Demo: Cellphone Localisation using an Autonomous Unmanned Aerial Vehicle and Software Defined Radio

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Abstract

We describe a system combining a low-cost autonomous Unmanned Aerial Vehicle, lightweight embedded computer and software defined radio for GSM cellphone localisation in emergency situations. We describe the hardware and software aspects of the system, how they are integrated, and detail the localisation approach. The demonstration comprises the system hardware and the use of video and animation showing the vehicle enacting automated search outdoors.[1]

1 Introduction

In recent years, low-cost consumer-grade unmanned aerial vehicles (UAVs) with autonomous flight capability have come onto the market. In the same period, practical, inexpensive software-defined radios (SDRs) and embedded computing hardware have also become increasingly available and capable. In this work we investigate integrating these technologies to create a low-cost aerial radio sensing platform, which we demonstrate in practical experiments (Figure 1) localising cellular phones using the Global System for Mobile Communications (GSM) 2G standard. Received Signal Strength (RSS) from the phone coupled with Global Positioning System (GPS) readings are used to determine location via non-linear optimisation combined with a spiraling approach pattern. This approach is motivated by the problem of identifying the location of persons who may be trapped or isolated in an emergency situation, for instance, a hiker lost in mountains away from cellular coverage, or individuals isolated after cellular infrastructure has been destroyed, such as after a natural disaster. By using a UAV to survey and locate individuals who may be in distress, the problem of difficult terrain is minimised, and safety personnel need not be exposed to unecessary risk. As the GSM standard is supported by most cellphones, and the SDR is capable of operating in multiple bands, this approach can recover RSS readings from the majority of cellphones. Furthermore, the relatively low cost of the hardware used in this platform is well-motivated by the desire to cover a lot of ground, as well as mitigating the financial risk of a vehicle loss. Related solutions for the UAV search and rescue task have made use of expensive, heavy UAVs and equipment [4], required custom applications installed on devices[6] or deal with other protocols such as Wi-Fi[2] that might not be available or enabled on all devices.This work expands on our previous investigations into UAV-based repair of embedded sensor networks[5], and makes use of some similar hardware and software in its implementation, particularly the IRIS+ UAV and the use of MAVLink for control.

Figure 1. UAV GMS Localisation Platform in flight

2 System Description

2.1 Hardware

2.1.1 Unmanned Aerial Vehicle

We use a 3DRobotics Iris+ Quadcopter UAV (Figure 2) . This UAV features a Pixhawk 4 flight computer which supports MAVLink (Section 2.2.1) protocol control. The UAV can carry up to 400 grams in extra equipment and has a flight time of approximately 30 minutes on a full charge. Control of the UAV is performed through MAVLink commands via 433MHz telemetry radio connection. The BladeRF x40 (Figure 2) is a less than €400 Software Defined Radio produced by Nuand, with an operating range between 300MHz and 3.8GHz. Using YateBTS (Section 2.2.2), the BladeRF can be configured to operate as a low-power mobile cellphone Base Transceiver Station (BTS). In these experiments, the BladeRF uses a pair of Vert900 antennae, for a total weight of 120g, making it well-suited to the limited payload capacity of the Iris+ UAV.

[1] An earlier version of this work was demonstrated but not published at the International Symposium on Wireless Communication Systems 2016.

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2.1.2 Embedded Companion Computer

While the Iris+ UAV has a flight computer, it isn't powerful enough to perform complex computation or to manage an SDR. A "Companion Computer" communicates with the flight computer via a MAVlink wireless connection, and is responsible for managing the radio search aspects of the platform, including operating the software BTS and localising user devices based on Received Signal Strength Indication (RSSI). In this work we use a Minnowboard Turbot (Figure 2) due to its light weight (45g), low cost, USB 3.0 support and effective computation capability.

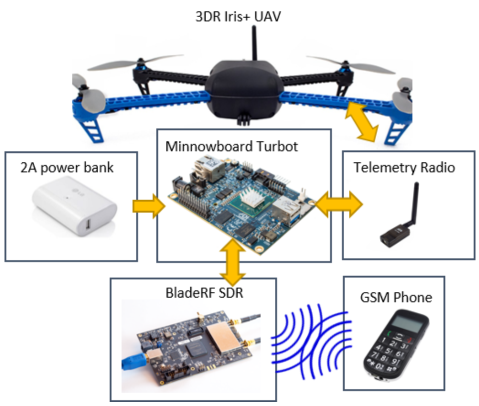

Figure 2. UAV GSM Localisation Platform

2.2 Software

2.2.1 Micro Air Vehicle Communication Protocol

Micro Air Vehicle Communication Protocol (MAVLink) provides for communicating flight commands to the UAV Pixhawk flight computer via 433MHz telemetry radio connection. The Companion Computer requests the UAV's current geographical position, altitude, velocity and other metrics. Through this connection, the Companion Computer also provides waypoint destinations for the UAV to visit. Through these communications, we associate radio readings with geographic positions, and use these for localisation.

2.2.2 Yate & YateBTS

Using the BladeRF as a transceiver, we implement the GSM stack using Yate as the telephony engine and YateBTS for wireless communications and subscriber management. By appearing to be a more powerful Base Transceiver Station, user devices are "spoofed" into attempting to associate with the aerial BTS. While the device is not accepted as a subscriber (to ensure it remains available on its original network), this is sufficient to establish an RSSI reading for the cellphone.

2.3 Levenberg-Marquardt Localisation

As radio propogation is inherently variable, and scattering and shadowing effects can have a significant impact on the utility of RSSI as a distance metric, trilateration of a user device using linear approaches yields ambiguous results. The Levenberg Marquardt (L-M)[3] algorithm is a non-linear least-squares optimisation algorithm. To tune the parameters of our localisation and investigate a number of possible search motion patterns before field tests, we used Longley-Rice path-loss coverage maps generated in SPLAT![1] in software simulation. Based on simulation results, we arrived at a Gaussian sampling approach and a spiral movement pattern for searching in the vicinity of the expected location and use this approach in outdoor flight experiments (Figure 1).

We select a random sampling of six readings (weighted towards choosing readings with stronger signals) and pass these location and signal strength pairs to the L-M algorithm to compute a close-matching model, on which we locate the optimum and consider the coordinates of the optimum to be the current candidate for cellphone location. The UAV then travels towards the estimated location, slightly offset in angle by 20° to produce a spiraling-in motion. As further readings are made and the estimate improves, the squared difference (error) between the actual readings and the L-M generated curve reduces, and a sequence of estimates that are consistently below a threshold constitutes the search termination criteria. The UAV returns home to inform the rescue team of the estimated location of the user device.

3 Conclusion

We designed a platform based on low-cost commercial off-the-shelf components and freely available software to implement a flexible aerial radio sensing platform. We demonstrate the UAV localisation system locating a user device based on the reception of GSM association requests broadcast by the device in response to GSM beacons emitted by the SDR operating as a GSM BTS in the air. In future work, we will investigate collaborative searching procedures using multiple coordinated UAVs and localisation of non-cellphone wireless devices such as wireless sensors or other other autonomous vehicles.

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