Rise of Mini-Drones: Applications and Issues

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ABSTRACT

Miniature (mini) drones are enjoying increasing attention. They have a broad market and applications. However, a powerful technology often has two ethical sides. Miniature drones can be abused, rendering security and privacy concerns. The contribution of this paper is two-fold. First, we will perform a survey of mini-drones on market and compare their specifications such as flight time, maximum payload weight, and price, and regulations and issues of operating mini-drones. Second, we propose novel aerial localization strategies and compare six different localization strategies for a thorough study of aerial localization by a single drone.

1. INTRODUCTION

Miniature drones are enjoying increasing popularity. For example, AR.Drone is a recreational drone for photography and reality games such as flight chase. It costs less than $300. The company Parrot SA launched AR.Drone in 2010 and has sold around half a million units to date [4]. AR.Drone can carry a maximum payload of 278g [29, 30] and is equipped with a 720p (1280 × 720) 30fps HD camera. AR.Drone 2.0 comes with a GPS dongle too. The unit can be controlled by an iPhone, iPad, Android phone, tablets and any computers with WiFi connection for fully automated flight. Table 1 lists selected drones on market. Mini drones can often carry a heavier load from tens of grams to tens of pounds. Fully charged and loaded, recreational drones can have a flight time of more than ten minutes.

Mini drones have a broad market and applications [25]. Drones have been regularly used in military. This paper focuses on drones for civilian use. Mini drones can produce incredible aerial photos and videos with onboard cameras for various applications such as real estate, industrial inspection, crime scene and accident reconstruction photography, perform search-and-rescue operations by detecting wireless beacons attached to victims' clothing, track wildlife by photographing and electronic beacons, trace wildfires by photography, inspect power lines by photographing, deliver goods as payload, and even monitor storm systems by photographing. A drone can also fly around buildings and locate criminals abusing WiFi such as downloading child pornography or hacking. Other drone applications include supplementing E911 [18] and locating an improvised explosive device (IED), which may be configured to detonate on receiving a certain cellular signal.

A powerful technology often has two ethical sides. Mini drones can be abused. With SkyNet that is transformed from AR.Drone [29], attackers may compromise computers and control those bots from the air. Recreational drones can also be used for tracking and stalking people [30]. Drones equipped with HD cameras stir the concerns of property and personal privacy and security.

The contribution of this paper is two-fold. First, we will survey mini-drones on market and compare their specifications such as flight time and maximum payload. Regulations and issues of operating mini-drones will be investigated for proper use of drones. Second, we propose novel localization strategies via a single drone. In a localization scene, there are three participants: the target, infrastructure and third party. Based on who calculates the position of the target, we categorize localization into three categories. In *self localization*, the target calculates its own location by interacting with the positioning infrastructure. In *Infrastructure localization*, an infrastructure such as cellular towers pinpoints the location of a phone. In *third party localization*, a third party is neither the infrastructure or the target. For example, a drone equipped with an appropriate wireless sniffer can sense received signal strength indication (RSSI) and locate the wireless target responding to a request. We call such on-demand localization as third party localization. We propose a novel contour map based localization strategy and compare six different localization strategies for a thorough study of aerial localization via a single drone.

The rest of the paper is organized as follows. Section 2 reviews mini drones on market. We will investigate regulations and laws on the use of mini drones and compare features of selected drones on market. In Section 3, we introduce novel aerial localization techniques via mini drones. Our theory can now answer some unanswered questions in the bibliography. Experiment results are presented in Section 4. We conclude this paper and discuss future work in Section 5.

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2. STATE OF THE ART

In this section, we investigate drones on market, the cause of their popularity, laws and regulations and security and privacy concerns.

2.1 Drones on Market

This paper focuses on drones for civilian use, particularly mini helicopter based drones. Fixed wing drones normally can fly much longer because of the flight mechanism. However, a helicopter can take off and land vertically, hover at a fixed position, and fly at a low speed. For example, we find that a mini helicopter drone can achieve better localization accuracy than an airplane drone [24]. For those interested in military grade airplane based drones, please refer to AeroVironment Solar Puma AE [9] that is 13 pounds and can fly for more than nine hours, and Boeing Insitu ScanEagle that is 44 pounds, and can fly for over 20 hours [13]. For radio controlled (RC) airplanes, please refer to W.A.S.P [1] and various online stores such as `http://diydrones.com/`.

Table 1 lists 20 selected mini drones. We have carefully chosen a combination of low-end and high-end drones. Without explicit notes, in the rest of this paper, drones refer to those mini helicopter based drones. The data in Table 1 come from the Internet, related research or inquiry of the manufacturers. *R&D* refers to the existence of SDK (software development kit) programming the drone. *Band* refers to the telemetry radio working frequency. *Range* refers to the range of the telemetry radio controlling the drone. Most drones with GPS have the “return home” function so that the drone can travel to a remote site and return to the start position autonomously without the control from the radio. The flight time is the claimed flight time by the manufacturer, often referring to the flight time without payload or with default camera payload. *Base price* often refers to the airframe, some with the default payloads. Accessories will cost more. *user-config* refers to the fact configurations can be chosen by the user.

2.2 Rise of Mini Drones

We believe the following factors play the role in the increasing popularity of mini drones. First, the price of mini drones drops sharply. For example, Parrot AR.Drone 2.0 Quadricopter costs only $299.95 at Amazon. Second, mini drones have more fun with various sensors. They are not just toys for kids any more. Mini drones with HD cameras can take sharp photos and videos from the air. In Table 1, most drones are equipped with GPS. With GPS, the drone can take the specified waypoints autonomously and perform the programmed task. We can also attach our own payload such as a smartphone to the drone.

Moreover, drones are now easy to operate. According to a report from PC Magazine on March 8, 2014 [26], Android smartphones have a mobile market share of 51.7% and iOS has 41.6% while Apple has market share of 41.6% and Samsung has 26.7%. Therefore, most people carry either an Android phone or iPhone. They can use their smartphone to fly mini drones such as AR.Drone, Phantom 2 and Iris, instead of using a cumbersome joystick. Many drones provide a programming interface so that researchers and developers can experiment their own ideas of flying drones. For example, AR.Drone provides a Linux, Android and iOS SDK.

High-end drones can deliver small goods. According to Table 1, many such drones as Md4-1000 can deliver 1 pound merchandise easily to a remote site given its hour long flight time. Amazon Prime Air is a good example of utilizing such drones for advertisement and future commercial use.

2.3 Laws and Regulations

Currently, regulations and laws about the use of mini drones are still in progress. According to the Federal Aviation Association (FAA) [17], no approval is needed for flying model aircrafts including drones for recreation. Model aircraft flights should be kept below 400 feet above the ground level, should be flown far from populated areas and full scale aircraft, and are not for business purposes.

Therefore, the question is the commercial use of drones. According to NBC News in February 2012, the congress passed a bill requiring FAA open the sky for drones by Sept. 30, 2015. Since then, FAA has been developing regulations and policies slowly and it is generally expected that they will not meet the deadline. Most people expect that drones will be commonplace in US skies in the future. On March 07, 2014, Fox News reported that a federal judge dismissed the FAA’s case against a commercial mini drone user for filming. The reason for the dismissal is “FAA has no regulations governing model aircraft flights or for classifying model aircraft as an unmanned aircraft.” Although FAA issues some guidelines for mini drones, those guidelines are voluntary and cannot be used in court. The dismissal of this case implies that people can “now” use mini-drones for anything if there is no damage to properties before enactment of new laws on mini drones.

2.4 Security and Privacy Concerns

Drones are flying over the US continent for surveillance. FBI Director Robert Mueller acknowledged the use of drones for surveillance in June 2013. According to the report, FBI did not have guidelines for using drones and there were few regulations. FBI claimed that the drones were used very unregularly and “focused on particularized cases and particularized needs and particularized cases”. FAA predicts that some 10,000 drones will operate for law enforcement and commercial use within five years. Drones have an advantage over commercial helicopters because of its low cost.

The Fourth Amendment of the Constitution protects people’s privacy. However, does the space of a house belong to the owner of the house? A slew of regulations have to be developed about where mini-drones or regular drones can fly. Particularly, mini-drones are susceptible to weather such as strong wind and rain. What is the liability of the operator of mini-drones that crash and damage properties? In December 2013, FAA announced six sites for testing civilian drones and hope that the testing data “will help the FAA answer key research questions such as solutions for ‘sense and avoid,’ command and control, ground control station standards and human factors, airworthiness, lost link procedures and the interface with the air traffic control system.”

3. LOCALIZATION VIA MINI DRONES

In this section, we present our research on third party localization by mini-drones. Localization by drones can be used for public safety such as search and rescue, but may be used for malicious tracking of a person such as localizing the smartphone the person carries. We believe that the debate will move on and will focus on the technical side of localization by mini-drones.

Table 1: Selected Mini Drones

Name	Flight Time(m)	GPS (Y/N)	Base Price	Max Payload	R&D	Band	Range
AR. Drone [27]	18	Yes	\$299.95	200g	SDK	WiFi	WiFi
Spiri [16]	15	Yes	\$575.00	100g	SDK	WiFi Bluetooth	WiFi Bluetooth
ELEV-8 [31]	15	Yes	\$599.00	2lb	Open Source	N/A	N/A
Spyder Large [7]	18	N/A	\$719.00	2.2kg w/b	N/A	self-config	self-config
IRIS [8]	13	Yes	\$749.99	425g	Open Source	915/433Mhz	1km
Phantom 2 [5]	25	Yes	\$869.00	320g	SDK	5GHz	300m
Scout 3[27]	17	Yes	\$1,399.00	600g w/b	SDK	2.4GHz	3.6km
RTX-X1 [11]	25	Yes	\$2,499.00	N/A	N/A	2.4GHz	1mile
HX3 [23]	90	Yes	\$2999.00	N/A	Open Source	2.4GHz	1.5km
CineStar-6 Basic Kit [28]	24	Yes	\$3,199.00	N/A	N/A	900/433MHz	N/A
Xtreme 2.0 Gen II [11]	N/A	Yes	\$3,750.00	N/A	N/A	self-config	self-config
Hummingbird [12]	20	Yes	€3,515.00	200g	SDK	24GHz	1km
CoaX [15]	20	Yes	\$4,999.00	340g	Open Source	2.4GHz	<100m
MikroKopter [22]	25	Yes	€4,999.00	2.5kg	SDK	2.4GHz	4km
Pelican [12]	30	Yes	€5,195.00	650g	SDK	2.4GHz	1km
Draganflyer x6 [15]	20	Yes	\$26,000.00	500g	SDK	2.4GHz	200m
MD4-1000 [3]	88	Yes	€40,000.00	1.2kg	N/A	433/920/35MHz	500m
Q-4 [6]	90	Yes	N/A	3lb	N/A	N/A	10miles
SkyRanger [10]	50	Yes	\$100,000.00	N/A	N/A	900MHz/2.4GHz	5km
LinkQuad [2]	40	Yes	N/A	300g	Open Source	WiFi Bluetooth	1km

Wireless localization has been extensively studied although few work is dedicated to the case of using mini-drones. We now give a brief review of most related work. Subramanian *et al.* use a directional antenna to measure the angle of arrival (AoA) of packets from an access point (AP) in a moving vehicle [32]. With measurements of AOA and the GPS locations of the vehicle, a triangulation approach is applied to calculate the location of the AP. Han *et al.* does not use a directional antenna and use received signal strength indicator (RSSI) variation to derive the gradient of such variation [20]. They denote the gradients as *arrows*. These arrows point to the AP, whose location is derived by minimizing the sum-squared angular error from the arrows. Gradient descents are also used in wireless sensor networks [19] although our work is different from those work. Han *et al.* uses aerial vision and locates a target using landmarks on ground [21].

3.1 Novel Contour Based Localization

We first present the problem of locating a wireless target such as a smartphone. Without loss of generality, we assume the smartphone has the WiFi functionality. This assumption is justifiable given the popularity of WiFi enabled smartphones. The target is relatively static at a location. The mini-drone carries a wireless sniffer, flies around and measures RSSIs from the target. The problem is how to accurately locate the target. In [24], we used a smartphone converted wireless sniffer and the drone flied a Moore space-filling curve to cover an area of interest. Figure 1 shows a level 3 Moore curve.

Given the RSSI samples, we propose a novel gradient based approach for localization. First, we need to prove gradients still point to the target in the three dimensional (3D) case given that the drone performs the localization in the sky. Formula (9) is an approximated wireless propagation model,

$$P(d) = P(1) - 10\rho \log d + R, \tag{1}$$

where $P(d)$ is the RSSI measured by the sniffer at a distance of d to the target. $P(1)$ is the RSSI measured one meter away from the target. ρ is the path loss exponent that captures the rate of RSSI attenuation. R is a random variable that measures the RSSI variation due to multi-path effects, asymmetries in the physical environment and other imperfections in the model.

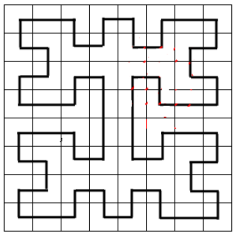

Figure 1: Level 3 Moore Curve

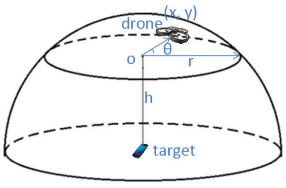

Figure 2: Aerial Localization

Now we derive the gradient when the drone flies in a horizontal plane $\mathcal{P}$ at an altitude of h above the ground as shown in Figure 2. The target is projected to $\mathcal{P}$ as O, which is the origin of the Cartesian coordinate system for plane $\mathcal{P}$ and is also the horizontal location of the target. We want to prove that a RSSI gradient measured by the drone points to O. Rewrite (9) as follows,

$$P(x,y) = -10\rho \log \sqrt{h^2 + x^2 + y^2} + P(1) + R, \tag{2}$$

where (x, y) is the location of the target on plane $\mathcal{P}$. The gradient $\bigtriangledown P(x, y)$ is the 2 partial derivatives of $\bigtriangledown P(x, y)$ at (x, y),

$$\begin{aligned} \bigtriangledown P(x, y) &= (\frac{\partial P}{\partial x}, \frac{\partial P}{\partial y}) & (3) \\ &= \frac{-10\rho}{h^2 + x^2 + y^2}(x, y). & (4) \end{aligned}$$

At (x, y), the angle of the drone to the origin O is θ. Obviously,

$$\theta = \arctan \frac{y}{x} = \arctan (\frac{\partial P}{\partial y} / \frac{\partial P}{\partial x}). \quad (5)$$

Therefore, in the plane of the flying drone, we can still use gradients to locate the target.

Now we introduce our strategy using a RSSI contour map for deriving gradients. A RSSI contour map consists of contour lines. A contour line is derived by connecting the GPS locations that have equal RSSI. The drone flies along the Moore curve in Figure 1 to collect RSSIs in the area of interest. The collected samples may be sparse. Therefore, we first perform necessary interpolation over the area and derive the contour map. Algorithm 1 gives the algorithm generating the contour map.

Algorithm 1 Generating Contour Map

```
Collect RSSI samples along the Moore curve flight route.
Generate a mesh grid (coordinates) over the area.
Interpolate RSSIs at coordinates of the mesh grid.
Derive the RSSI contour map.
```

Once the contour map is derived, we can use the contour map to derive the gradients. We use the inner contour lines which correspond to large RSSIs. Assume we have contour lines A and B, where A's RSSI is smaller than B's RSSI. We randomly pick up positions along line A. For each such position a, we find the closest position b along line B. Therefore, $\vec{ab}$ refers to the gradient. Once gradients are derived, we can minimize the sum-squared angular error of angles corresponding to these gradients to derive the target location. Algorithm 1 summarizes this localization strategy.

Algorithm 2 Localization via Contour Map Gradients

```
Require: Contour lines A, B, where B has stronger RSSI.
for each chosen random coordinate $a$ along line A do
    Calculate $a$'s distance to all coordinates along line B.
    Select a coordinate $b$ along line B and it has a minimum distance to $a$. $\vec{ab}$ is the gradient.
end for
Derive the target location by minimizing the sum-squared angular error of angles corresponding to gradients.
```

Figure 3 shows a RSSI contour map, generated from RSSI samples collected on a track field. The target is a smartphone in the hotspot mode. The curves in different colors show the contour lines with different RSSI values. Figure 3 shows: (i) Contours lines are not circular. These are consistent with practical observations of wireless attenuation from related research. Moreover, although we face the WiFi antenna of the smartphone downward, the construction of the smartphone may still affect the signal receiving process. (ii) Most contour lines are closed. This justifies the basic principle of Formulas (2) and (4). Therefore we can use the gradients on the RSSI contour map to derive the location of a target device.

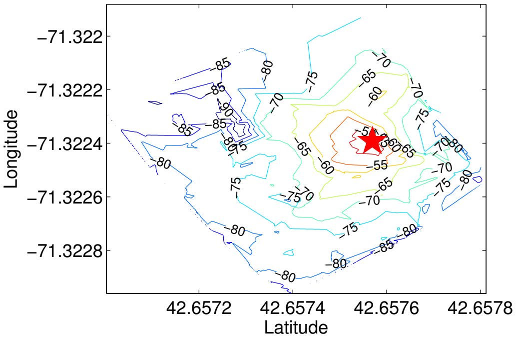

Figure 3: RSSI Contour Map

3.2 RSSI Model Based Localization

We also introduce the model based strategy for deriving the target location. Formula (2) gives the relationship between the RSSI and the distance from the target to the drone. Thus, when a drone flies in a plane at certain altitude, theoretically, the collected RSSIs form a curved surface. The strongest RSSI on this surface is located at coordinate O, where the distance to the target is minimum. Therefore, from RSSI samples collected by the drone, we can fit a surface and derive the formula of this surface. Then we calculate the location where the surface produces the maximum value and use this location as the target device's location.

We fit a polynomial surface using the least absolute residual robust (LAR) method over the data of the GPS coordinates and RSSIs. Figure 4 shows an example of fitting a polynomial surface of degree 2 in x and degree 2 in y using LAR.

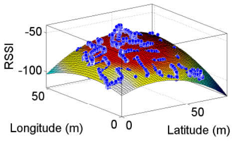

Figure 4: Model Based Localization

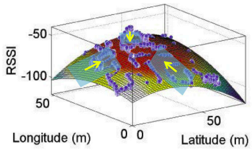

Figure 5: Gradient Based Localization

The formula that denotes the surface in Figure 4 is,

$$f(x, y) = p_{00} + p_{10}x + p_{01}y + p_{20}x^2 + p_{11}xy + p_{02}y^2, \quad (6)$$

where $p_{00} = -92.65$, $p_{10} = 0.6646$, $p_{01} = 0.6678$, $p_{20} = -0.01247$, $p_{11} = 0.01258$, $p_{02} = -0.0167$. (x, y) is the GPS location, and $f(x, y)$ is the RSSI at location (x, y).

To calculate the local maximum value, we perform a partial derivative with respect to the variables x and y and derive the formulas as below,

$$\begin{aligned} p_{10} + 2p_{20}x + p_{11}y &= 0, & (7) \\ p_{01} + 2p_{02}y + p_{11}x &= 0. & (8) \end{aligned}$$

Combining Formulas (7) and (8), we can get the value of (x, y). We do get a maximum RSSI value and the localization accuracy is 8.07m.

The model based localization strategy explains why the gradient approach in [20] works. In [20], the authors collect a few, for example 3 sets of RSSI samples from different directions toward the target. They then fit each set of RSSI samples to a plane and use the plane's gradient as the direction toward the target. By collecting multiple gradients, the target location is derived by minimizing the sum-squared angular error of these gradients. Apparently, as shown in Figure 5, RSSI samples from the target are distributed over a curved surface, not a plane. However, fitting them to a plane works since the gradient of the plane indeed points to the direction of the target. Figure 6 shows one example of the gradient approach in our context. The triangle in this figure is the true location of the target wireless device. The accuracy of this localization is 3.28m.

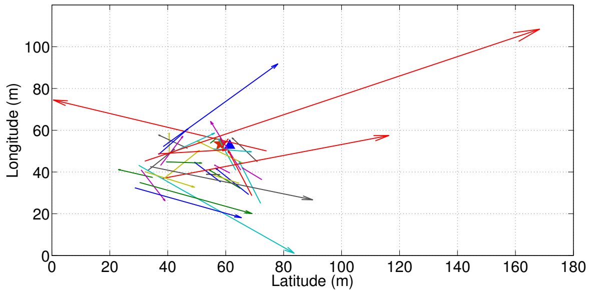

Figure 6: Gradient Approach

4. EVALUATION

In this section, we will introduce the experiment setup, recall a few existing localization strategies, present experiment results for our novel localization strategies and compare six localization strategies.

4.1 Setup

We performed real-world field experiments to evaluate the aerial localization via mini drones. The drone is a Draganflyer X6. The WiFi sniffer is converted from a Nokia N900 smartphone. Nokia N900 is a Linux powered smartphone and we install the WiFi sniffing software *Kismet* on it. We configured 12 smartphones as APs and randomly distributed them on a track field. The Nokia N900 running Kismet was attached on the helicopter to log packets from these 12 smartphones. RSSI can be extracted from wireless packet radiotap headers and Kismet also logs the GPS coordinates of receiving those packets. Kismet was configured to hop among all the channels (default mode). To test the accuracy for different flight routes, the drone flew level 1, level 2 and level 3 Moore curves, and we also performed warwalking around the track field.

4.2 Other Localization Strategies

In addition to the contour map based localization strategy and RSSI model based strategy, we have included results from known localization strategies for comparison. Here we give a brief introduction to those strategies.

Maximum RSSI Strategy: Kismet has the capability to log GPS coordinates where the wireless sniffer senses the maximum RSSI of a wireless device, and then saves the information into the file *.nettxt* automatically. Our first approach is to simply find the GPS coordinate where the sniffer receives the first maximum RSSI of the target device from the *.nettxt* file, and use this coordinate as the target device's location.

Centroid approach: We search and select all GPS positions where the strongest RSSIs are sensed. Then, we use the average value of these GPS positions as the target location. Among the logfiles generated from Kismet, there is a *.gpsxml* file which logs a mapping between the GPS coordinates and sensed RSSIs.

Quasi-Newton Strategy: Based on RSSI formula (9), we can calculate the location of the target device directly,

$$p_i = P(1) - 10 \times r \times \log d_i + R, \tag{9}$$

$$d_i = \sqrt{(D_g)^2 + (alt_i - alt)^2}, \tag{10}$$

where p_i is the RSSI that sniffer gets at the GPS location (lat_i, lon_i, alt_i). (lat, lon, alt) is the location of the target device. D_g is the great circle distance [14] between the target device and sniffer. Therefore, we can select four pairs of RSSIs and GPS coordinates, construct four equations and use the Quasi-Newton iterative approach to calculate the location of the target device. The initial value for the 1 meter signal strength was set as -5, the path loss exponent was 4, and the target device's initial position was set as the location derived from the centroid approach.

4.3 Comparison of Localization Strategies

Figure 7 compares the accuracy of various localization strategies. We can make the following observations:

- The novel contour map based localization performs almost the best and similar to the best in all cases. This strategy is more flexible than the gradient approach [20] since the gradient approach requires that measurements must be performed at one a side of the target. However, such requirement is not practical in aerial localization since the drone may fly over the target.

- The localization accuracy increases with the level of the Moore curve based flight route for all localization algorithms. This validates the Moore curve based flight strategy for accurate localization.

- Overall, the model based localization and Quasi-Newton localization perform the worst. This is understandable since all prorogation models including Formula (9) are approximate. The multipath effect and environment noise play a tremendous role for the poor localization result. Actually, the reason why we introduce the model based approach is to explain how RSSI distributes over the space in aerial localization.

- Surprisingly, the simplest approach - the maximum RSSI approach - performs the second best in all cases. One reason is the use of the space-filling curve based flight route. If very sparse samples such as only 3 samples are collected, other approaches such as the Quasi-Newton localization will help the localization accuracy.

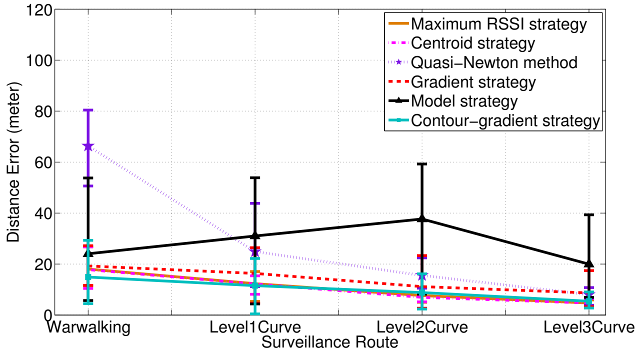

Figure 7: Localization Error by Different Strategies

5. CONCLUSION

This paper studies the applications and issues of the rising mini drones. Civilian applications of mini drones include public safety, aerial photography and many others. We compare features such as flight time and max payload of a selected list of mini drones, introduce related laws and regulations and discuss the security and privacy concerns. Because of a recent case, drones can be put into commercial use if no damage to properties and safety is incurred. We introduce our research on aerial localization via mini-drones. A contour map based localization strategy is proposed. We compare six localization strategies and find that the novel contour map based localization performs the best or similar to the best in all cases. Surprisingly, the simplest approach - the maximum RSSI approach - performs very well in all cases. Our future research includes localization of mobile targets and localization via a swarm of mini-drones. We also plan to perform a deeper investigation of the impact of drones on personal security and privacy.

6. REFERENCES

[1] Wireless aerial surveillance platform. `https://rabbit-hole.org/`, 2011.

[2] Linkquad. `http://www.uastech.com/platforms.htm`, 2014.

[3] md4-1000. `http://www.microdrones.com/products/products.php`, 2014.

[4] Parrot AR.Drone. `http://en.wikipedia.org/wiki/Parrot_AR.Drone`, 2014.

[5] Phantom 2 vision. `http://www.dji.com/product/phantom-2-vision`, 2014.

[6] Q-4 drone. `http://torrobotics.com/`, 2014.

[7] sky-hero. `http://www.sky-hero.com/`, 2014.

[8] 3D Robotics Inc. IRIS, all-in-one aerial performance. `http://3drobotics.com/iris/`, 2014.

[9] AeroVironment. Solar-powered puma ae small unmanned aircraft achieves continuous flight for more than nine hours. http://www.avinc.com/, August 2013.

[10] Aeryon Labs inc. . Skyranger. `http://www.aeryon.com/`, 2014.

[11] Ascending technologies. `www.robotshop.com`, 2014.

[12] Ascending technologies. `http://www.asctec.de/?locale=en_US`, 2014.

[13] Boeing. Scaneagle. http://www.boeing.com/boeing/defense-space/military/scaneagle/, 2014.

[14] C. Carter. Great circle distances. `http://inventeksys.com/GPS_Facts_Great_Circle_Distances.pdf`, May 2002.

[15] Draganfly Innovations Inc. Innovative uav aircraft & aerial video systems. `http://www.draganfly.com/`, 2014.

[16] P. Edwards-Daugherty. Meet spiri, the programmable, autonomous flying robot. designed for you and your projects. `https://www.kickstarter.com/projects/914887915/spiri`, 2014.

[17] FAA. Unmanned aircraft (UAS) questions and answers. `http://www.faa.gov/about/initiatives/uas/uas_faq/`, 2014.

[18] Federal Communications Commission. Enhanced 911 - wireless services. `http://www.fcc.gov/pshs/services/911-services/enhanced911/Welcome.html`, 2014.

[19] R. Garg, A. L. Varna, and M. Wu. An efficient gradient descent approach to secure localization in resource constrained wireless sensor networks. *IEEE Transactions on Information Forensics and Security*, 7(2):717 – 730, 2012.

[20] D. Han, D. G. Andersen, M. Kaminsky, K. Papagiannaki, and S. Seshan. Access point localization using local signal strength gradient. In *Proceedings of Passive and Active Network Measurement*, 2009.

[21] K. Han, C. Aeschliman, J. Park, A. C. Kak, H. Kwon, and D. J. Pack. Uav vision: Feature based accurate ground target localization through propagated initializations and interframe homographies. In *IEEE International Conference on Robotics and Automation (ICRA)*, pages 944–950. IEEE, 2012.

[22] HiSystems GmbH. Flight systems. `http://www.mikrokopter.de/en/products/flightsystems`, 2014.

[23] KMel Robotics LLC. Hx3 - next generation of aerial photography. `http://kmelrobotics.com/`, 2014.

[24] Z. Liu, Y. Chen, B. Liu, C. Cao, and X. Fu. HAWK: An unmanned mini helicopter-based aerial wireless kit for localization. In *Proceedings of Infocom*, 2012.

[25] T. W. Lynch. Commercial drone market stirs excitement (and worry). USA TODAY, `http://www.usatoday.com/story/tech/2013/09/24/reviewed-commercial-drones/2857355/`, 2013.

[26] D. Murphy. Comscore: Apple wins u.s. smartphone sales, android wins platform share. PC Magazine,`http://www.pcmag.com/article2/0,2817,2454740,00.asp`, March 2014.

[27] Parrot.com. AR.Drone. `http://ardrone2.parrot.com/`, 2014.

[28] Quadrocopter, LLC. Cinestar-6 basic kit. `http://www.quadrocopter.com/CineStar-6-Basic-Kit_p_405.html`, 2014.

[29] T. Reed, J. Geis, and S. Dietrich. Skynet: a 3g-enabled mobile attack drone and stealth botmaster. In *Proceedings of the 5th USENIX conference on Offensive technologies (WOOT)*, 2011.

[30] F. Samland, J. Fruth, M. Hildebrandt, T. Hoppe, and J. Dittmann. AR.Drone: security threat analysis and exemplary attack to track persons. In *Proceedings of the Society of Photographic Instrumentation Engineers (SPIE)*, 2012.

[31] Scout UAV. `http://www.scoutuav.com/`, 2014.

[32] A. P. Subramanian, P. Deshpande, J. Gao, and S. R. Das. Drive-by localization of roadside wifi networks. In *Proceedings of Infocom*, 2008.