Exploring RSSI for UAV-to-GCS distance estimation

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ABSTRACT

This study investigated the use of the Received Signal Strength Indicator (RSSI) to improve the Follow Me autonomous flight mode of an Unmanned Aerial Vehicle (UAV). RSSI data was fused with Global Positioning System (GPS) information to estimate the distance between the mobile device Ground Control Station (GCS) and the UAV. Using a weighted scheme, the estimated distance was computed and used to adjust the position of the UAV with respect to the GCS. Several schemes were tried: GPS only, combinations of GPS and RSSI, and RSSI only. Using GPS only gave the lowest mean distance error, but certain combinations of RSSI and GPS gave lower variances than GPS only.

CCS CONCEPTS

• **Computer systems organization** → **Robotics**; **Robotic autonomy**; • **Networks** → *Wireless access networks*;

KEYWORDS

UAV, Drones, distance estimation, RSSI

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1 INTRODUCTION

Unmanned aerial vehicles (UAVs) are powered devices that fly without a human pilot on board. They can be remotely controlled or autonomously flown using autopilot software. UAVs are popularly known as *drones*. They can carry loads which can be lethal or nonlethal[15]. UAVs were originally developed for military purposes and were used as weapons or surveillance equipment[9]. Recently, UAVs are being used in other civilian and commercial applications, such as, film making, construction, logistics, rescue, disaster management, and agriculture[17].

Two popular types of UAVs used for various commercial applications are the fixed-wing and multi-rotor. Fixed-wing UAVs are similar to airplanes in design while multi-rotor UAVs are similar to helicopters. Multi-rotors, specifically quadcopters, are becoming popular lately with several commercial vendors available on the market.[1][2][3]

When operated in remote mode, UAVs are manually controlled by a human pilot using a radio controller. In autonomous mode, UAVs depend on autopilot software that communicates with a Ground Control Station (GCS) using some protocol such as MavLink[4]. The GCS is the software installed on a laptop (ex. APM Planner[5]) to give the instructions for the UAV to follow, such as flying over a predefined flight path. UAVs rely on its sensors (barometer, accelerometer, gyroscope, compass) to be able to orient and position itself on its environment.

UAVs are also equipped with receivers that process radio signals from the Global Positioning System (GPS) satellites. The information from the satellites enable a UAV to determine its location by using information from at least four satellites[6]. However, the GPS receiver needs a clear view of the sky to work effectively. This makes GPS suitable for outdoor environments. GPS is accurate within +/- five meters, depending on the signal quality.

For UAVs that support IEEE 802.11 wireless networks(WiFi), distances can also be approximated using the Received Signal Strength Indicator (RSSI). RSSI also has its limitations when used in areas with walls and radio interference.

UAVs can operate in different flight modes. The Follow Me[6] mode is one example of autonomous flight mode that allows the UAV to follow the GCS that it is connected to using GPS information. The movement of the UAV is based on its relative position to the GCS. Given the altitude and ground distance, this flight mode controls the UAV to follow the GCS. In this mode, the GCS and the UAV must be both GPS-enabled. The difference in the GPS readings between the GCS and the UAV is used to estimate the distance between them. Follow-Me mode is widely used in cinematography to position the UAV relative to the subject.

This study investigates the combination of GPS and RSSI to provide a more accurate measure of distance between a UAV and its GCS in the Follow Me autonomous flight mode. A good combination will allow the UAV to fly more reliably in situations when one sensor fails or in more constrained environments with tighter spaces or partial view of the sky.

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[1]http://www.dji.com/
[2]https://www.parrot.com/global/drones
[3]https://3dr.com/
[4]http://qgroundcontrol.org/mavlink/start
[5]http://ardupilot.org/planner2/
[6]http://ardupilot.org/copter/docs/ac2_followme.html

This paper is organized as follows. Sections 2 and 3 describe in detail distance computation using GPS and RSSI, respectively. Section 4 describes the experimental design. The results are presented in Section 5 and similar studies in Section 6.

2 GLOBAL POSITIONING SYSTEM

GPS[7] is used to determine the location of devices by performing calculations based on the information contained in signals received from satellites. The information includes the position of the satellites in orbit and timing data. Signals from at least four satellites are needed by a GPS-enabled device in order to correctly compute its location on the Earth's surface[6]. The GPS location is expressed as a combination of latitude and longitude. Latitude is the measure of degrees of distance from the Equator. Longitude is the measure in degrees from the Prime Meridian. Given two GPS locations, the distance between them can be computed using the Haversine formula (Equation 1) below.

$$d = 2r \arcsin\left(\sqrt{\sin^2\left(\frac{\varphi_2 - \varphi_1}{2}\right) + \cos(\varphi_1)\cos(\varphi_2)\sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right) \tag{1}$$

φ_1 and φ_2 are the latitudes in radians of location 1 and location 2, respectively. λ_1 and λ_2 are the longitudes in radians and r is 6,371Km, the mean radius of the earth.

GPS has its limitations. GPS signals may be obstructed resulting to the delay in reaching the device. Also, buildings or terrains may cause the signal to bounce causing it to fade [2]. This is the reason why it is better to use GPS in wide open areas and outdoors rather than indoor or places that are surrounded by many of tall buildings. GPS also cannot be used if there are no satellites that can be detected such as when it is rainy or cloudy.

3 RECEIVED SIGNAL STRENGTH INDICATOR

RSSI is mainly used for localization using WiFi. It is used outdoor or indoor and as a parameter for a localization technique such as fingerprinting. In this technique, RSSI is collected and stored in a database to be used in making a comparison to determine the position of the target [20] [11]. RSSI may differ from one device model to another, which can affect the accuracy of locating a target[5]. The RSSI value at one meter for a specific device is used to normalize its value across different devices. There are other factors that can affect RSSI, such as reflection, refraction, and scattering of signals caused by objects in between and around devices [7].

RSSI on its own is not entirely reliable measure of distance. A study found out that RSSI was very unstable if used in indoor localization even in an ideal scenario [18].

The RSSI can be computed using the following equation (Equation 2) [16].

$$RSSI = -10n\log_{10}(d) + A \tag{2}$$

In this formula, n is the propagation path loss, d is the distance, and A is the RSSI value at a distance of one meter. A must be calibrated depending on the particular device model being used.

[7]http://www.gps.gov/

Distance can then be derived resulting to the formula (Equation 3) below.

$$d = 10^{\frac{RSSI-A}{-10n}} \tag{3}$$

4 MATERIALS AND METHODS

4.1 Integrating GPS and RSSI

GPS and the RSSI should ideally measure the same distance, but actual measurements may be different. Thus, both data were fused to output a single value for distance. To integrate the data taken from the RSSI and GPS, a selective weighing scheme was used. This is the same weighing scheme used in the experiment of Yeh[22].

The following equation was used to derive the final distance between the GCS and the UAV.

$$\begin{aligned} FusedDistance = {} & (GPSDistance * AssignedWeightGPS) + \\ & (RSSIDistance * AssignedWeightRSSI) \end{aligned} \tag{4}$$

In Equation 4, *GPSDistance* is the horizontal distance obtained from the UAV using GPS. The *RSSIDistance* is the horizontal distance computed from Equation 3. The sum of *AssignedWeightRSSI* and *AssignedWeightGPS* must be equal to 1.0.

4.2 Updating the position of the UAV

Once the *FusedDistance* was obtained, the new position of the UAV was updated. This is achieved first by getting the ratio of the *HorizontalDistance*, set in the GCS, to the *FusedDistance* (Equation 4) as shown in Equation 5.

$$NewDistancePercent = \frac{HorizontalDistance}{FusedDistance} \tag{5}$$

This ratio is then multiplied to the distance obtained from GPS (Equation 6).

$$NewDistance = NewDistancePercent * GPSDistance \tag{6}$$

Equation 5 was used to get the percentage of the desired horizontal distance in the *FusedDistance* as it was assumed to be the accurate measurement of the distance between the UAV and the GCS. Since the GCS is still heavily reliant on the GPS coordinates to move the UAV, Equation 6 was used to get the desired horizontal distance in terms of GPS measurement. The reason is that *GPSDistance* and *FusedDistance* were assumed to be measuring the same distance but with different actual readings.

4.3 UAV Platform

The Erle-Copter Drone Kit[8] was used in this study. It is powered by Erle-Brain[9] 2 with the autopilot software based on ArduPilot[10]. This platform was chosen because it supports WiFi (through an Edimax 802.11bg/ac USB dongle). Figure 1 shows the actual copter without the propellers.

[8]https://erlerobotics.com/blog/product/erle-copter-diy-kit/
[9]http://erlerobotics.com/blog/erle-brain-2/
[10]http://ardupilot.org

Figure 1: Erle-Copter powered with the Erle-Brain 2.

4.4 Ground Control Station

Tower[11], an Android application, was used as the GCS. Tower uses the DroneKit-Android[12] library. Its source code was modified to incorporate RSSI in the computation of the UAV's position in the Follow Me autonomous mode. Two files were modified, *GeoTools.java*[13] (Listing 1) and *FollowLeash.java*[14] (Listing 2). Tower was then rebuilt using the modified Dronekit-Android library. To avoid having compatibility issues, the build was set to support at least Android 4.0. Timber[15] was used to log the observed measurements for later analysis. The application was installed on a Samsung Galaxy J7 2016 Edition phone running Android 6.0.1. This unit has a built in storage of 16 GB and RAM of 2 GB with octa-core CPU clocked at 1.6 GHz.

```
public static double getHypRSSI(){
        WifiManager wifiMgr = (WifiManager) AppHolder.getApp().
              ↪ getApplicationContext().getSystemService(Context.WIFI_SERVICE);
              ↪
        WifiInfo wifiInfo = wifiMgr.getConnectionInfo();
        //Signal sigRSSI = (Signal) drone.getAttribute(AttributeType.SIGNAL);
        int rssi = wifiInfo.getRssi();
        double rssiPerMeter = -22; //-22dBm recorded from Wifi Analyzer
        // RSSI to distance
        double hypRSSI = Math.pow(10.0, ((rsi - rssiPerMeter)/(-20.0)));
        Timber.d("FollowLeash:␣Get_Hyp_RSSI_Vars_1:␣rssi="+rssi);
        Timber.d("FollowLeash:␣Get_Hyp_RSSI_Vars_2:␣hypRSSI="+hypRSSI);
        return hypRSSI;//returns in meters
}
```

Listing 1: Method added in *GeoTools.java* to return the distance based on RSSI. Using Equation 3, the parameter A is set to $-22dBm$ and n is set to 2 in this implementation.

```
public class FollowLeash extends FollowWithRadiusAlgorithm {
    public FollowLeash(MavLinkDroneManager droneMgr, Handler handler, double
          ↪ radius) {
         super(droneMgr, handler, radius);
    }
    public double getHorizontalDistance (Double droneAlt, Double hypRSSI){
       if(hypRSSI > droneAlt){
           double horizontalDist = Math.sqrt(Math.pow(hypRSSI, 2) - Math.pow(
                 ↪ droneAlt,2));
           return horizontalDist;
       }
       return 0.0;
    }
    @Override
    public FollowModes getType() {
        Timber.d("FollowType:␣LEASH!");
        return FollowModes.LEASH;
    }
    @Override
    protected void processNewLocation(Location location) {
        final LatLong locationCoord = location.getCoord();
        final Gps droneGps = (Gps) drone.getAttribute(AttributeType.GPS);
        final Altitude droneAlt = (Altitude) drone.getAttribute(AttributeType.
              ↪ ALTITUDE);
        final LatLong dronePosition = droneGps.getPosition();
        if (locationCoord == null || dronePosition == null) {
            return;
        }
        if (GeoTools.getDistance(locationCoord, dronePosition) > radius) {
            double headingGCStoDrone = GeoTools.getHeadingFromCoordinates(
                  ↪ locationCoord, dronePosition);
            double horizontalDistRSSI = getHorizontalDistance(droneAlt.
                  ↪ getAltitude(), GeoTools.getHypRSSI());
            double desiredDist = radius;
            Timber.d("FollowLeash_Vars_1:␣horiDistRSSI=" + horizontalDistRSSI);
            if(horizontalDistRSSI > 0.0) {
                double horizontalDistGPS = GeoTools.getDistance(locationCoord,
                      ↪ dronePosition);
                //Fuse the data with the use of Weighing scheme -> Hardcoded
                      ↪ weight
                //double horizontalFuseDist = (horizontalDistGPS * AssignedWeight
                      ↪ ) + (horizontalDistRSSI * AssignedWeight);
                double horizontalFuseDist = (horizontalDistGPS * 0.9) + (
                      ↪ horizontalDistRSSI * 0.1);
                double desiredDistPercent = radius / horizontalFuseDist;
                desiredDist = desiredDistPercent * horizontalDistGPS;
                //Logs
                Timber.d("FollowLeash_Vars_2:␣horiDistGPS=" + horizontalDistGPS);
                Timber.d("FollowLeash_Vars_3:␣horiDistFuse=" + horizontalFuseDist
                      ↪ );
                Timber.d("FollowLeash_Vars_4:␣desiredDist=" + desiredDist);
                Timber.d("FollowLeash_Vars_5:␣droneAlt=" + droneAlt.getAltitude()
                      ↪ );
                Timber.d("FollowLeash_Vars_6:␣radius=" + radius);
            }
            LatLong goCoord = GeoTools.newCoordFromBearingAndDistance(
                  ↪ locationCoord, headingGCStoDrone, desiredDist);
            //LatLong goCoord = GeoTools.newCoordFromBearingAndDistance(
                  ↪ locationCoord, headingGCStoDrone, radius);
            drone.getGuidedPoint().newGuidedCoord(goCoord);
        }
    }
```

Listing 2: Modified *FollowLeash.java* that uses fused RSSI and GPS data to determine the new position of the UAV. The last line in the method instructs the UAV to move to the new position.

4.5 Field Testing and Measurements

Tests[16] (see Figure 2) were performed in an authorized flying field for remote controlled devices at Bacoor, Cavite, Philippines. The location has no cell sites nearby that may interrupt the signals used to communicate with the UAV. There were also no electric posts and wires over the field that may interfere with the UAV's flight. The experimentation was executed in a clear day from 7 AM to 7 PM. Safety precautions were observed to prevent any accident during the tests.

[11] https://github.com/DroidPlanner/Tower
[12] https://github.com/dronekit/dronekit-android
[13] https://goo.gl/1pkVXk
[14] https://goo.gl/6iqy4R
[15] https://github.com/JakeWharton/timber
[16] https://www.youtube.com/watch?v=CtvLhixgp5I

Figure 2: Field testing.

The modified Follow Me mode was tested on different weight settings for GPS and RSSI. The weight settings were (*GPS-RSSI*): 1.0-0.0(GPS only), 0.9-0.1 , 0.8-0.2, 0.7-0.3, 0.6-0.4, 0.5-0.5, 0.4-0.6, 0.3-0.7, 0.2-0.8, 0.1-0.9, and 0.0-1.0(RSSI only).

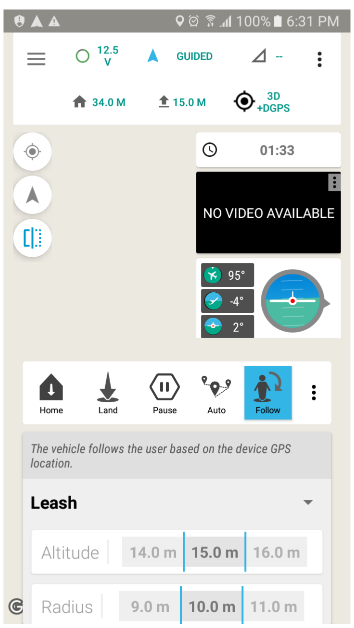

Figure 3: Tower in Follow Leash mode with fused GPS and RSSI distance computation.

Figure 3 shows the set constants when the modified Tower application was tested. The altitude was set to 15 meters and the horizontal distance, which is the radius set in the GCS, was set to 10 meters. To check the accuracy of the feature, the physical distance between the GCS and the UAV was measured ($MeasuredDistance$). This is subtracted from the expected distance, which is 18.0278 meters (obtained using Pythagorean theorem on the set altitude and horizontal distance). The absolute value of the difference is the $DistanceError$ (Equation 7). The observed distance error was used to analyze what was the best weight combination of GPS and RSSI distances. Every distance measured was in meters.

$$DistanceError = |MeasuredDistance - 18.0278| \quad (7)$$

Distance measurements were conducted three at a time for the same weight setting per flight. Each flight was configured with a new weight setting. To allow for variations in external factors such as wind and radio interference, lots were drawn to determine the sequence of the flights over two sunny days. In total, each weight setting had three flights and nine observations. The actual distance between the GCS and the UAV was measured using a *nylon string*. The string was hooked to the UAV and the other end of the string was with the person holding the GCS. Markings were placed on the string to indicate the trial number and weight combination being tested. The distance was taken by measuring the length of the string from the end attached to the UAV to a marking.

5 RESULTS AND DISCUSSION

Table 1 shows that using GPS only gives the lowest mean distance error. Using two-tailed Student T-Test on related samples to compare each weight setting against GPS only shows that we cannot say that their mean distance errors are the same. Since GPS only has the lowest mean distance error, this suggests that GPS only is a more accurate measure of distance than the other weight settings. However when we consider the variation of the distance errors observed, certain weight settings have lower Standard Deviations than GPS only. When using two-tailed F-Test to determine if the variances are the same, only weight setting 0.7-0.3 may be said to be significantly lower with a P value of 0.0099. Other weight settings such as 0.8-0.2 and 0.4-0.6 notably gave lower variances although not statistically significant. This suggests that these weight settings may give more accurate measures when corrected for the mean distance error as their observations are more tightly clustered. For example, the weight setting 0.3-0.7 is off by 1.7633 meters compared to GPS only but its standard deviation is less by 1.0055 meters. If the estimated distance can be adjusted by 1.7633 meters then this estimate will give a better overall measure of actual distance than GPS only.

It is also worth noting that there is no linear trend in the observed data. The mean distance errors and variances do not decrease as GPS weights are increased. Also worth noting is the 0.4-0.6 weight setting since its mean distance error is not significantly different from GPS only. It ranks second in least mean distance error and third in least variance.

6 RELATED WORK

A UAV tracking a target in autonomous flight with high accuracy has always been a challenge. Many variables are considered, such as, the location of the target relative to the UAV and the velocity at which the target and the UAV are moving. Several studies used different approaches to accurately target objects to be followed by the UAV. Husby[10] used flight patterns and made the UAV persistently fly near its target to get the desired data and process

Table 1: Distance error in meters.

GPS-WiFi	Mean	SD	T-Test	F-Test	Variance
1.0-0.0	1.8243	1.5822	(n/a)	(n/a)	(n/a)
0.9-0.1	3.2740	1.7921	0.0324	0.7330	same
0.8-0.2	3.5023	0.8787	0.0106	0.1163	lower
0.7-0.3	3.2136	1.4526	0.0737	0.8150	same
0.6-0.4	3.7504	1.2765	0.0519	0.5577	same
0.5-0.5	4.6745	1.1927	0.0004	0.4414	same
0.4-0.6	2.0529	0.9909	0.7627	0.2072	lower
0.3-0.7	3.5876	0.5767	0.0086	0.0099	sig. lower
0.2-0.8	4.2779	1.2546	0.0009	0.5265	same
0.1-0.9	3.4305	1.1269	0.0102	0.3565	same
0.0-1.0	4.6508	1.5620	0.0143	0.9720	same

this data to keep up with the target. Naseer[14] used the camera to track their target. In another study, Livermore[13] used the camera to detect gestures in order to control the UAV and detect its moving target while finding the optimal path wherein the UAV can fly to overwatch the target. This study employed a heuristic-based algorithm in order to find the optimal flying path.

Lee[12] in another study designed a path planning algorithm to follow a target that has no constant velocity. The UAV has two flight modes namely sinusoid and loitering. Changing the mode of the UAV depends on the speed of the target. Backstepping approach is used on another study to track a moving target which is on the ground. The approach used is the most commonly used control for the UAV. The study also mentioned that underactuated quad-rotor that is compatible with the backstepping approach was used [19].

In another study, the researchers made it possible for the UAVs to fly correctly even if the UAV is out of the sight of the operator. The UAV can also make decisions based on its perceived environment[8].

Data Fusion, coordinating and collecting data from multiple sensors by observing the same real world object or phenomenon, can be useful to generate a more reliable estimate of the real world. Kalman Filtering (KF) is one of the most commonly used techniques for data fusion and object tracking.

For example, Yan [21] used KF to integrate WiFi and GPS when the conditions require the system to do so. KF is usually used when the system is linear. When it is nonlinear, Extended Kalman Filtering (EKF) would become applicable. In another study, the researchers developed a low cost navigation system for indoors and outdoors using WiFi and GPS. WiFi and GPS are employed interchangeably depending whether the user is indoors or outdoors. To implement this navigation system, they used EKF to integrate their data [4]. EKF can help in estimating the next state of the system more accurately.

When targets move, some conditions may be violated which may give KF unoptimal solutions. Using multiple sensors may not necessarily improve estimation but in some cases, having multiple sensors degrades the data that is being collected[3]. In another study, Akselrod [1] implemented hierarchical Markov decision processes to collaborate different data from multiple sensors. The system is able to decide what action it would perform depending in its current state using dynamic programming. The study discussed use states and conditions to decide on what action to do next.

Using a selective weighting scheme is another approach used in implementing offline outdoor positioning technology using GPS and WiFi networks. The approach gave specific weights to GPS and WiFi positioning system (WPS) according the weather that is believed to affect the mean distance error for the output of the GPS. The study showed that combining GPS and WPS can result into increased accuracy in locating the user even at unstable weather[22].

7 CONCLUSIONS

It was demonstrated that RSSI data, when fused with GPS data, can be used to estimate the distance between a UAV and the GCS. Although using GPS only still gave the least mean distance error, certain weight settings gave lower variances. A lower variance indicates more consistency of the distance estimated.

It is recommended that there should be future studies to explore other approaches to further reduce the variance of the distance error and how to calibrate fused distance measures in order to minimize the distance error.

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