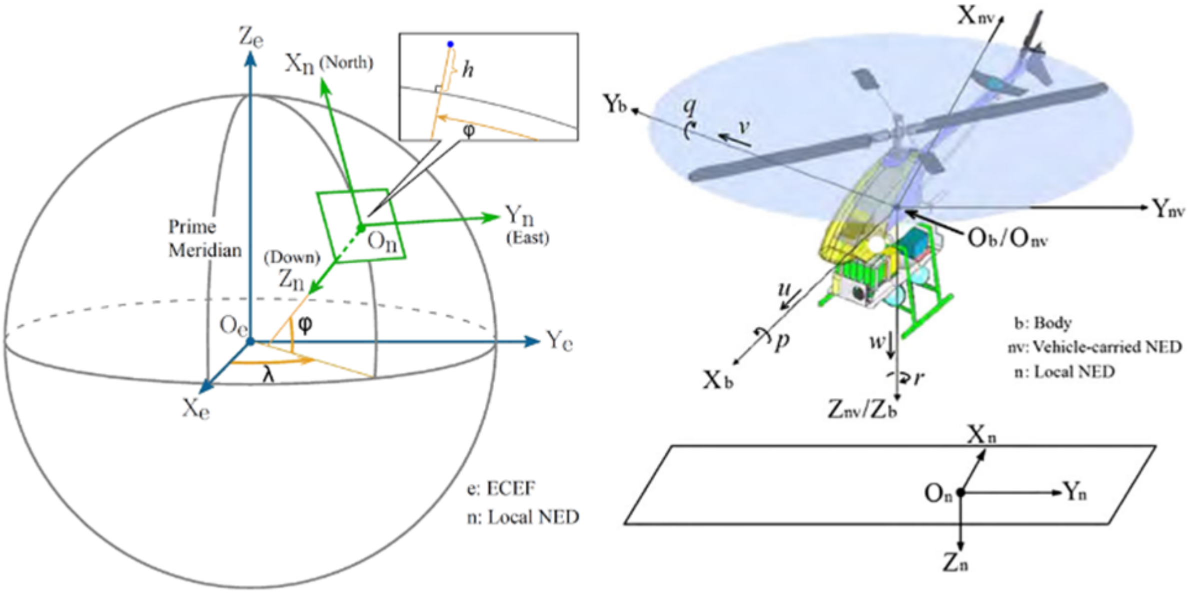

Figure 2. Geodetic coordinate system, expressed in *latitude* (φ), *longitude* (λ) and *altitude* (h) (left), and body coordinate system expressed in X_b, Y_b, Z_b (right) [7]

2.3. **Bearing.** Bearing is an angle between 2 geodetic coordinates. To find bearing a bearing between current position and destination position, the formula is stated below:

$$d_\lambda = p_\lambda^c - p_\lambda^d \tag{1}$$

$$X = \cos\left(p_\varphi^d\right)\sin(d_\lambda) \tag{2}$$

$$Y = \cos\left(p_\varphi^c\right)\sin\left(p_\varphi^d\right) - \sin\left(p_\varphi^c\right)\cos\left(p_\varphi^d\right)\cos(d_\lambda) \tag{3}$$

$$B = a\tan 2(X, Y) \tag{4}$$

where B denotes the bearing, p is a geodetic coordinate with superscript c denoting current geodetic coordinate, d denotes destination coordinate, the subscript λ denotes longitude, and subscript φ denotes latitude [8].

2.4. **Hubeny distance.** Hubeny distance is a formula to calculate the distance between a geodetic coordinate in an earth model. The formula is stated below:

$$\overline{p_\varphi} = \frac{\pi\left(p_\varphi^d + p_\varphi^c\right)}{180 * 2} \tag{5}$$

$$M = \frac{a\left(1 - s^2\right)}{\sqrt{\left(1 - s^2\sin\left(\overline{p_\varphi}\right)^2\right)^3}} \tag{6}$$

$$N = \frac{a}{\sqrt{1 - s^2\sin(p_\varphi)^2}} \tag{7}$$

$$d_\varphi = \frac{\pi\left(p_\varphi^c - p_\varphi^d\right)}{180} \tag{8}$$

$$d_\lambda = \frac{\pi\left(p_\lambda^c - p_\lambda^d\right)}{180} \tag{9}$$

$$d^{c,d} = \sqrt{(M d_\varphi)^2 + \left(N\cos\left(\overline{p_\varphi}\right)d_\lambda\right)^2} \tag{10}$$

where a denotes the major axis and s denotes eccentricity of the earth model. d with superscripts c, d denotes the distance between 2 different geodetic coordinates. A commonly used earth model is WGS84, which has major axis value 6378137, and eccentricity value 0.0818191908426215 [9].

3. Proposed Method.

3.1. System architecture. In our previous research, we use an object detection module that can detect what is in the video stream by using a combination of MobileNet and the Single Shot Detector (SSD) framework for fast and efficient deep learning-based methods to object detection [9]. We use Erle-Brain 3 which consists of a Linux based embedded computer and an autopilot shield that we design our system on. Inside the embedded computer, there is an ROS system and Autopilot Software installed. Research on the autonomous drone is using a drone that utilizes GPS/GNSS devices [13]. To get precise positional data, we need to collect a large amount of satellite data which is why we use GNSS and compass that could connect to more variations of satellites. The architecture of the drone is shown in Figure 3; we add a relay and a water pump to the output of the ROS system to make a drone as a sprayer pesticide system.

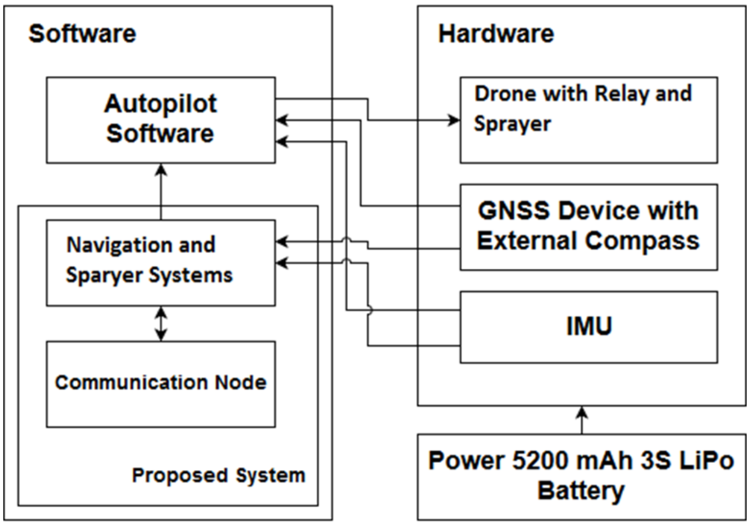

FIGURE 3. The architecture of the proposed system

3.2. Proposed system on ROS. ROS uses publisher and subscriber pattern as its design, every process that runs on ROS is doing publishing and subscribing towards other processes. These processes are called ROS nodes. As the Autopilot Software provides our system with filtered state of the drone, our system has to subscribe to the pool which provided such data. The pool is called an ROS topic. When the proposed system wants to command the drone to do the take-off sequence, the system would request the Autopilot Software to do the take-off sequence using an ROS service. The relationships between nodes in our proposed system are described in Figure 4.

3.3. Navigation algorithm. Our proposed system would plan a trajectory from the current location to the target location using bearing. The bearing value will be compared with the heading of the drone, as it will apply the velocity in a body coordinate system. The trajectory from start position to goal position described in the algorithm with "angle_fix" and "time_to_angle_fix" Booleans to provide system information whether the trajectory recalculation should be done. Moreover, the system will check the distance between the current coordinate and target coordinate iteratively. The system will slow down the velocity applied to the drone if the distance to the target is lower than 5 meters.

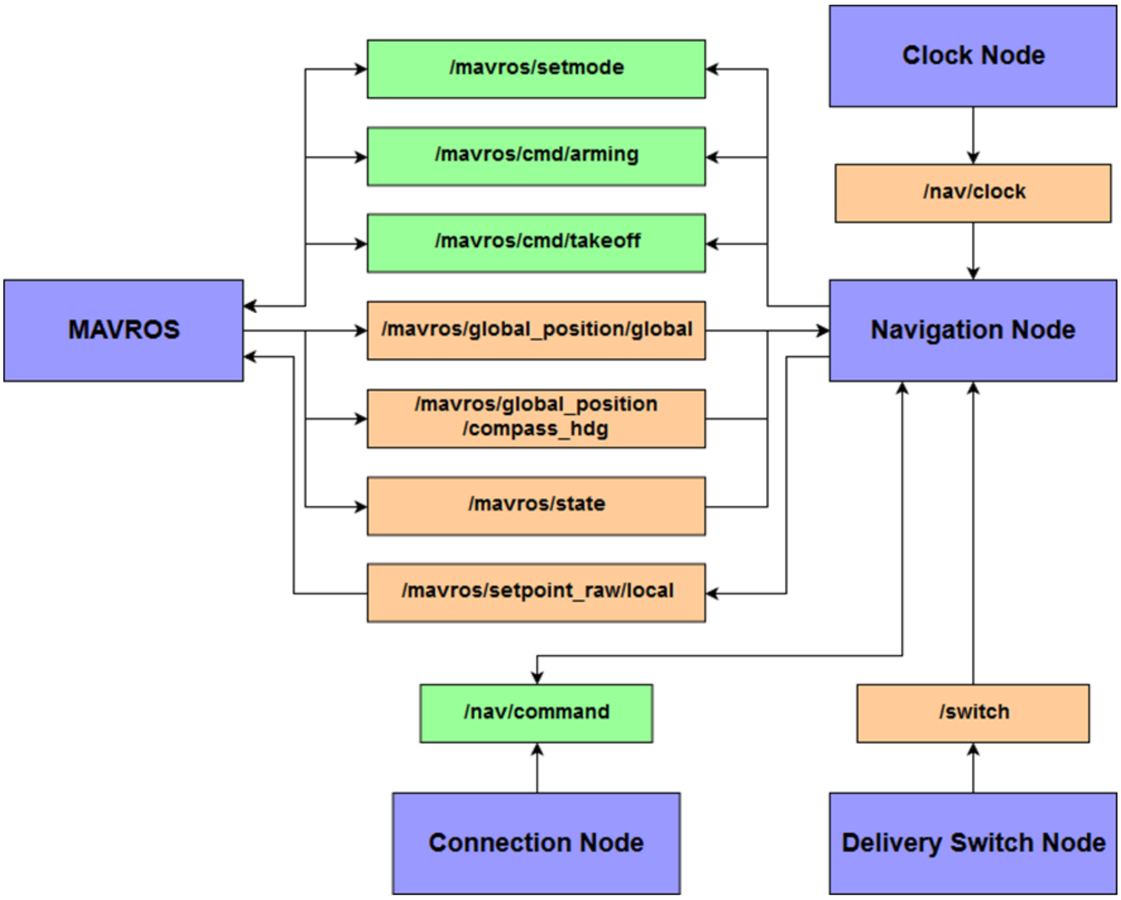

Figure 4. Relationships between ROS nodes in our proposed system

In our proposed system, the drone has to land if the distance to the target is lower than 0.5 meters. These iterative processes are run every time the information about the current position is acquired.

3.4. **Navigation algorithm using course-over-ground.** Aside from using only heading information from the IMU sensor, we proposed using course-over-ground information as another sensorial data that we could use to further refine the drone navigation. Course-over-ground is calculated using bearing between 2 recorded geodetic coordinates while drone flying in a specific trajectory created with the previous algorithm. To further refine the course-over-ground value, our proposed method uses position covariance provided by Autopilot Software which sent together with the current geodetic coordinate of the drone. We use Unscented Transform [9] to calculate bearing between 2 coordinates considering those 2 coordinates have covariances. The problem lies in position covariance provided by the Autopilot Software, which is in meters. This causes some disagreement in the convention to define the position of the drone. To fix this, we have to calculate the variance of the position back in degree form. To do this, we could use the Taylor approximation of the Hubeny distance to provide us the reverse function from meters to degree. If there are more than one course-over-ground data, we could use Kalman filter [11] to refine measurement.

To use course-over-ground, we could imagine the course-over-ground being the output trajectory of the current trajectory input created from the previous iteration of trajectory calculation. We calculate the new trajectory together with heading information. To do this, we use the Kalman gain concept [10,11] to fuse the two calculations into one trajectory input. We use unscented transform to calculate bearing between 2 coordinates considering those 2 coordinates have covariance [14].

4. **Experimental Result.** An experiment is conducted in the soccer field, Jakarta. Before we begin our experiment, first the drone needs to be powered in a level ground to let the Autopilot Software do a calibration. In our experiment, we let the device in the open until the value of dilution of precision hit 0.9 or visible satellites count reached a minimum of 10. After that, we execute the flying mission to the goal position using our proposed algorithm. For each algorithm, we run this test 4 times.

FIGURE 5. The start and goal position of the experiment

We conduct 4 times experiments for each algorithm with the parameter of distance about 26 meters. Autonomous navigation system using the GNSS module and compass succeeded in finishing a flight mission from a start position to goal position nicely and has a relatively small positional deviation. The proposed navigation algorithm still has weaknesses, for example, this algorithm is not good for short-distance navigation, so when the drone is near the goal position, the drone is having a bit of difficulty reaching the goal position perfectly. The result of the experiments is shown in Table 1, and the trajectories created from the recorded filtered position while doing the experiments are shown in Figure 6.

TABLE 1. Positional deviation from navigation algorithm (left) and positional deviation from navigation algorithm with course-over-ground (right)

Experiment-n	Positional deviation (m)
1	0.44
2	1.04
3	1.15
4	1.82
Average of error	1.1125

Experiment-n	Positional deviation (m)
1	2.5
2	4.46
3	2.2
4	0.4
Average of error	2.39

We also develop a mobile application to send the command consisting of a geodetic coordinate of the goal position, altitude, and speed of the drone. The application will connect to the drone via pre-determined IP and port and we can control the drone easily.

5. **Conclusions.** The drone for pesticide sprayer designed has an interface in the form of a mobile app that could be used easily. Moreover, the system could run separately from Ground Station, so with only a mobile app and the drone. The proposed navigation

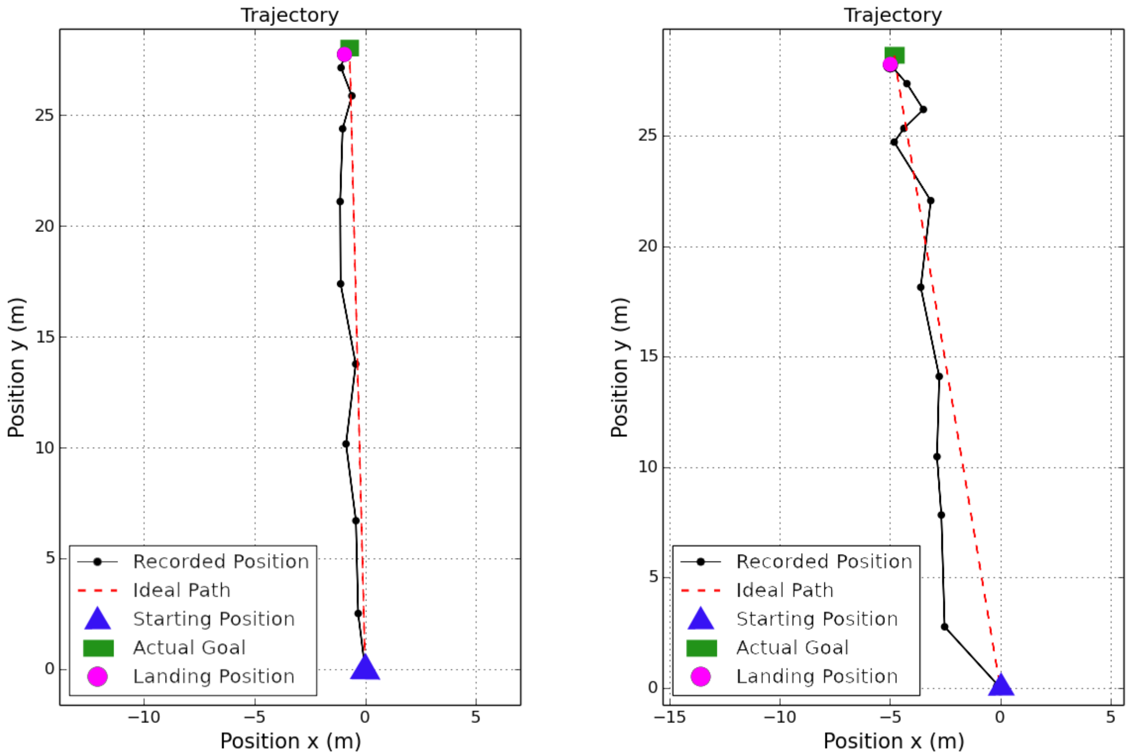

Figure 6. Drone navigation algorithm trajectory for sprayer pesticide from first experiment (left) and drone navigation algorithm with course-over-ground trajectory from first experiment (right)

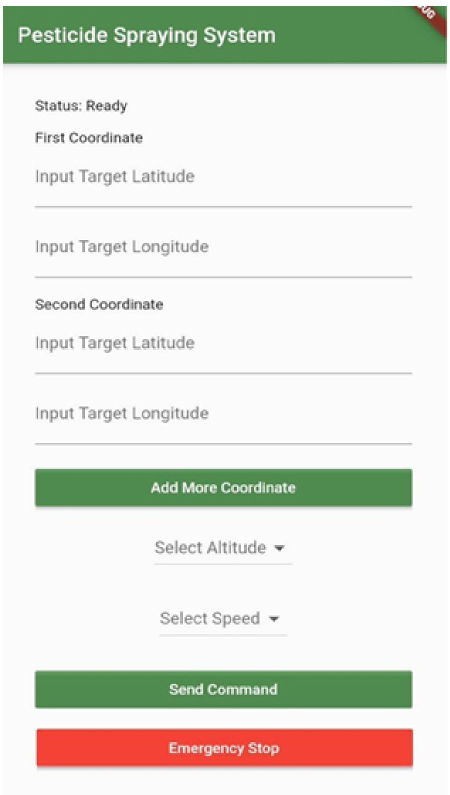

Figure 7. Mobile application

algorithm successfully makes our drone fly from the start position to goal position without a problem and have an acceptable deviation, with the mean of deviation in navigation algorithm without course-over-ground 1.1125 meters and 2.39 meters for the navigation algorithm using course-over-ground. Navigation using the course-over-ground algorithm is not more reliable than the navigation algorithm with GNSS and compass at a navigation distance of less than 1 meter. The navigational algorithm itself could be further enhanced and fixed using a more precise and adaptive algorithm that could navigate from any distance and for any usages.

Acknowledgment. This work is fully supported by Penelitian Unggulan BINUS (PUB) 2018 for third year by BINUS University.

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