Poster: Homecoming: A Wireless Homing Device for UAVs

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ABSTRACT

Unmanned Aerial Vehicles (UAVs) are quickly becoming a viable delivery platform for physical packages with promise to transform the retail industry's supply chains. This work focuses on the last leg of such delivery: physically approaching a customer's landing zone. This has traditionally relied on a combination of GPS and computer-vision to locate and identify a landing zone. Instead of using computer vision, we propose to use ultra-wideband beacons (UWB) to assist in the landing process. The UAV's location relative to the landing zone is continuously measured based on the wireless propagation delay between the UAV and the landing zone's corners. We show that a single pair of wireless devices, one at the UAV and one at the landing zone, suffices to obtain the UAV's location. The landing zone's UWB device, connected to multiple antennas, receives multiple copies of the UAV's signals, that enables a sub-decimeter 3D-localization of the UAV. This helps the UAV's control logic governing the approach and landing process.

CCS CONCEPTS

• **Computer systems organization → Sensors and actuators**; *Robotics.*

KEYWORDS

Drone Delivery, UAV, UAV Landing, UWB Localization

1 INTRODUCTION

We imagine a future where UAVs are routinely used for package delivery, search and rescue operations [4], disbursement of medical supplies and food in distressed areas etc. Such a future, is already being explored by Amazon [1], Google [5], and a few others. The vision of an an end-to-end UAV based package delivery system is outlined in Figure 1. A user orders

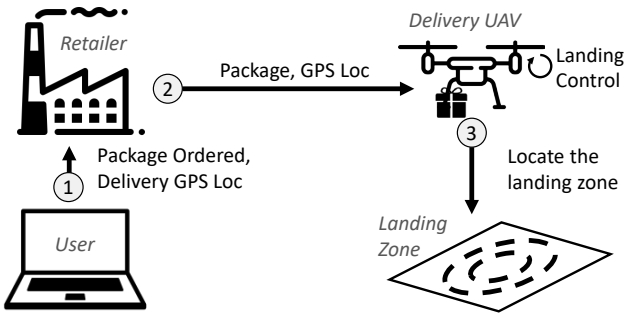

Figure 1: A drone-based package delivery system.

an item from a retailer and pays for it online. In lieu of specifying a physical address, the user specifies the GPS location of the landing zone where the user expects to receive this delivery. The retailer creates a package for the user and loads it onto a UAV, which carries this package to the GPS location and then "looks" for the user's landing zone (LZ). The UAV's control logic adjusts throttles based on its relative location to the observed LZ, and manages the landing.

Realizing such a future requires significant efforts from various quarters. This work focuses on the final leg of the delivery system: *How should a UAV approach a designated landing zone?* Existing UAV delivery systems rely on computer vision with assistance from GPS to recognize the specialized marks at the landing zone [2]. However, such computer-vision based approaches invoke privacy concerns, and naturally limit the usability of the system—visual markers fail in low-visibility conditions, and cannot be dynamically modified. Further, they require compute intensive vision algorithms to be run on an already resource-constrained UAV platform, captured using heavy camera systems.

We propose a wireless localization system, called Homecoming, that enables UAVs to approach and land at a landing zone without cameras. The core intuition behind this work is as follows: Assume a square landing zone. We measure the UAV's exact distance from each of the four corners, using a process called wireless ranging, which is then fed to multilateration algorithms, solving for the drone's current *relative* location from the landing zone. This information provides precise inputs to the UAV's control logic which constantly makes fine-grained throttle adjustments and navigates to the landing zone, for the UWB. To achieve high accuracy

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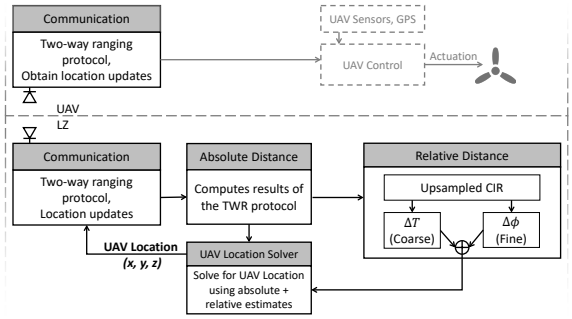

Figure 2: Homecoming system modules.

in localization, Homecoming uses UWB radios with 1 GHz bandwidth (nanosecond-level clocks) to measure a wireless signal's time of flight (ToF) between two devices, and then multiplying it by the speed of light. However, this mechanism still endures multi-decimeter-level errors. Our core innovation is a *synchronization mechanism* that enables a *single* multi-antenna UWB device on the LZ to obtain the UAV's relative location. Signals from all the antennas share the same signal processing modules in the same timeline at the receiver, i.e., they are inherently synchronized. The UAV carries a lightweight (<50 g) single-antenna UWB device that actively ranges with the LZ's multi-antenna setup. Our real world triangular test-bed shows a localization accuracy of around 10 cm. In most scenarios, this is a 2× improvement over using 3 independent UWB devices.

2 SYSTEM DESIGN

Figure 2 shows various components of the wireless the localization system running partly at the UAV and partly at landing zone. At a high level, the communication modules exchange wireless packets to determine the relative location of the UAV with respect to the LZ. The UAV's control logic uses this relative location, in addition to information from other on-board sensors, as an input to determine the actuation signals sent to its motors, moving progressively closer to the landing zone. Homecoming primarily focuses just on the problem of providing the UAV its relative location with respect to the landing zone and not on the control logic.

2.1 Wireless Ranging

Wireless distance estimation is performed using the standard two way ranging (TWR) protocol derived from the IEEE 802.15.4 standard to estimate the propagation delay between two devices. The TWR message exchange mitigates clock offset and clock drift issues between the UAV and LZ. Further, UWB's 1 GHz bandwidth and an equivalent sampling frequency, yields a nanosecond ToF, thereby leading to a 0.3m precision ($3 \times 10^8 m/s \times 1ns$) in distance measurement. In Figure 2, this functionality is provided collectively by the *Communication*, and *Absolute Distance* modules.

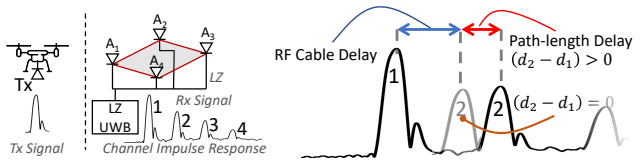

Figure 3: (a) UAV's transmission arrives as multiple replicas at the LZ through each antenna. (b) Received signal copies capture the RF cable + path-length delay.

2.2 UAV Localization

A single distance estimate is not sufficient to *locate* the UAV; multilateration uses at least 3 distances to locate an object. In our context, the LZ's corners can be treated as anchors, $A_1..A_4$ and Eq. 1 be solved for the UAV's location:

$$\arg\min_{x,y,z} f := \sum_{i \in 1..4} \left(\sqrt{(A_x^i - x)^2 + (A_y^i - y)^2 + (A_z^i - z)^2} - d_i \right) \tag{1}$$

For a square landing zone, a naive approach would be to use four UWB radios at the four corners and perform TWR to get independent distance measurements from each UWB radio. However, such distance measurements lead to significant localization errors. Instead, we propose using a multi-*antenna* setup connected to a *single UWB device* at the LZ. All antennas receive delayed copies of the same signal, which, through phase comparisons, reduces localization errors.

Consider the setup of Figure 3(a): four antennas ($A_1..A_4$) are placed at the four corners of the LZ, all connected to a single UWB device using different lengths of RF cables. The wireless signal transmitted by the UAV is now received four times by the LZ's UWB device, once through each antenna (four copies are received). There is a slight delay between the arrival of each signal copy, introduced by travelling different distances from the UAV to each antenna, and then by traversing the various lengths of RF cables from the antennas to the LZ's UWB. From the receiver's perspective, this appears similar to receiving multiple delayed copies of a transmitted signal—a usual artifact of wireless multipath. However, since we can control the exact distance between the antenna placements and the RF cable lengths, we have the ability to calibrate the expected delay between these multiple copies for a specific location of the UAV. When the UAV is equidistant from all antennas, the delay observed at the LZ's UWB is only that introduced by the RF cables (the $(d_2 - d_1) = 0$ case in Figure 3(b)). If the UAV moves to another location, the difference in wireless path-lengths to each antenna becomes non-zero, causing a corresponding change in the position of these delayed copies (the $(d_2 - d_1) > 0$ case in Figure 3(b)). Observing these delays provides us information about the *relative distance* of the UAV from each of the four LZ corners.

Note that we obtain two type of distance estimates: absolute measurements, and relative measurements. The standard TWR mechanism is still used to estimate the absolute

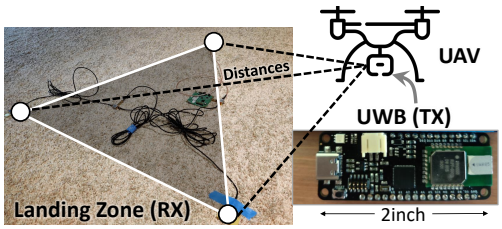

Figure 4: Homecoming test LZ ranging with UAV

distance between A_1 and the UAV. The gaps between the received signal copies provides only the *differences* of the UAV's distance from the other corners. *What is the benefit of relative measurements?* A UWB receiver tries to determine the exact instant that a signal arrived. However, the ability to determine the signal arrival accuracy is limited by the signal's bandwidth, and can be improved only marginally through signal processing (to about 10 *cm* [3]). To improve accuracy further, the signal's phase might provide an opportunity, however, every signal is transmitted with arbitrary phase. On the contrary, in Homecoming, since replicas of the same signal arrive, the phase of subsequent replicas can indeed be compared with the first copy. The phase difference, $\Delta\phi$, faithfully captures path-delay between two arriving copies, and is polluted only by phase noise of the oscillators (to an extent of only a few degrees). It is this comparison of phases that helps us improve the distance estimates in the *Relative Distance* module. Together with distances from the *Absolute Distance* module, the *UAV Location Solver*, estimates the UAV's location, which guides the UAV's landing process.

3 EXPERIMENTS

3.1 Implementation

In this work, we aim to show the feasibility of the core techniques used by Homecoming, through minimalist experiments. One UWB device functions as the UAV-device, while another *three*-antenna UWB functions as the LZ-device (Figure 4). We use Decawave DW1000 chip with Adafruit Feather M0 with only one antenna as the UAV-device for its small size, exchanging packets with TREK1000 LZ-device to achieve real-time ranging estimates and channel impulse response. The LZ-device's RF port is connected to *three* antennas, which constitutes a triangular landing zone for UAV. Data from the LZ is analyzed in MATLAB on Windows 10.

3.2 Localization Errors

Figure 5(a) compares Homecoming's localization accuracy with that using a naive approach of using 3 independent UWB devices, one each at the triangular landing zone's corners. We test 7 locations, 3 outdoors, and 4 indoors at various distances from the LZ. Homecoming consistently obtains 2× better localization accuracy, while significantly reducing hardware costs, demonstrating the benefit of our technique.

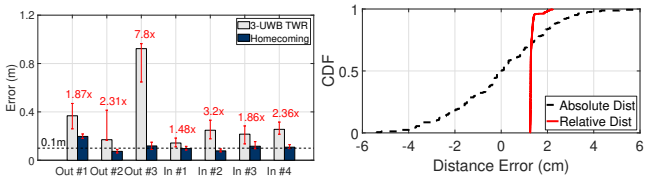

Figure 5: (a) Overall localization errors of Homecoming. (b) Comparison of distance measurement stability using time of flight and relative phase differences.

3.3 Microbenchmarks

The overall localization accuracy obtained in Figure 5(a) is a combined effect of the absolute TWR accuracy and the precision of the relative phase measurements. We now discuss the effect of each of these sub-modules separately.

3.3.1 Stability of Absolute Distance Measurements. The UAV-LZ distance is obtained from the standard TWR protocol. Figure 5(b) shows the precision of the two way ranging protocol that obtains the absolute UAV-LZ distance. Most measurements are within ±3 *cm*. Note that the same TWR protocol is employed from all three locations of the triangular LZ when compared in Figure 5(a).

3.3.2 Stability of Relative Distance Measurements. The distance difference between the UAV and two of the LZ antennas provides a relative distance measurement. This measurement is computed from a combination of the coarse-grained peak detection and fine-grained phase differences. Figure 5(b) also shows the CDFs of the relative distance errors measured for all the possible antenna combinations at all UAV locations. We observe that the relative distance measurements are accurate to around 1.2 *cm* with a precision of around 2 *mm*. These high quality relative measurements result in the better quality of final localization for Homecoming, in Figure 5(a).

4 CONCLUSION

In this work, we have focused on the UAV's task of accurately locating the customer's landing zone and approaching it using wireless UWB beacons. We have obtained promising first results with localization errors within 10 *cm* which allows for precise homing-in maneuvers.

REFERENCES

[1] Amazon Prime Air. 2016. https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011
[2] Scott Patrick Boyd and et al. 2019. Drone marker and landing zone verification. US Patent 10,198,955.
[3] DecaWave. 2017. DW1000 User Manual.
[4] Ashutosh Dhekne and et al. 2019. TrackIO: tracking first responders inside-out. In *16th {USENIX} Symposium on Networked Systems Design and Implementation ({NSDI} 19).*
[5] Google X Wing Project. 2019. https://x.company/projects/wing/