

Towards The Development of a Smart Drone Police: Illustration in Traffic Speed Monitoring

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Abstract. Applications, such as, mapping, highway traffic monitoring and punishment (drone police), surveillance, rescues, precision agriculture, medical resupply missions, require a stable mobile platform for remote sensing. Sensing is an important component to prevent traffic congestion and traffic monitor to make decision. This paper studies a smart drone police based on a unmanned aerial vehicle (UAV): Illustration in traffic speed monitoring. The using of a UAV instead of static cameras/sensors provide some advantages, such as, its super flexibility, real-time operations, rich information and low cost. The experiment is performed on a lab-scale system to verify the effectiveness of the proposed methodology.

1. Introduction

Nowadays, with the rapid of population and the surge in vehicle ownership, the traffic supply and demand face with many problems including traffic congestion and traffic safety issues. To prevent these troubles, various traffic-monitoring devices are used, such as cameras, infrared monitor, vehicle induction loops. These devices can collect the information of vehicles' speed and the traffic flow. However, traffic inspection equipment are not able to have densely distribution. Consequently, the traffic information cannot always be provided. Unmanned aerial vehicles (UAVs) can be used as new monitor equipment to get better traffic information by using different imaging sensors. UAVs can capture images and videos to transmit real-time traffic information to a control station via a wireless system. The operation of UAV provides numerous advantages, for example, super flexibility, remarked efficiency, real-time operations, rich information and low cost. The reason is the UAV's capacity to observe wider areas compare to other fixed monitor equipment. It is able to cover 300 to 500 square meters at a height of 150 to 300 meters [1].

The speedy development of sensor technology and computer science have produced the better performance of UAVs. Information collection is a fundamental function of UAVs and has been extensively applied in autonomous navigation [2-4]; precision agriculture [5-8]; disaster monitoring [9], geological surveys [10], environmental monitoring [11], medicines delivery [12]. This paper



presents the first conceptual study for smart drone police using as a flying platform. The task of estimation the speed of a moving platform is used as a test case to illustrate the concept of smart remote sensing. In the context of this study, smart device is linked to autonomous ability and the independence to make decisions. Therefore, automatic detection of the mobile platform, precise position control to automatically estimate the speed of moving platform are some of the characteristics that make this a smart drone police. The proposed methodology in this research can applied to monitor and punish the car in the highway if the car over speed.

In this study, firstly, the dynamic of the quadrotor is investigated to obtain the transfer functions of pitch, roll, and yaw movements. Secondly, the localization of the drone is implemented based on IMU. Thirdly, the control algorithm is performed based on Frequency Response Toolbox (FRTool). Lastly, a development of detection and estimation of a moving platform for a smart drone police is executed.

The paper is structured as follows: The discussion on the characters of UAV system and its identification are presented in section 2. The localization of the drone is described in section 3. The controller design is introduced in section 4. Section 5 presents experiment setup and results. The final section summarizes the main contributions of this study and presents the future challenges.

2. The UAV System Specification

A Parrot Ar.Drone 2.0 is used in this study to illustrate the development of a smart drone police. This UAV has two cameras, front camera and bottom camera with the resolutions 320 x 240 pixels at 30 frames per second (fps) and 640 x 360 pixels at 60 fps, to have information about UAV's working space. The sensor system includes a three-axis accelerometer, a three-axis gyroscope, and a three-axis magnetometer. They are together integrated in IMU. The IMU measures the pitch, roll and yaw angles. The measurements are implemented for its internal controllers. In addition, the drone has two ultrasonic sensors and a pressure sensor to estimate its altitude. The drone is controlled via Wifi by three separate communication channels [2]. The drone is able to be controlled six DOFs. It is a multiple inputs-multiple outputs system as represented in Figure 1. For more detail, please refer [2].

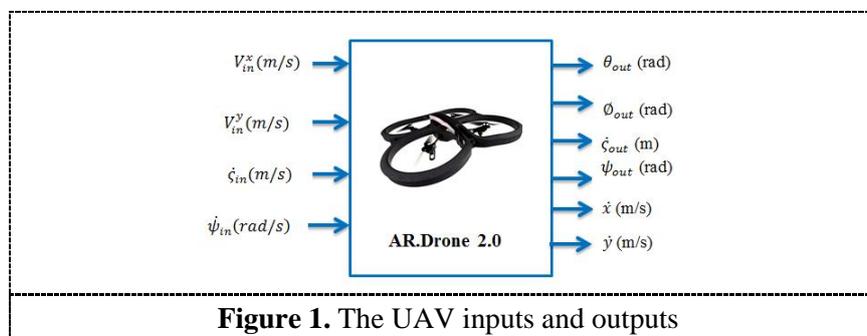


Figure 1. The UAV inputs and outputs

3. Identification UAV system

The Ar.Drone 2.0 has not direct sensors to obtain the position. Therefore, the speeds are used as the outputs for the identification process. Then the position models are obtain by using an integral action. In this study, a parametric identification using prediction error is used to obtain the transfer functions of the movements. Using the prediction error method PEM, a model with prediction focus is calculated as a discrete-time polynomial model. In this study, we use a complex signals to excite the system. As this drone is a symmetric system, the x and y axis has the same model.

The transfer function for x/y and z axis:

$$F(x) = \frac{\dot{x}(s)}{\dot{V}_{in}^x(s)} = \frac{7.27}{s(1.06s+1)} \quad (1)$$

$$F(y) = \frac{\dot{y}(s)}{\dot{V}_{in}^y(s)} = \frac{7.27}{s(1.06s+1)} \quad (2)$$

$$F(\zeta) = \frac{\zeta_{out}(s)}{\zeta_{in}(s)} = \frac{0.72}{(0.23s+1)} \tag{3}$$

4. Localization UAV system

As mentioned before, the IMU provides the roll, pitch, yaw angles measurement. The speed estimations are archived by fusing the data form a 3-axis gyroscope with the information from a 3-axis accelerometer and a magnetometer. The position of the drone along each axis is calculated by integrating the velocity. The position along x-axis is formulated as follows.

The bottom camera is used to discover the drone’s underneath environment. The drone is also equipped IMU which provide the pitch, roll and yaw angles. In order obtain more precise position and orientation of the drone, the sensor fusion technique is implemented to fuse IMU and camera’s signals. Firstly, the schematic of the two synchronized signals are depicted in Figure 2. The following equation presents the integrated method to fuse IMU signals and camera signals obtained from the image processing.

$$x_k = T_s \sum_{i=k-(t_d/T_s)-1}^k \dot{x}_i + x_{cam} \tag{4}$$

Where: x_k is the position of the drone using sensor fusion method at sample k . T_s is the sample time (0.66s), \dot{x}_i is the speed along x axis which obtained from IMU, t_d is time delay with the value is 0.33s

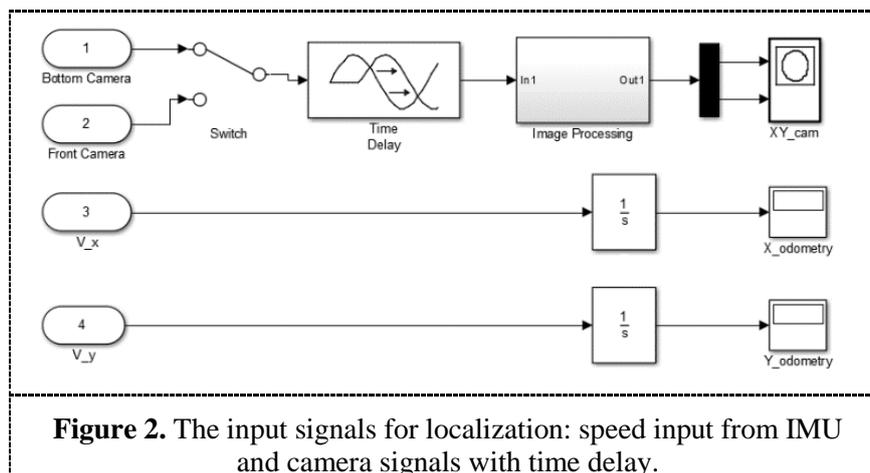


Figure 2. The input signals for localization: speed input from IMU and camera signals with time delay.

5. Control UAV system

The tuning of the different controllers are implemented using computer-aided design, namely the Frequency Response Toolbox (FRTTool) [13]. The design speciation: robustness (R_o), settling time (T_{set}), overshoot percent ($\%OS$) and gains of the tuned PID controllers are presented in Table 1. The controller designs with frequency response design tool are illustrated in Figure 3.

The following controllers are designed of this application.

$$C_{\dot{x}}(s) = 0.45(1.64s + 1) \tag{5}$$

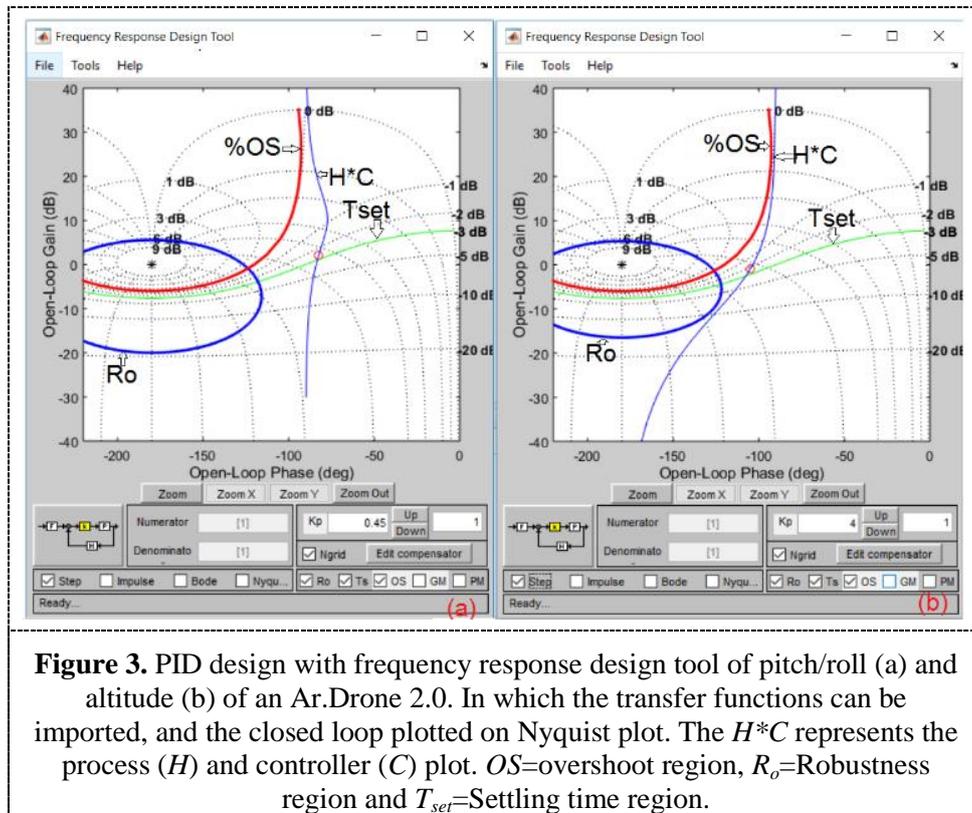
$$C_{\dot{y}}(s) = 0.45(1.64s + 1) \tag{6}$$

$$C_{altitude}(s) = 4 \tag{7}$$

The specification of the controllers are stated in the table

Table 1. Controller parameters

Controller	R_o	T_{set}	$\%OS$	K_p	T_d
x,y	≥ 0.85	2.5s	$\leq 5\%$	0.45	1.64
z	≥ 0.85	2.5s	$\leq 5\%$	4	0



The stabilization under wind gust condition is extremely important for UAV controller. If its controller can not handle the disturbance rejection problem properly, its performance cannot be managed. Figure 4 and Figure 5 illustrate the wind disturbance to the step response where wind gusts are 0.1m/s; 0.2 m/s; 0.3 m/s during 0.5s respectively. The results show that the designed controllers are stable with wind gust disturbances.

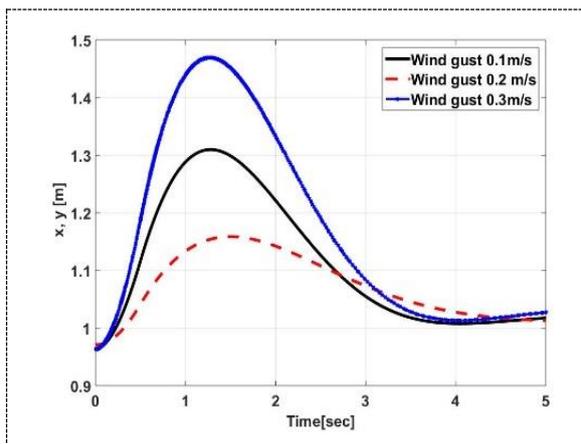


Figure 4. Wind disturbance X(Y) response comparison.

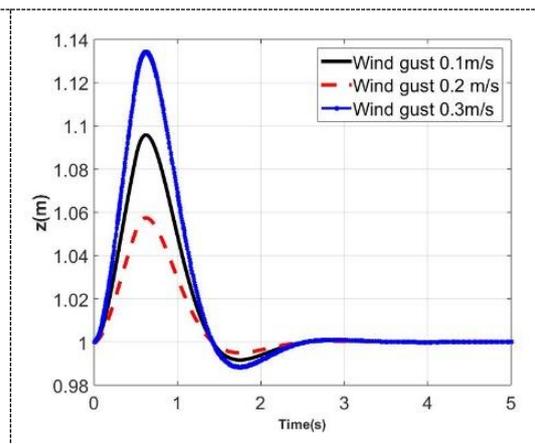


Figure 5. Wind disturbance Z response comparison.

6. Experiment Results

To validate our approach, the system setup consists of a Lego Mindstorm that is driving with a speed of 0.2 m/s and an Ar.Drone 2.0 that estimates the velocity of the robot using its bottom camera as shown in Figure 6.



Figure 6. The lab-scale experiment setup system

To obtain the moving object's velocity estimation properly, a cumulative moving average filter is implemented in this application. This experiment outputs proves that the measurement is reasonable at the first stage (error is smaller than 0.015 m/s), thereafter, the velocity is estimated accurately, as shown in Figure 7. It suggests that the velocity estimation by the drone's vision system is practicable. This velocity information enables the autonomous UAVs to perform its task as a smart police device.

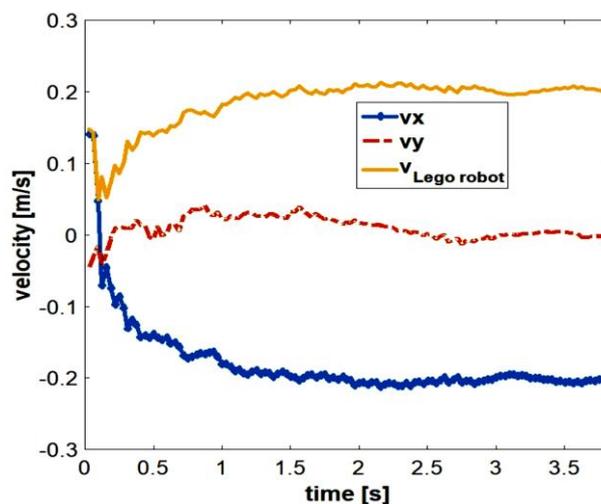


Figure 7. The velocity measurements of the moving object.

7. Conclusion

This paper presented the first step towards the development of a smart drone police based on an unmanned aerial vehicle (UAV). The effectiveness of the proposed smart device is illustrated in traffic speed monitoring, using lab-scale system. The UAV's localization based on the sensor fusion method is developed which combine the IMU signals and Pozyx signal to obtain its position and orientation. The PID controller is designed using FRTool. The detection and estimation of the moving object is implemented based on the drone's on-board vision system. For the control performance it is indicated that the controllers are stable with wind gust disturbance. The experiment results show the model is archived properly. The vision based strategy detects and estimates the state of the moving object accurately.

Future work includes applying AI technique to recognize the moving object and implementation the algorithm with multiple moving obstacles moving in variable speeds.

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