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Capstone Project Writeup
GEOG 596B

Adventures building a low-cost, DIY drone for mapping

Introduction

Drone

In the not too distant past drones were mostly known as tools for military activities; the word drone mostly evoking aerial surveillance and strikes carried out by government entities and less so for their potential for humanitarian or other non-violent purposes (Currier, 2012; Sandvik & Lohne, 2014). In recent years there has been a surge in public interest, as well as commercial availability, supporting the civilian use of smaller aerial platforms. Drone use ranges across a variety of sectors including hobbyist, commercial, conservation, and humanitarian. A diversity of terms are used depending on the country and the context. The most common, apart from drone, are unmanned aerial vehicle (UAV), unmanned aerial system (UAS), and remotely piloted aircraft system (RPAS). This project uses the term drone to reference a small, remotely piloted aircraft that includes a flight controller onboard, operated by a pilot with radio transmitter and base station with telemetry.

The potential of drones

As civilian use of drones has risen, the variety of ways people utilize them has continuously grown. On YouTube you can find examples of drones used for cinematography[1] and there are events such as the New York City Drone Film Festival[2]. There are groups that focus on drone racing. Commercial applications include monitoring agriculture fields, rail or electric line inspection, production of materials for real estate sales, volume measurement for stockpiles or holes, and cargo delivery. Some of the commercial applications are still in the early stages, but as Amazon notes on the website regarding their in-development drone delivery service called Prime Air[3], "it looks like science fiction, but it's real". Drones have been used for public safety for response activities such as search and rescue and firefighting. Journalists have made use of drones when researching or documenting events. Conservation uses include environmental monitoring. Ways in which humanitarian operations can benefit from the use of drones include: mapping, delivering lightweight essential items to remote or hard-to-access locations, supporting damage assessments, increasing situational awareness, and monitoring changes (Soesilo, Meier, Lessar-Fontaine, Plessis, & Stuhlberger, 2017).

As the technology has become more developed and widely available many exciting opportunities have arisen. Resources such as "an expanding do-it-yourself drone community, low-cost UAVs and cameras as well as open-source software" is putting the technology within reach of those without significant financial capacities (Radjawali & Pye, 2017). This project is an exploration of available resources to show by example how drones can be utilized as a low-cost, aerial imagery collection platform for citizen science, humanitarian, and development purposes.

[1] https://youtu.be/BgC9ktMMbYE
[2] http://nycdronefilmfestival.com/
[3] https://www.amazon.com/Amazon-Prime-Air/b?node=8037720011

Background

Humanitarian interest

Before the rise of small drone systems, the UN was grappling with the use of large drone systems in peacekeeping missions. They found that drones “add[ed] to the complexity, and thus the challenges,” and that it was dangerous to believe that “technological solutions can alone solve complex problems” (Karlsrud & Rosén, 2013). The same cautions should be applied to the use of small drone systems outside of conflict settings. However, there is certainly great promise in the use of drones, as recognized early on in a UNOCHA report published in 2014.

The variety of case studies since that first report have grown and some of the recommendations have materialized (Gilman & Easton, 2014). For example, the UAViators Humanitarian UAV Network[4], pronounced you-aviators, was formed and works to establish and promote safe, coordinated, and effective use of drones in humanitarian and development situations. They have supported a variety of research, policy, and implementation activities. Their website includes resources such as a code of conduct and best practices. UAViators helps address key concerns regarding research and guidelines highlighted in the 2014 UNOCHA report.

Technology can help save lives, but excitement over the implementation of new technology should not preclude examination of possible consequences. Drones should be integrated into existing systems and the effects of their use on privacy and other matters carefully considered. Policymakers and drone operators should engage productively in the necessary dialogues, while also providing avenues of contribution for local authorities and communities (Htet, 2016; Lichtman & Nair, 2015). It is encouraging to see positive initiatives supporting research into the use of drones, such as the recent partnering of the government of Malawi and UNICEF to launch Africa's first air corridor to test the use of drones in humanitarian missions (“Africa’s first humanitarian drone testing,” 2017).

GIS at American Red Cross, International Services Department

I am on a small GIS team within the International Services Department (ISD) at the American Red Cross focused on our work with other Red Cross and Red Crescent Societies around the world. The International Red Cross and Red Crescent (RCRC) Movement works to prevents and alleviates human suffering. They adopted the Fundamental Principles in 1965 to express their values and guide their work. The principles are humanity, impartiality, neutrality, independence, voluntary service, unity, and universality (“The Seven Fundamental”, n.d.).

Our team supports disaster resilience, response, and recovery programs. We try to improve the creation, storage, and use of data to create information that can be used to increase the efficiency and impact of our humanitarian work. We try to be aware of interesting geospatial data and new technology. Recently we became interested in drones and initiated the exploration of the use of drones within our international programs and activities. The most direct integration of drones into the existing competencies of the GIS team is through mapping.

[4] http://uaviators.org/

Drone imagery for mapping

In a recent study, humanitarian professionals were 60% favorable of the use of drones in humanitarian crises and only 22% unfavorable, with the remaining 18% neutral. The use of drones that was most interesting for respondents was mapping. There are many examples of drones for mapping: the 2012 support of a post-earthquake census in Haiti, the 2015 mapping of Dar es Salaam, Tanzania for flood disaster risk reduction efforts, the 2015 small-scale mapping post-earthquake in Nepal, the 2015 damage assessments in Vanuatu after the devastating impact of typhoon Pam, and displaced persons camp management (Soesilo, Meier, Lessar-Fontaine, Plessis, & Stuhlberger, 2017).

For a small area there is considerable less cost and logistics surrounding the use of a drone compared to manned aircraft or satellites. A drone can be launched on short notice, to, for instance, take advantage of breaks in inclement weather. With drones it is feasible to collect repeat imagery of an area over short time intervals. The direct cost of a successful flight, assuming no accidents, is minimal; batteries need to be charged and there is some operational wear on the equipment. Drones can fly under atmospheric conditions, such as cloud cover, that would affect satellite imagery. The resolution and overall quality of imagery collected by drone can be much higher than other platforms. The benefits of higher resolution imagery become more pronounced in circumstances like dense, informal settlements. There are tradeoffs, for example in how much area can be covered, but there are many advantages.

The American Red Cross is one of the four founding members of the Missing Maps[5] Project. The collaborative initiative is intended to bring together digital volunteers and communities at-risk of disasters in order to put those areas on the map. The “map” in this case being OpenStreetMap; a community-built, open-source, global repository of spatial data. Tracing buildings, roads, and other features is a key first step before local knowledge can add value and enhance the utility of the map. In some parts of the world good imagery for that first step is not available. Drone imagery can help fill that gap.

Initial experiences

Changing regulatory environment

In the United States the FAA has established Small Unmanned Aircraft Regulations (Part 107). Work by a non-profit organization or research generally falls under commercial use. Recreational use of drones has fewer controls. Regulators have scrambled to keep up with technology and enact clear, sensible rules. There are still a number of ambiguities. For instance under Part 107, “you can’t fly a small UAS over anyone who is not directly participating in the operation, not under a covered structure, or not inside a covered stationary vehicle.” Does the drone have to pass directly over the person to violate that rule or is there some buffer around people on the ground that needs to be observed? Those writing the regulations “find themselves in the unenviable position of regulating a technology in its infancy” (Choi-Fitzpatrick, 2014).

When the FAA released the Part 107 regulations it allowed remote pilots to become certified after only a written test. Previously, remote pilot certification required that an individual first have a traditional pilot’s license, an expensive and time-consuming endeavor (Karpowicz, 2016). Any usage outside of hobbyist purposes, including activities conducted by humanitarian and research groups, requires the organization

[5] http://www.missingmaps.org/

have a certified remote pilot. The Part 107 regulations greatly lowered the barrier of entry for organizations to have staff trained and certified to fly drones. I am one of two individuals on the Red Cross ISD GIS team certified under Part 107 regulations.

Ready-to-fly drones

We learned on two ready-to-fly mapping drones: the Event38 E384 (below left) and the Tuffwing UAV Mapper (below right). Both are mid-range in terms of cost; they are in the range of $2,000 to $4,000, whereas some of the more advanced drones available on the market can cost tens of thousands. We joined Capital Area Soaring Association (CASA)[6], a local model sailplane and electric flying group, and regularly drove the 45 minutes to their field outside of Washington, DC to practice launching the drones, executing mapping missions, and landing.

Philippines mapping pilot project

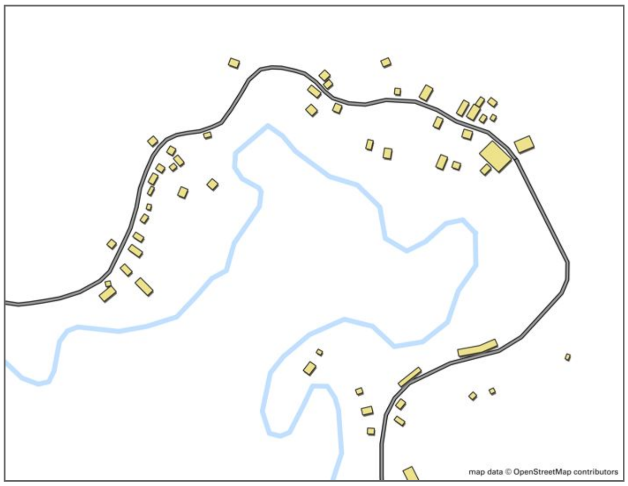
The ISD GIS team was able to pilot the use of drones for mapping in the Philippines. Alongside the Philippine Red Cross, the American Red Cross has been running a multi-year recovery program in Leyte, Philippines in response to the devastation resulting from the November 2013 landfall of Typhoon Haiyan. The program activities have included a range of activities to both rebuild and strengthen resilience and preparedness for future disasters. In May 2017, I led activities to collect high resolution aerial imagery of 23 towns and villages where program activities have occurred. Due to challenges finding suitably large, clear areas for the launching and landing of the fixed-wing drones we relied heavily on two DJI Mavic Pro quadcopters. The high resolution imagery was collected in order to create detailed, accurate, up-to-date maps of the areas which could then be used for various planning initiatives, analyses, and in any future disaster responses.

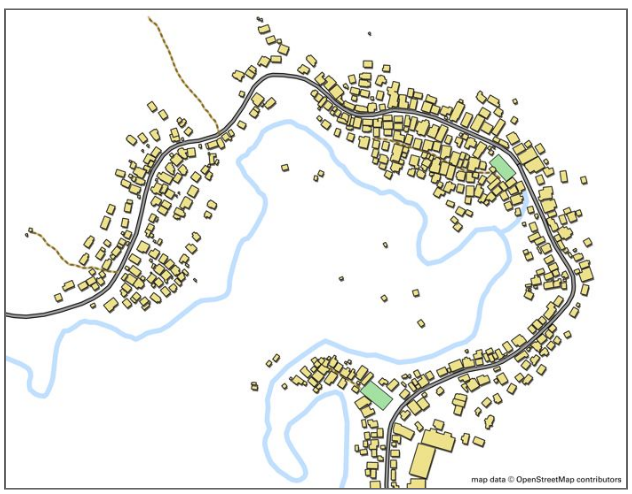
When flying drones it is important to comply with regulations, conduct activities professionally, and operate safely. Failing to do so could result in backlash against the future utilization of the technology. During planning stages we talked through the activities with the Philippine Red Cross. Then we communicated with all the local authorities

[6] http://soarcasa.org/

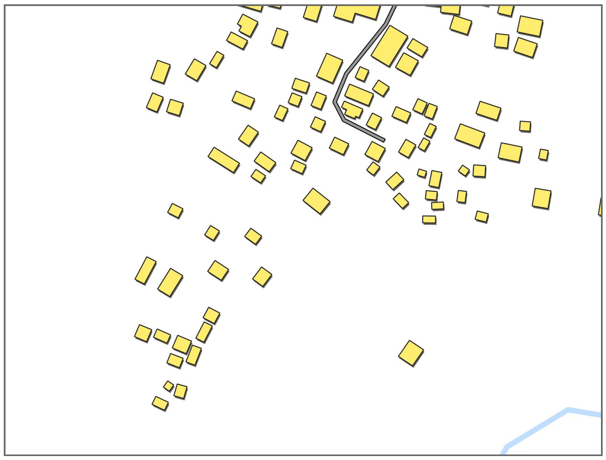
to obtain their approvals. We then obtained all necessary authorizations from the Civil Aviation Authority of the Philippines (CAAP). Preparation for the trip was a several month process!

Below is the OpenStreetMap data for one of the barangays created by tracing available satellite imagery (top left), drone imagery coverage from the pilot project (right), and the updated OpenStreetMap data after the drone imagery was used to trace features (bottom left).





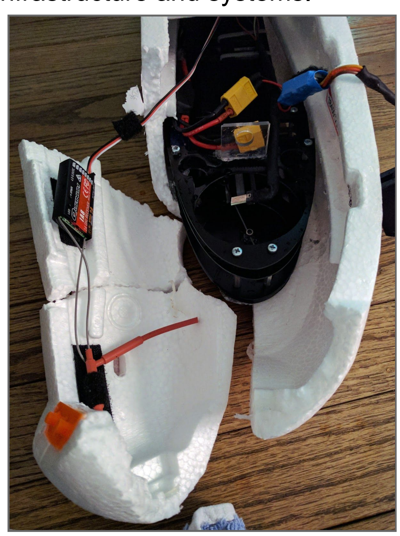
Below is another stark example of the difference focused tracing efforts using high-quality drone imagery can make even in denser, more urban areas. Note the differences between the OpenStreetMap data for another of the barangays created by tracing available satellite imagery (left) and after the drone imagery was used to trace features (right).



DIY rationale

The autopilot software and the electronic components of the two fixed-wing, ready-to-fly drones are open-source and readily available. The ready-to-fly mapping drones worked well, but paying a company to do all the hard work setting them up meant that we didn't really understand them. We ended up calling and emailing a lot when things did not work as expected. When practicing near home that was not an issue, but during our pilot in the Philippines we were many time-zones distant from the companies, with sometimes limited connectivity. The companies were responsive and helpful, but if we had been more involved ourselves in setting up the drones we would have been able to better troubleshoot and operate the drones.

Flying can be hard. If you have built something yourself it can be easier to practice flying. Learning through failure can be powerful; DIY reduces the negative consequences of failure. Rebuilding an airframe constructed from readily available materials is a lot less painful than sending in a multi-thousand dollar drone for repairs by the company. Also, every rebuild will improve your construction skills. Having built the drones yourself, it may be possible to make quick repairs, resulting in delays rather than permanent groundings when operating away from support infrastructure and systems.



Being able to control your drone manually is an important skill for emergency situations or in the event something goes wrong with a planned mission. Flying skill is also important for launching and landing in challenging environments. Our practice field outside of Washington, DC is a giant field of recently mown grass. Such ideal conditions were never present during the Philippines activities. With better piloting skills we may have been able to take advantage of some of the smaller areas that were available.

Patrick Meier is well known in the humanitarian drone realm and he has a great example of a team that successfully used a repurposed drone, which had originally cost under $3,000 and was held together with duct tape, to deliver medical cargo in the Amazon. The drone held together with duct tape beat out a $40,000 drone which did not work, even with the company present to support the operation. The technology doesn't have to be shiny or expensive; it just has to work.

While very sophisticated products are appropriate in certain circumstances, there are plenty of applications in which a customizable, more basic, hands-on approach can be beneficial. For example, mapping the buildings and roads of a village for resilience planning does not require the same level of accuracy as a survey for industrial mining. An environmental NGO with a single drone does not need their system to include automated mid-air collision avoidance for multi-drone operation, which is a feature included with some products on the market.

I want to know enough about the drones I intend to fly to be able to fix them with duct-tape. As I learned more, it increasingly seemed like do-it-yourself (DIY) was a feasible path to achieve that. If you have built a drone yourself it becomes easier to troubleshoot in situations where it may not be practical, or even possible, to get custom service support from the vendor. Quick repairs may be possible, resulting in delays rather than permanent groundings, when operating away from support infrastructure and systems. There is a lot of information on the internet about DIY drones and the tech components are increasingly available and affordable.

Building and flying

Foamies

My initial forays into DIY flying was building foamies. The nickname for these scratchbuilt remote controlled planes comes from the foam-core poster board used for the construction. The material is inexpensive and readily available from a number of sources, including Dollar Tree stores. There are a number of online communities organized around their construction, as well as businesses. Flite Test[7] sells kits, provides a forum, publishes manuals and guides, and provides free plans for most of their builds. My first builds were their FT Tiny Trainer (below left) and FT Spear (below right). Building these simple planes and having them fly gave me the confidence to expand my ambitions and think about building something that could carry more advanced electronics and a camera.

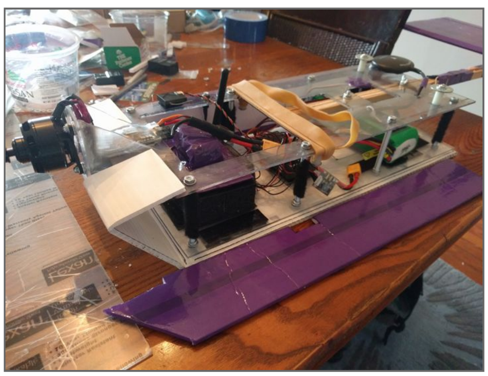
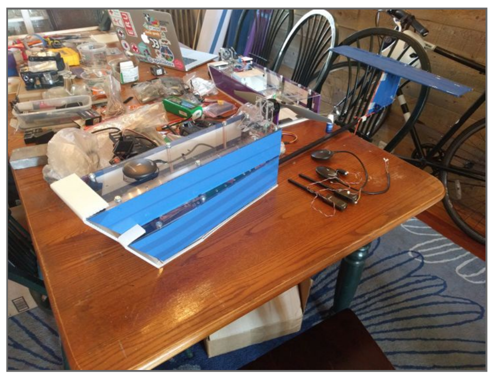
[7] https://www.flitetest.com/

Lexan skeleton airframe

My initial thoughts on airframe construction for a mapping drone were to sandwich the electronics between protective layers of polycarbonate sheets held apart by screws. It seemed sturdy and a good way to protect the electronics. I could then use foam-core board for the sides and front.

I experimented with a couple of iterations of both a pusher design, with the propeller at the back of the main fuselage, and version with the propeller at the front.

The materials did make for sturdy airframes. I crashed the prototypes multiple times. One of the attempts did go down in some woods and though I found the main fuselage, I did not find the tail and the small motors that were on it. But otherwise, despite destroying the airframes several times over trying to get them to work, I did not destroy any electronics.

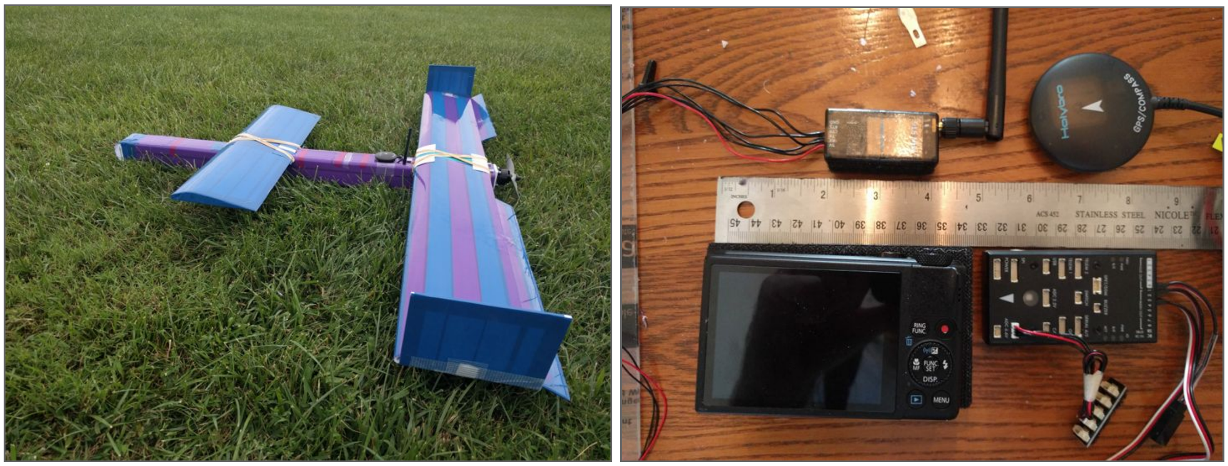
The prototypes were sturdy but simply too heavy and not aerodynamic enough. One attempt at overcoming this issue was to just upgrade to a bigger motor and propeller. Needless to say a bigger motor is also heavier and additionally made the drone less aerodynamic. It did not fix the problem. More work on paper to figure things out probably could have saved me some time, effort, and cash. Just because it looks like a plane does not mean it will fly like a plane.

Foamcore board airframe

After deciding that the lexan skeleton airframes were not a viable option, I was downtrodden but not void of all hope. Returning to the internet, I found Ed and his YouTube Channel ExperimentalAirlines. He has designed a foam-core board airframe dubbed the Ansley Peace Drone (APD). One version of it he describes as pushing 2 kilograms of total weight, which would be enough for everything I wanted to carry for mapping.

The design is simple with a single fuselage tube, a front canard wing, and a large rear wing. The only control surfaces are two elevons on the rear wing. Airframes more commonly have 4 controls surfaces: ailerons on the wings, and an elevator and rudder on the tail. The 2 elevons of the APD combine the pitch control of an elevator and the roll control of ailerons, halving the number of control surfaces and servos needed. Pre-covering the foam-core board gives added strength and water resistance.

ExperimentalAirlines has a large number of videos uploaded. I watched them all and built a variation of Ed's APD. The camera is in the front. During tests and practice flights, I replaced the camera with an equivalently weighted and sized cardboard box. Within the fuselage tube following the camera is the battery, the various electronics for autonomous flight, and then the motor in the back.



The final airframe (left) and some of the electronics (right)

Mapping

DIY autonomous flight

The autopilot functionality of the drone lets it fly a path and trigger a camera with the precision needed to achieve the necessary coverage to map an area. The hardware component I chose to use in the drone for autonomous flight, the open-source Pixhawk flight controller, is manufactured by a number of companies. The Pixhawk is part of ArduPilot[8], an open source autopilot system with a community behind it and with lots of resources available online. The firmware for the drone, as well as the Mission Planner[9] software to run a ground control station, is open-source and freely available.

Imagery products

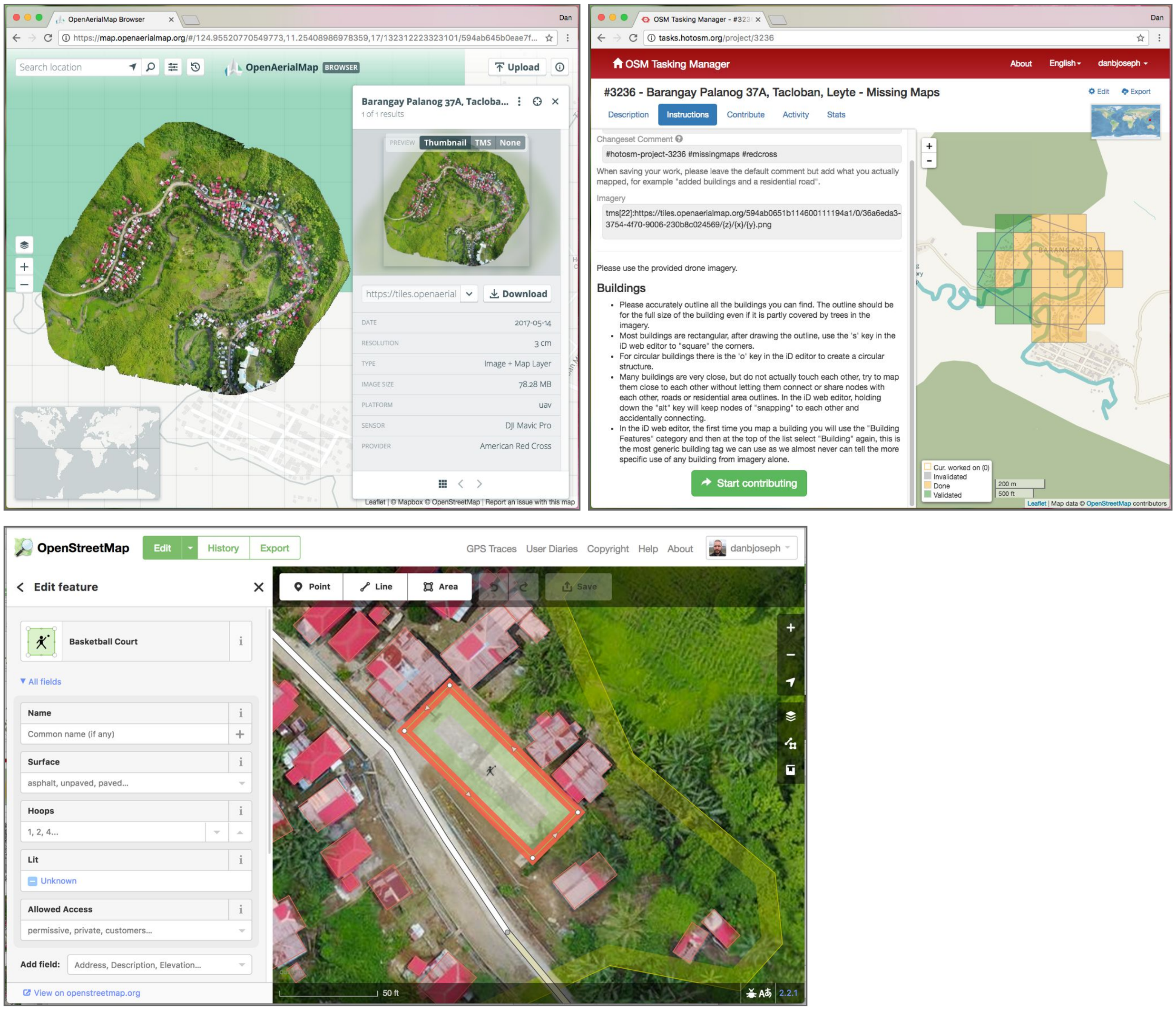
Creating imagery products for mapping requires taking a lot of pictures. In order to stitch the images together you need overlap between each picture taken along a pass and sidelap between pictures of adjacent passes. Features on the ground need to show up in multiple pictures to match pictures and successfully stitch them into a single product. OpenDroneMap[10] is an open source toolkit for processing aerial drone imagery that makes it possible to mosaic and orthorectify images without paying thousands of dollars in licensing fees. With OpenDroneMap and a collection of images it is possible to produce geotiffs and digital surface models. These derived products are much more useful than the individual pictures.

OpenAerialMap and OpenStreetMap

There are plenty of data and GIS portals that get it wrong (Mheadd, 2015; Timoney, 2013) but some are starting to get it right. The Humanitarian Data Exchange[11] has done a laudable job of bringing together open datasets in an accessible, searchable manner. Specific to imagery, especially drone imagery, is OpenAerialMap[12]. It is a great platform for easily sharing and discovering openly licensed imagery. It allows users to upload imagery and discover what imagery is available for a given area. The imagery is

[8] http://ardupilot.org/
[9] http://ardupilot.org/planner/docs/mission-planner-ground-control-station.html
[10] http://opendronemap.org/
[11] https://data.humdata.org/
[12] https://openaerialmap.org/

made available as a TMS tile service and can be loaded into OpenStreetMap editors[13], used to trace features, and update the map. The Humanitarian OpenStreetMap Team Tasking Manager[14] lets you define a grid over an area of interest so that digital volunteers can check-out squares to collaborate effectively in updating an area of the map. We were able to quickly update OpenStreetMap as part of our work in Philippines using OpenAerialMap and the Tasking Manager. All of our imagery is available for others to use[15] and the tracing efforts are now part of the OpenStreetMap database.



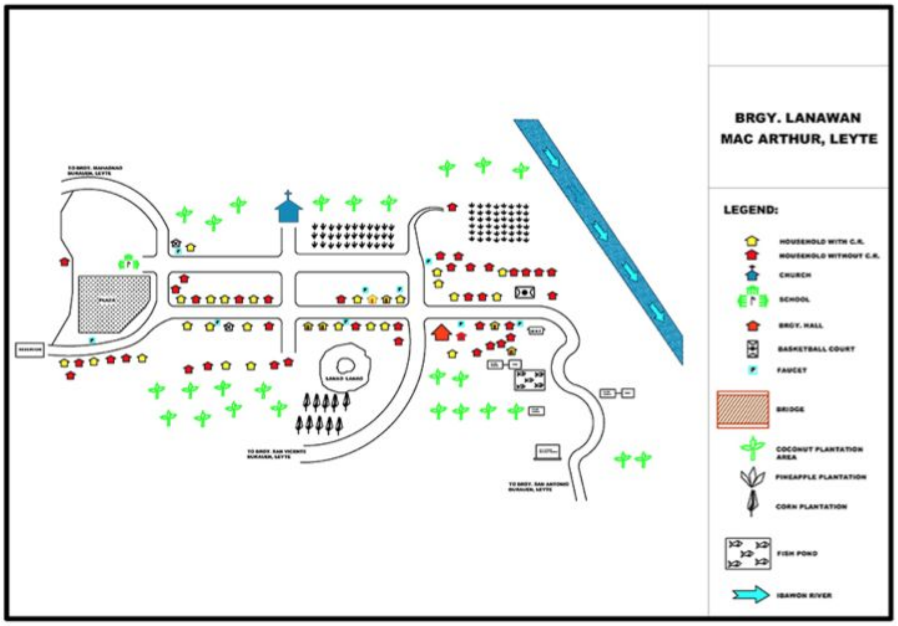
OpenAerialMap imagery brower (top left), the Tasking Manager (top right), and the OpenStreetMap iD editor (bottom)

Improved maps

When data are interpreted or presented in a meaningful manner they become information. Below is one of the maps used by local government in the Philippines for planning purposes. It contains a fair amount of detail but is not particularly geographically accurate. Organizations that want to work in the villages usually ask for maps and are often not satisfied with the sometimes hand-drawn offerings. When informed

[13] https://wiki.openstreetmap.org/wiki/Editors
[14] http://tasks.hotosm.org/
[15] https://goo.gl/UV6WhB

of the mapping purposes behind the drone flights conducted during the Philippines activities, community leaders were excited by the prospect of more accurate maps.



With accurate base maps you can collect additional data for more advanced analyses. The below image is of an area of Zimbabwe where American Red Cross supported a community mapping project. In addition to data like addresses, we helped people collect other details such as structure type and perceived condition. In the image below, the red houses are those perceived as the poorest quality. Additional data seemed to show a correlation between the poor quality and concrete structures. Conversations with the locals revealed that those were older, government-built structures. The data was supported by the anecdotal evidence, all of which then provided guidance when planning future programs in the area. Humanitarian organizations tend to be resource constrained and so effective allocation of program resources is important.

Next steps

Airframe refinements

The airframe I am currently working with requires that the camera be mounted sideways in the drone. Ideally, the camera's top would point towards the front of the drone in an orientation to the flight path so that each image captures more ground to either side of the drone instead of along the flight path. Having it as such would allow flight passes when mapping to be spaced farther apart while still achieving good side-lap for image stitching.

The airframe would benefit from being refined in other ways. There are advanced techniques from Ed's APD build videos, such as folding wings and magnets to attach the winglets, that would make the drone easier to pack and transport. My documentation is heavily reliant on referencing segments of the various APD build videos. I would like to bring the instructions together into a single, seamless narrative. The build process needs to be better documented so that it is easier to follow along, learn, and build something successfully on a first attempt. Although I did my best to document as I went along, my process was constantly changing as I learned more.

Open-source OS for the ground control station

The Mission Planner software I have been using only runs on Windows. A newer software called QGroundControl[16] is available and it runs on Windows, OS X, Linux, iOS and Android. Eliminating the need to pay for a Windows license by running a Linux operating system would further reduce the costs of building and flying a mapping drone.

Processing in the field

During the Philippines activities we did some of the image processing using OpenDroneMap running on an Intel NUC mini-computer with 32 Gigabytes of RAM. Processing was the most significant bottleneck during our activities. Improvements to OpenDroneMap, some of which are already being worked on by the developers, would let us scale up and take significantly more powerful hardware into the field. One possibility is to link multiple NUCs as separate nodes and divide the processing work between them. Ideally we would like to collect imagery all day and process it all locally overnight, making the products available the next morning.

Better georeferencing

I want to explore more accurate georeferencing. One method of georeferencing involves the images being individually geo-tagged from the flight computer onboard the drone and using those geo-tagged coordinates to georeference the mosaic output. But the images might be off-nadir resulting in the center of the image not being the location of the drone above the ground. To match an image with coordinates along the flight path, either the trigger signal or some sort of feedback signal from the camera, such as

[16] http://qgroundcontrol.com/

through the camera hotshoe, is usually recorded. There can be an offset between the signal used and when the camera actually took the picture. The accuracy of the GPS hardware onboard the drone is yet another limitation. If various errors and inaccuracies compound, the accuracy of the mosaicked output can suffer.

Ground control points, identifiable features in the imagery with associated coordinates, can be used to georeference more accurately than the previously described method. I have experimented with DIY ground control points. I came up with 12 unique designs, borrowed a sewing machine, and made 1 meter by 1 meter flags that can be laid out during imagery collection to create easily identifiable features to serve as ground control points. My design consisted of a white on black or black on white cross with patterns of smaller squares in the corners.

From left to right: sketching my designs, sewing, a ground control point as seen from the ground with a Garmin GPS device laid at the center, and a ground control point visible in imagery taken in the Philippines.

So far, I have only used the waypoint averaging function of a Garmin GPS62 handheld to collect the coordinates of the ground control points. However, even without an expensive GPS device the ground, control points improved the georeferencing, as judged by comparison to satellite imagery and GPX traces along paths and roads. There are possible efficiencies in the deployment and use of GCPs and more robust GPS hardware options for collecting the coordinates of GCPs. There are also options to improve georeferencing such as using GPS records from a ground control station to correct the recorded coordinates of the drone’s flight path.

Alternative airframes

Fixed-wing drones tend to be simpler in structure than rotary, which can result in less complicated maintenance and repairs as well as increased operational time at a lower cost. The aerodynamic structure of a fixed-wing results in longer flight times. The wings generate lift, as opposed to the thrust from the motors as with rotary drones. This means that many fixed-wing models can still be successfully landed even in the result of motor failure, assuming the control surfaces are still powered and adjustable by the transmitter held by the remote pilot. Compared to fixed-wing, rotary drones tend to have slower cruise speed, less wind resistance, and shorter flight times. However, they require a much smaller takeoff and landing area, have no minimum cruise speed, can hover in place, and have more detailed control in flight. Right now I am focused on fixed-wing designs but that doesn't mean in the future I won't look at quadcopters, hexacopters, or even octocopters. Vertical takeoff and landing designs (VTOLs) are also an airframe type I would love to explore. But one thing at a time.

Alternative cameras

For remotely sensed data collected via drone there are a variety of sensors available. Numerous commercially available digital cameras have been successfully used for collection of 3 band, RGB aerial imagery. Examples include the Canon Powershot S110, which can be custom configured using Canon Hack Development Kit software[17]. The Sony Nex series is also popular; as is the Sony QX1, which is a mirrorless camera meant to be used with a mobile phone, so it benefits from a smaller profile and lighter weight than cameras with similar specifications that have features such as a built-in viewing screen. Action cameras such as the GoPro are desirable for being rugged, small, and lightweight. Some of the newer action camera models have integrated GPS. The megapixels, sensor size, lens specifications, and camera body all affect the effectiveness of a camera for use on a drone (Miguel, 2015). It would be interesting to do a detailed review of the various options available on the market.

Advanced sensors

Other types of sensors are available but their specialized nature and newer presence on the market means a much higher price tag. Drones can carry multi-spectrum cameras, most commonly for plant health analysis. MicaSense produces the Parrot Sequoia[18] which captures green, red, red edge, and near IR, as well as the RedEdge[19] which captures blue, green, red, red edge, and near IR. These rugged, compact, lightweight sensors are marketed towards professionals and carry price tags of $3,500 and $5,195 respectively. There are thermal cameras that can be mounted on a drone such as the FLIR Vue[20], which costs $1,500. Lidar sensors are also being made small and light enough to be carried by a drone with examples such as the Velodyne HDL-32E[21] and the Routescene UAV LidarPod[22]; however, the associated cost means these are still beyond the reach of most.

Conclusion

The learning process

Everything for the drone, minus a laptop for the ground control station, comes in at just over $1,000. The airframe itself is by far the cheapest part of that. It is easy to crash, learn from mistakes, and rebuild, as long as the crashes are not serious enough to damage your electronics. The effort required for the entire process is significant, but I think the payoff in terms of understanding the drone you will be flying is worth it. I have put, and will continue to place, all the resources and experiences I am accumulating up on the internet[23], so hopefully others can benefit and duplicate what I havedone. I also presented[24] on my work at FOSS4G 2017 and there was considerable interest. Hopefully people will tell me what I'm doing wrong, what worked for them, and help improve what I've done.

There are numerous online communities focused on a DIY ethic. These include both ones with a general focus that include projects involving drones, such as Instructables[25] and Make:[26] and ones specific to

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[17] http://chdk.wikia.com/wiki/CHDK
[18] https://www.micasense.com/sequoia/
[19] https://www.micasense.com/rededge/
[20] http://www.flir.com/suas/vue/
[21] http://velodynelidar.com/hdl-32e.html
[22] http://www.routescene.com/products/product/uav-lidarpod/
[23] http://danbjoseph.github.io/drones
[24] http://foss4g.guide/#9M4SVbV9EHnkBbgCPl
[25] https://www.instructables.com/

drones, such as the aptly name DIYDrones[27]. There are communities surrounding the various open source softwares that made this project possible. Open source communities thrive when people participate and contribute back. These communities are an excellent resource to learn, ask questions, share, and gather feedback. By learning, building, and sharing, I have hopefully helped to strengthen these communities and added resources that might support others. Humanitarians, citizen scientists, and other such groups interested in mapping with drones can and should look to DIY and open source solutions.

Whether flying a drone you built or bought, it is important to understand the regulations wherever you may operate and follow them. Best practices prioritizing safety should be followed regardless of the legal framework in the place of operation. If the drone users utilize the technology safely and appropriately, it will help the positive benefits to society across sectors outweigh the negative and make it easier to leverage the technology in the long-term.

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[26] http://makermedia.com/
[27] http://diydrones.com/

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