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The Development of an Airport Obstruction Identification System

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16. Abstract

The State of New Jersey is extremely populated and rather small geographically. In order to ensure safety at all of the airports in New Jersey, an airport obstruction identification system must be developed. The New Jersey Department of Transportation (NJDOT) Division of Aeronautics is statutorily obligated to identify all obstructions to the approaches at the State's public use airports and heliports; and to have these obstructions removed. The objective of this research is the development of a prototype system to easily acquire data either at fixed intervals or over time and generate a tree removal or trimming plan for discretized trees or tree areas.

There are many different technologies that could be used for raw data collection at the airfields. It was subsequently determined that a radio-controlled helicopter rather than a blimp, balloon, or airplane would be better suited for the needs of this project. From a proof of concept perspective, the project was a success. Even though certain technical obstacles such as vibration were not overcome in the full-scale implementation, the development of an airport obstruction identification system utilizing low altitude mapping technologies is an extremely promising technology. Once fully developed, it can enable NJDOT to accurately identify, map, and remove trees that are currently posing a danger to arriving and departing aircraft at various airports within New Jersey. It will also enable the DOT to remove the suspect vegetation from property the first time, without missing any obstructions. The technology used within this project has the potential for use in many different future applications. Other uses for this technology include the possibility of use with DOT's search and rescue operations and accident investigations.

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ABSTRACT

The State of New Jersey is extremely populated and rather small geographically. In order to ensure safety at all of the airports in New Jersey, an airport obstruction identification system must be developed. The New Jersey Department of Transportation (NJDOT) Division of Aeronautics is statutorily obligated to identify all obstructions to the approaches at the State's public use airports and heliports; and to have these obstructions removed. The objective of this research is the development of a prototype system to easily acquire data either at fixed intervals or over time and generate a tree removal or trimming plan for discretized trees or tree areas. The areas will be identified using state of the art technologies, such as Global Positioning Systems (GPS). Once the data has been collected, the information will then be post processed through the use of advanced computer software systems.[1]

There are many different technologies that could be used for raw data collection at the airfields. For this project, five such technologies were examined. These five included LIDAR, ground based tools, cranes/lifts, normal aircraft, and radio-controlled aircraft. The fifth technology, the use of a radio-controlled (R/C) aircraft was finally selected for use on this project. It was subsequently determined that a radio-controlled helicopter rather than a blimp, balloon, or airplane would be better suited for the needs of this project.

From a proof of concept perspective, the project was a success. The system was integrated and used to acquire sample data. The data was then analyzed and compared against "truth" data. There was a high degree of correlation between the manually collected data and the computer generated analyzed data. The project then moved toward full-scale implementation and automation.

Even though certain technical obstacles such as vibration were not overcome in the full-scale implementation, the development of an airport obstruction identification system utilizing low altitude mapping technologies is an extremely promising technology. Once fully developed, it can enable NJDOT to accurately identify, map, and remove trees that are currently posing a danger to arriving and departing aircraft at various airports within New Jersey. It will also enable the DOT to remove the suspect vegetation from property the first time, without missing any obstructions. The technology used within this project has the potential for use in many different future applications. Other uses for this technology include the possibility of use with DOT's search and rescue operations and accident investigations.

BACKGROUND

The State of New Jersey is one of the smallest state's in the country yet is the most densely populated. As you can see in Figure 1, there are many different operating airports in the State. New Jersey has a total of 479 licensed aviation facilities. Of those, 45 are public use airport that base about 4,200 aircraft.[2] Many of these airports are nestled within residential communities and are surrounded by dense vegetation. As vegetation grows, primarily large trees, they begin to impede on the airspace of the airport. In doing so, the trees begin to encroach upon the glide path for the airport. The glide path is the angle at which an aircraft ascends or descends when departing and arriving an airport. However, when a tree encroaches on an airport's glide path it causes a hazard to aircraft using that particular facility. As a result aircraft may be forced to deviate from a given glide path to land safely. However, collisions with a vegetative obstruction do occur which many times results in injuries and fatalities to both crew and passengers.

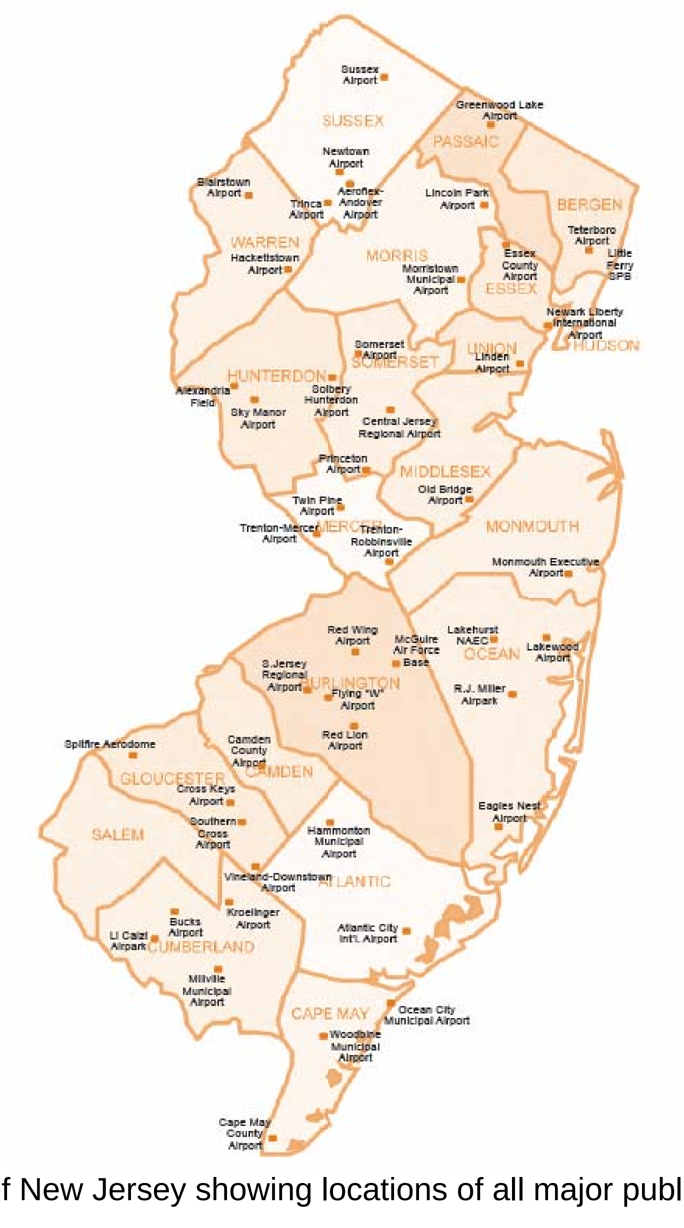


Figure 1: Map of New Jersey showing locations of all major public use facilities.[2]

The photograph shown in Figure 2 is an aerial view of Blairstown Airport in Warren County, New Jersey. This picture was taken in the fall and thus the color variations in the trees give the ability to pinpoint individual trees. This is an extremely useful tool, but unfortunately the timeframe per year is extremely limited to acquire such images. However, from the picture of this airport during the fall, the obstructions on each end of the runway can clearly be seen as consisting of heavy, very condensed vegetation with 60-70 ft trees surrounding the entire airport. The tree area of greatest concern is at both ends of the runway. The estimated maximum heights of the trees are approximately 60-70 ft. This airport is an excellent example of the vegetative conditions surrounding airports throughout the State.

Figure 2: Aerial photograph of Blairstown airport in northern New Jersey.[3]

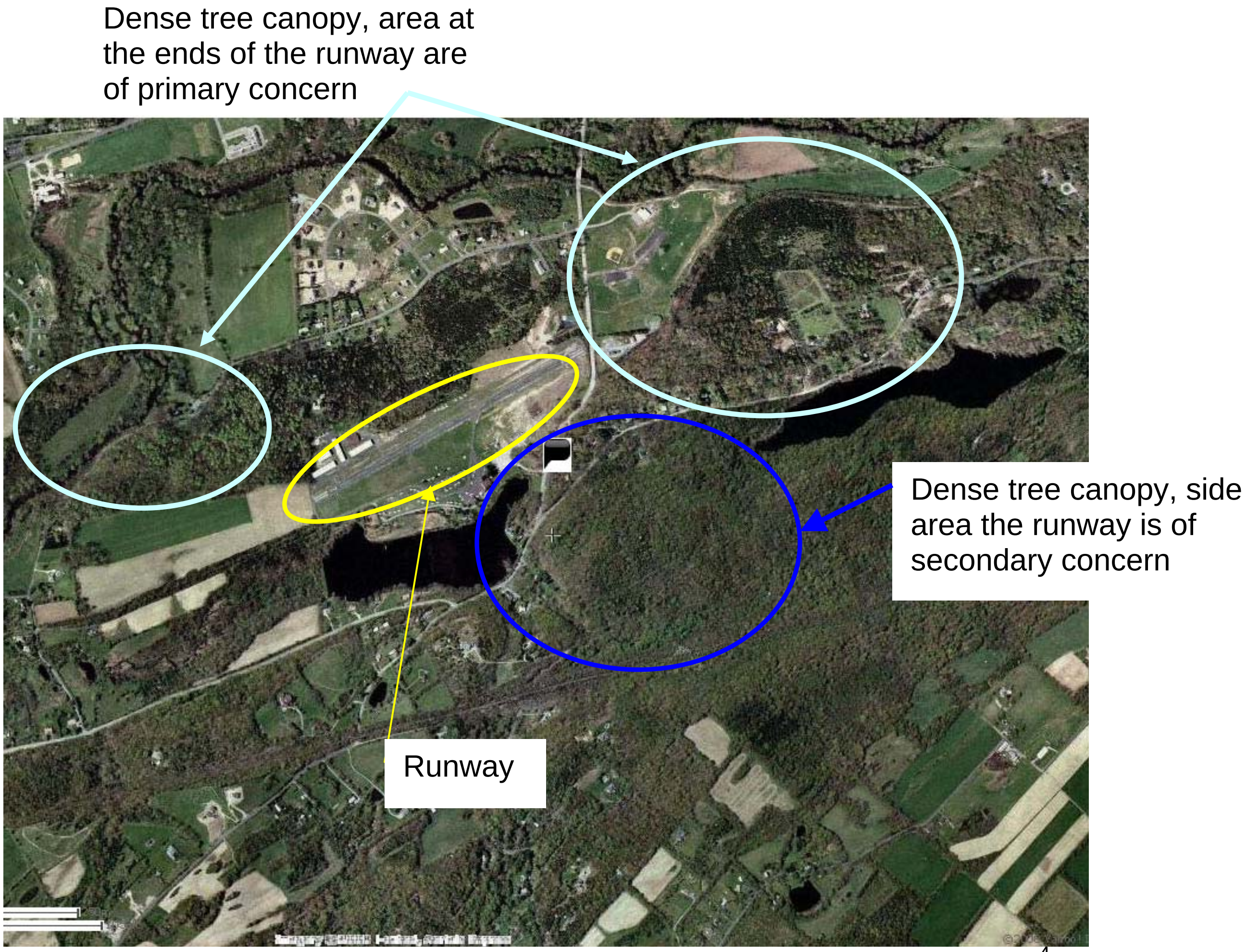


Figure 3: Satellite image of Blairstown airport showing dense tree growth.[4]

PROJECT GOALS

In order to ensure safety at all of the airports in New Jersey, an airport obstruction identification system must be developed to minimize the chance of aircraft collisions with vegetation on arrival or departure from a facility. The NJDOT Division of Aeronautics is obligated to identify all obstructions to the approaches at the State's public use airports and heliports; and to have these obstructions either remedied or removed. In many cases, the first line of trees (when observing from the runway) may be shadowing other obstructions that are not visible until the first line of trees is removed. Since tree removal or trimming often impacts surrounding landowners, multiple cuts or frequent removals are not desirable, and in some jurisdictions are not feasible. A device or methodology for the State to identify a tree removal or trimming strategy is necessary, such that the trees surrounding the airport will remain within regulations between cuts.

Identifying strategies to comply with the Federal Aviation Administration (FAA) regulations regarding maximum tree heights surrounding airports is a continuous obstacle nationwide. In over 30 recent instances cited for situations requiring tree removal or trimming for areas surrounding existing airports or expanding airports, no scientific method for tree identification was used. In all cases, human inspection was used to determine which trees should be removed or trimmed and in many cases, mass clusters of trees were simply cut down altogether. In the literature search conducted, there was no existing device or scientific method found to inexpensively, quickly, and accurately identify a tree trimming or removal strategy for airports to meet the FAA maximum height regulations. Several projects and prototypes are underway nationwide while other methods are extremely expensive and are time/labor intensive.[1]

This problem is almost impossible to solve using ground based technologies, without entering properties and surveying the trees one at a time. As shown in Figure 4 and Figure 5 a tree that is clearly an obstruction can be obscured from ground view by other trees directly in the line of sight. This fundamental problem is created by the first line of trees that may be shadowing other obstructions that are not visible until the first lines of trees are removed. Since tree removal/trimming often impacts surrounding landowners, multiple cuts or frequent removals are not desirable and in some jurisdictions are not feasible.

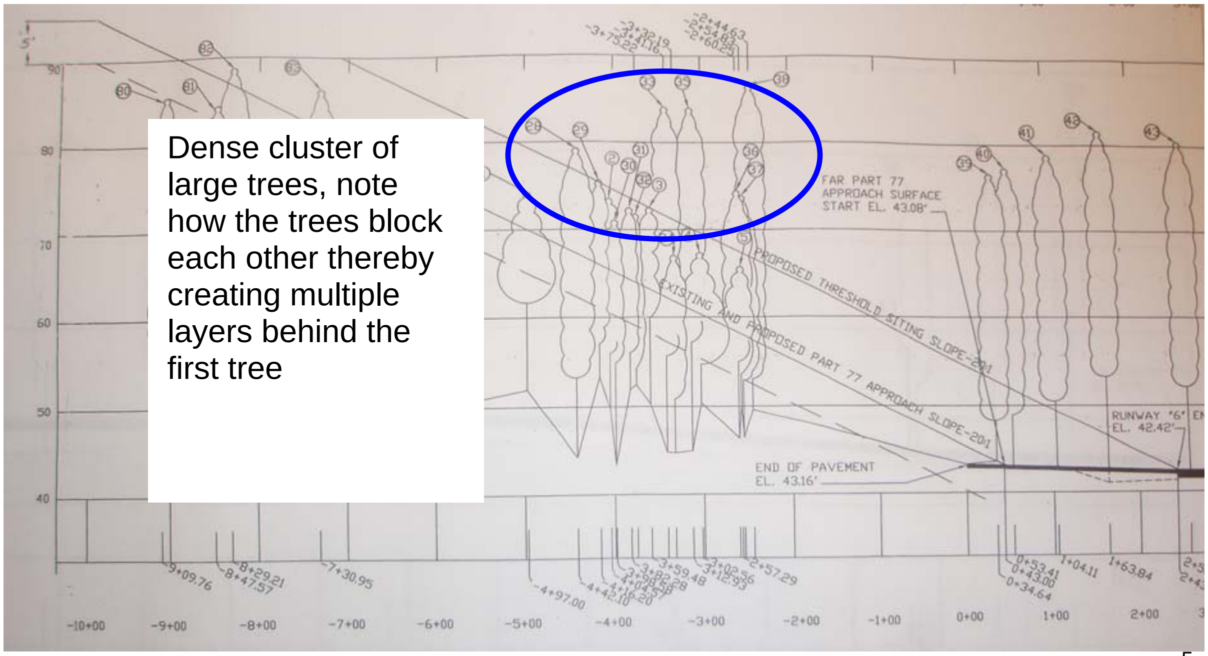
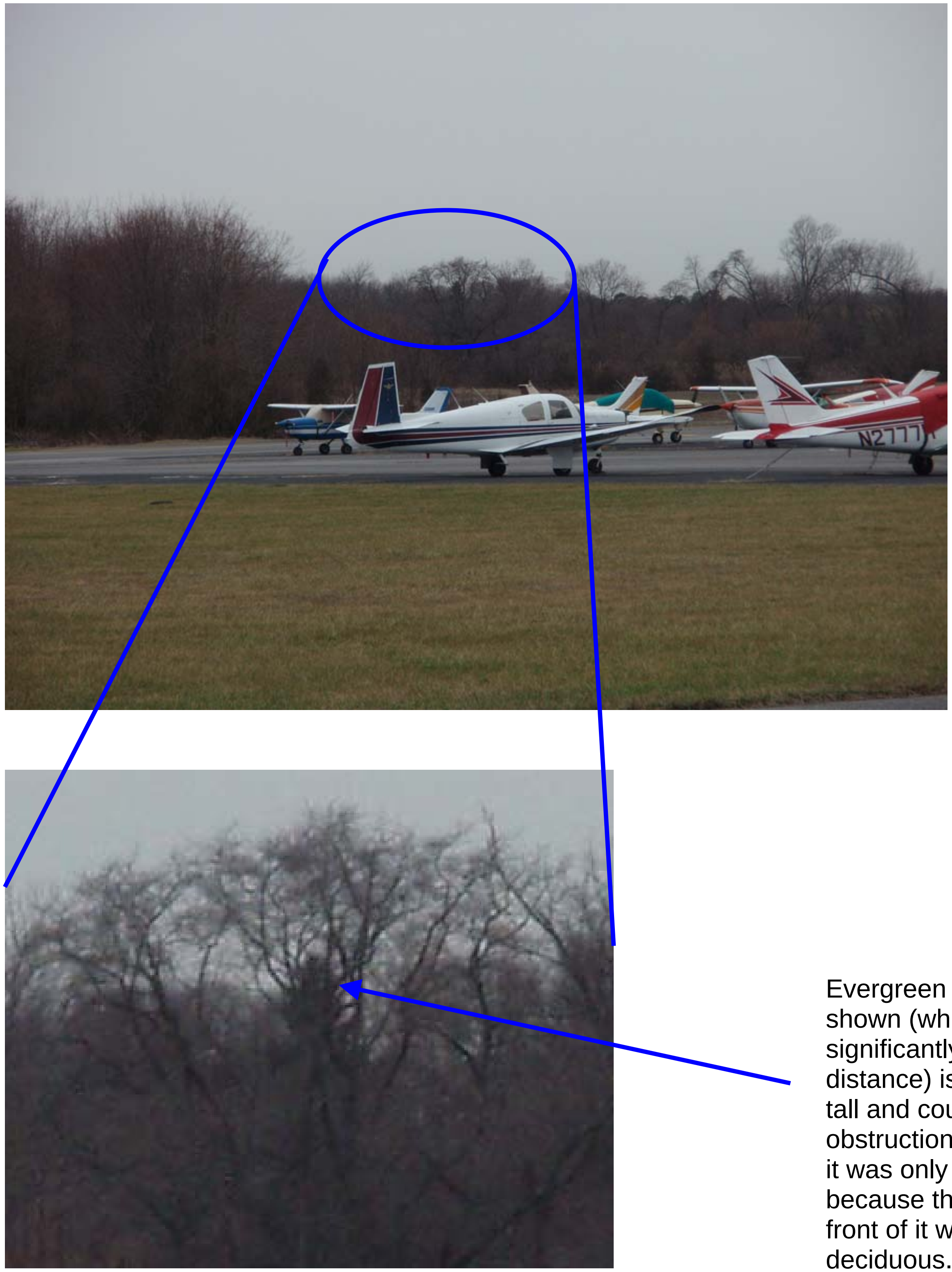

Dense cluster of large trees, note how the trees block each other thereby creating multiple layers behind the first tree

Figure 4: Image showing typical tree trimming plan and second layer obstructions. [5]



Evergreen tree shown (which is significantly in the distance) is rather tall and could be an obstruction, however it was only observed because the tree in front of it was deciduous.

Figure 5: Image showing second layer obstruction.

Identifying a tree removal or trimming plan electronically involves four basic steps:

1. Acquiring appropriate 3-dimensional data from cameras, sensors, and similar appropriate monitoring devices.
2. Using modern pattern recognition and intelligent decision techniques to process the 3-dimensional data obtained.
3. Electronically discretize the continuous 3-dimensional space into trees or tree areas.
4. Electronically produce a plan for tree removal or trimming for the discretized spaces.

The question may be asked if the U.S military has used this type of technology (unmanned aerial surveying aircraft) for years, why is DOT spending time trying to develop a new system? The answer is simple, as previously stated this project is looking to develop a **low cost** and easily implemented mapping system. In the past, other types of low altitude mapping technologies were not very precise, or were cost prohibitive. With advances in GPS and Digital Camera technologies, it was the research team's intent to develop a system that could be driven to an airport and used to collect data in a matter of minutes by a DOT employee. Usage of full scale aircraft, consultants, full ground survey crew or other methods proves time consuming and costly. This project was initiated for less than the cost of one full manual ground based survey.

INTRODUCTION

The objective of this research is the development of a prototype system that will easily acquire data either at fixed intervals or over time and generate a tree removal or trimming plan for discretized trees or tree areas.

Using multispectral technology, reflected energy is transformed in a target device into processable data. The amount of data directly correlates to different degrees of precision; limited by the memory and data array in the target device. For this project, the research team will use advanced techniques in image analysis, computer vision, and image processing. In particular, advanced techniques in computer vision, which deals primarily with taking an input image to produce geometrical information from the images (often used in robotics for navigation), will be modified and developed to separate the trees into individual trees or tree sections where the physical base and top of high trees can be identified and measured by the computer.[1]

This information will be valuable, coupled with advanced algorithms for image analysis that has been developed or hybridized techniques based on classical algorithms. Using image analysis techniques, information regarding obstruction height, distance, and perhaps growth rates will be taken into account. Combining the information from these two methods, either a digital image or image from a multispectral device will be processed to produce either text instructions or a computer-marked image for adjustment of the obstruction.

The development of an airport obstruction identification system is an extremely promising technology. It will enable users to accurately identify, map, and plan the removal of trees or other obstructions that are currently posing a danger to arriving and departing aircraft at various airports within New Jersey.

BACKGROUND AND THEORY OF MAPPING TECHNOLOGIES

There are many different technologies that could be used for this project. Five such technologies were examined. These five are listed below with some comments regarding each and why they were not chosen. The fifth technology, the use of a radio-controlled helicopter (R/C) was the ultimate choice for this project.

1- Use of LiDAR: Light Detection And Ranging uses a similar principle as RADAR. The LiDAR instrument transmits light out to a target. The transmitted light interacts with and is changed by the target. Some of this light is reflected / scattered back to the instrument where it is analyzed. It was agreed that the LIDAR option is expensive and off budget, even though it is practical and time effective. One quote provided by a vendor with preferential pricing was $725,000 plus another $100,000 per year for maintenance and support.

2- Use of Ground-Base Tool: Cost effective but not time effective. Also, NJDOT personnel would need to enter into landowners' property or homeowners' backyards to map each and every tree.

3- Use of lifts or 'cherry picker' with a camera/scanner: This method was not looked into any further due to the three main disadvantages that are associated with the equipment. In order for the data collection device to see the second layer of trees, the lift would need to be above the tree canopy; which can exceed 70 ft. The first problem being that a scanner or camera onboard a static 70 ft lift is unable to collect data from all the trees in the area efficiently and without shutting down an airport for a prolonged period. Another major disadvantage is the weather conditions, especially the wind that will have a significant effect on the lift. Finally the safety factor: a 70 ft lift on the end of the runway will itself be an obstruction.

4- Use of full size planes for aerial images: This option was considered as a possibility for use in the project. However, due to the high expense of buying or hiring a plane and the flying restrictions that are in place near runways, this option does not seem feasible.

5- Use of remote controlled aircraft for aerial images: It was agreed that this option would be the best and most effective for use in this project. Its advantages are that it can fly at various heights, safety, relative cost, and it can be used for several purposes. In the following section, this method is outlined with more detail and the options are discussed.

LOW ALTITUDE MAPPING PHOTOGRAPHY (LAMP)

It's widely accepted that aerial photography used to generate survey data is considerably cheaper than ground-based surveys. Typically fixed wing aircraft which traditionally are used to conduct aerial surveys aircraft are not allowed to fly at less than 1000 ft. Costs involved with owning or hiring a fixed wing aircraft coupled with the equipment needed to acquire the images and the accuracy of the end result have caused many to seek alternatives. One such alternative is the use of helicopters for low altitude mapping, according to a recent study conducted by Woolpert a helicopter can fly as low as 300-500 ft, carry the identical equipment as a traditional fixed wing aircraft, and achieve a much higher degree of accuracy. The closer to the ground the image is taken the more accurate the survey result. A helicopter may cost four or five times as much to fly and maintain but they claim that the increased level of accuracy +/- 0.05 ft justifies the expense.[6] Also, a helicopter flies at much slower speeds allowing more data to be collected and making camera cycle times less critical.

Aerial photography from unmanned aerial vehicles basically falls into three categories; military, hobby and entertainment, and agricultural. Military grade units are extremely expensive and not commercially available, though they are highly accurate for the use in surveillance, reconnaissance, troop movement, targeting, mine removal, and other such activities. Hobby and entertainment units such as those used by film productions are designed for high quality imagery but typically operate within a very close proximity to the users, plus they do not require precise GPS or location data. Agricultural uses include growth patterns, crop health, grading monitoring, and even crop spraying; once again these are not precision units.

The premise of low altitude mapping photography is to be as close to the ground as possible, thereby increasing the survey accuracy (closer is better). However the use of full sized helicopters is highly criticized. “Many of the problems associated with doing conventional aerial mapping in a fixed wing aircraft are amplified when using a helicopter for the camera platform. Most airplanes have a positive stability about all three axes, whereas all helicopters have absolute negative stability. In an airplane, vibration is seldom thought about but most helicopters can have several different vibration modes that, if not properly dealt with, can markedly degrade the usability of the photography.”[7] Therefore, it must be acknowledged that helicopters have their own intrinsic problems, however if a system can be developed using a radio controlled aircraft (possibly a radio controlled helicopter) the increased level of accuracy may be sufficient to over come the technical obstacles and make such a system feasible.

It is important to note that when flying a model aircraft for low attitude mapping, there needs to be two operators. The first is the pilot who controls the take off, landing, and in general flying the unit. The navigator can use a video downlink and provide direction to the pilot, as well as control the camera and other onboard equipment.

Since the mid 1990’s with the technological boom, there has been considerable development of radio-controlled aircraft for aerial mapping. Previous systems were extremely limited, however with the advent of computerized systems the payload requirements of the aircraft was significantly reduced. However, even in the 1990’s camera and GPS technology was still too big and heavy except for the largest of aircraft some of which were over 10 ft long by 8 ft wide. Therefore small-scale units were not feasible nor developed, however now with state-of-the-art equipment it may be possible. See Table 1 below for a comparison of some of the advantages and disadvantages of a radio controlled versus traditional full-scale aircraft for aerial photography. It should be noted that this table is directly quoted from RC Airplane Advisor and may or may not reflect the views of the authors of this report; the table has been provided as part of the literature search to establish a beginning point for the evaluation of such technologies.

Table 1: Comparison of radio controlled versus traditional full-scale aircraft for aerial photography.[8]

Low Altitude Radio Controlled Aerial Photography	Traditional Aerial Photography
Advantages	
Lower Cost: cheaper to outfit, operate and maintain equipment	Tends to be much higher cost.
Lower (1-1000') altitude benefits: • Less atmospheric distortion at lower altitudes so photos are clearer and sharper. • Much wider range of angles on the subject. • Smaller, distortion-free lenses can be used.	• Most full scale airplanes and helicopter are limited to no less that 1000' in many areas. • Limited range of angles. • Long-range telephoto lens can result in image-distortion.
Quiet – property owners, occupants not disturbed by fly-overs.	Occupants could be disturbed by full-size aircraft.
Fast – no travel to and from a traditional airfield is required.	Longer time to get pics.
Disadvantages	
Weather – Lightweight aircraft are sensitive to winds above 12-15 mph. Mornings or late afternoons are best for photo shoots.	Heavier aircraft not as sensitive to wind – can shoot in more varied weather.
Low lying obstacles (eg. Power lines), or other safety hazards – Safety of persons and property is a primary concern.	Full-size aircraft generally fly high enough to avoid common obstacles.

For traditional aerial photography a camera could cost $400,000, weigh 250+ lbs, and take up over 4 ft^2 whereas a medium format camera might only cost $2,500 plus lenses. There is a significant difference in equipment and accuracy based on professional and amateur quality equipment.

Glide Path and Area to be Surveyed

The glide path is the angle at which an aircraft ascends or descends when departing or arriving at an airport. Typical glide paths are 20:1 slope for a visual approach whereas it's a 34:1 slope for an instrument approach. By making some very basic assumptions, it is possible to determine the distance away from the edge of a runway that must be surveyed to identify approach path obstructions. Assuming that the maximum tree height in New Jersey is 80ft, with a glide path of 34:1 slope clearance the distance is 2,720ft (or just over half a mile) from the edge of a runway. Also, based on the FAA regulations Part-77 for a typical runway with visibility over ¾ of a mile, a non-precision instrument runway has an imaginary surface with a width of 500 ft by 3,500 ft distance to the outer edge; resulting in over 1,750,000 square feet of area to be surveyed. It is likely that any survey will not only cross the property of numerous homeowners but also possibly even multiple municipalities. Such a survey conducted using a survey team may take several weeks to complete.

The Federal Aviation Regulation (FAR) Part 77 surfaces were devised by the FAA to protect specific airspace areas surrounding an airport. See Figure 6, Figure 7, and Table 2 for specific information regarding Part 77 surface dimensions, note that the exact dimensions of Part 77 is dependent on the type of runway approach.

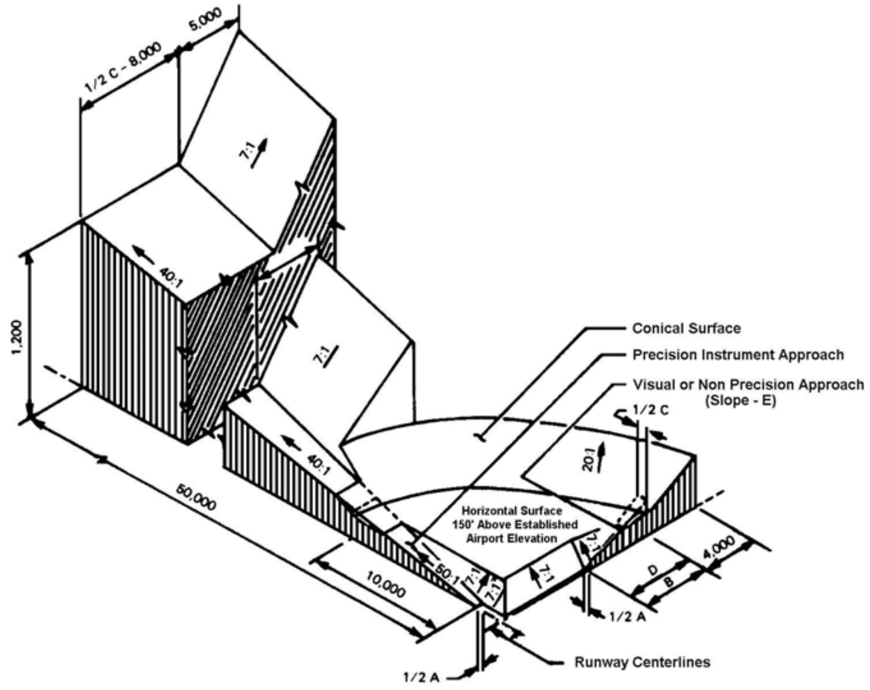


Figure 6: Image of FAR Part-77 surface.[9]

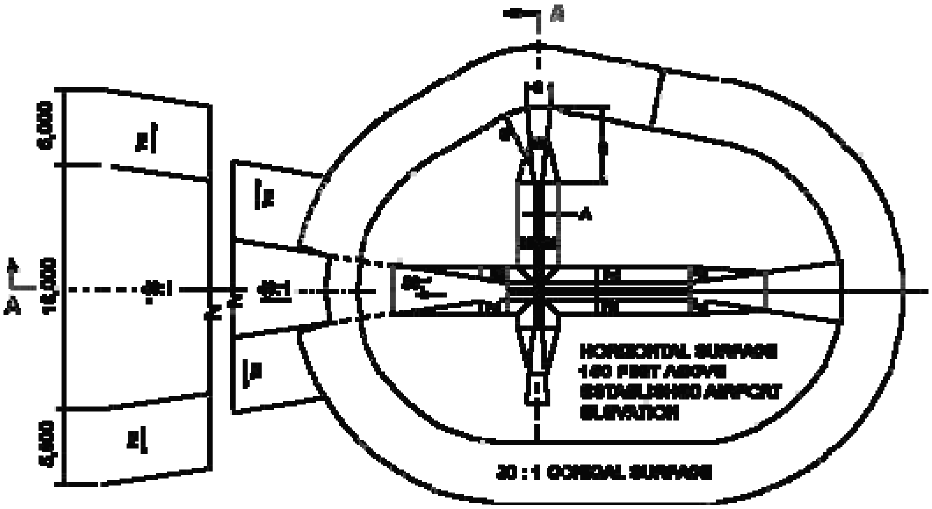


Figure 7: Plan view image of FAR Part-77 surface.[9]

Table 2: Obstruction identification surfaces based on FAA FAR Part 77.[9]

DIM	ITEM	DIMENSIONAL STANDARDS (FEET)					
		VISUAL RUNWAY		NON - PRECISION INSTRUMENT RUNWAY			PRECISION INSTRUMENT RUNWAY PIR
		A	B	A	B		
					C	D	
A	WIDTH OF PRIMARY SURFACE AND APPROACH SURFACE WIDTH AT INNER END	250	500	500	500	1,000	1,000
B	RADIUS OF HORIZONTAL SURFACE	5,000	5,000	5,000	10,000	10,000	10,000
		VISUAL APPROACH		NON - PRECISION INSTRUMENT APPROACH			PRECISION INSTRUMENT APPROACH
				A	B		
		A	B		C	D	
C	APPROACH SURFACE WIDTH AT END	1,250	1,500	2,000	3,500	4,000	16,000
D	APPROACH SURFACE LENGTH	5,000	5,000	5,000	10,000	10,000	*
E	APPROACH SLOPE	20:1	20:1	20:1	34:1	34:1	*

- **A - UTILITY RUNWAYS**
- **B - RUNWAYS LARGER THAN UTILITY**
- **C - VISIBILITY MINIMUMS GREATER THAN 3/4 MILE**
- **D - VISIBILITY MINIMUMS AS LOW AS 3/4 MILE**
- *** - PRECISION INSTRUMENT APPROACH SLOPE IS 50:1 FOR INNER 10,000 FEET AND 40:1 FOR AN ADDITIONAL 40,000 FEET**

Image Acquisition Plan

Stereo imagery, one of the fundamental concepts of the image post processing required the collection of stereo images. The basic concept of depth perception of the human eye is based on the offset distance between the two eyes. The basic image seen by each eye is almost identical; the human brain performs an extremely complex analysis of each eyes image resulting in depth perception. Analysis of two photos of the same general area can be compared and used to determine the precise height of each tree.

Automated image post processing will use two or more overlapping images to automatically generate a 3D landscape. The coordinates of the source image will be correlated and matched to a second image. The images will then be aligned, leveled and scaled to match. And produce a stereo 3D image. The 3D image will then be processed to automatically distinguish and measure the height of individual ground elements; mainly trees and other obstructions. Orthorectification is the process of removing geometric errors inherent within photography. Post processing can remove errors associated with sensor orientation, topographic relief displacement, and other errors. Orthorectified data will serve as the building blocks for the final obstruction maps.[10]

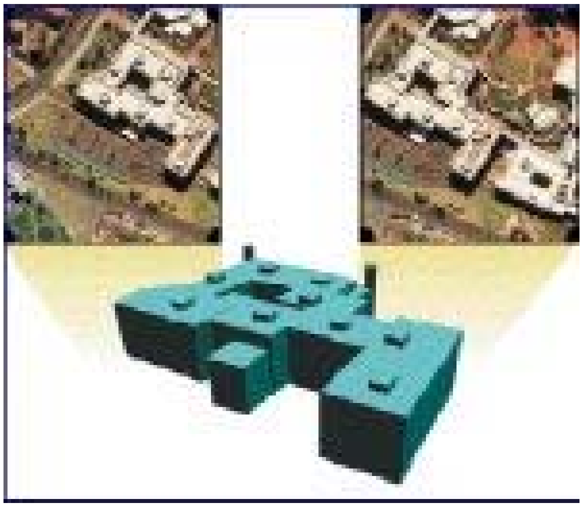


Figure 8: Stereo imagery analysis aligned, leveled and scaled to match.[10]

The perception of depth in humans and other binocular animals results from the brains interpretation of different perspectives due to the slight disparities between the left and right view of the object. It is interesting to note that the accuracy of this depth perception is thought to fade in humans after 600 ft or so, this is a direct resultant of focal point and will be important when selecting a camera.[11] Replicating the idea of depth perception using two camera lenses has been a key priority in many research studies in recent years.

The algorithm behind stereoscopic vision can be modeled using two cameras to be able to create a 3D sense that would allow not only the distance of the object to be deciphered, but also the height of the object, giving you the perception of depth.

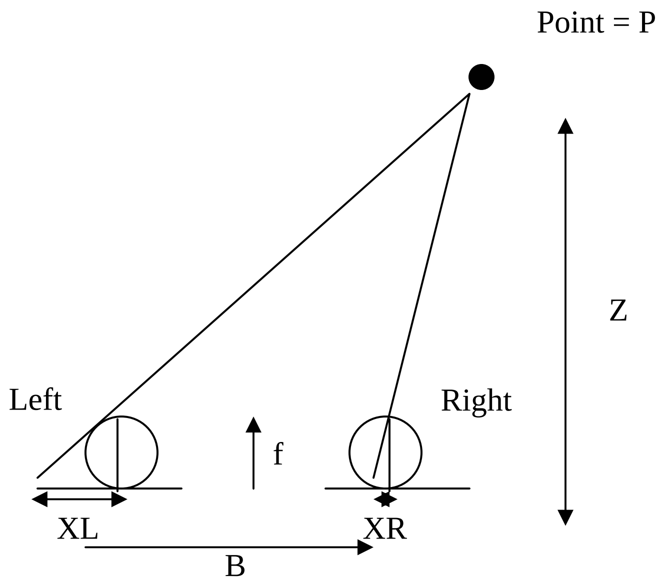


Figure 9: Stereo imagery analysis illustration.

The diagram as shown in Figure 9 demonstrates the mechanism behind achieving the perception of depth and therefore, being able to calculate and pinpoint the objects distance from the observer; in this case, two cameras, one to the left, and the other to the right. The point P in the diagram represents the object, f is the focal length, or some other constant define by the system properties, and B is the distance between the two cameras, represented in the figure as circles. The difference between the focal length of each camera (X L and X R) represents the difference between each cameras position, called disparity, and can be related to depth (Z) of point P through this basic algorithm. The difference in disparity, which can be found by subtracting X L from X R, is equal to the distance between the cameras (B), multiplied by the focal length, all divided by Z. If solved for Z, the depth can be determined.

If this premise is expanded, and an additional set of camera images are acquired of the same object at a different vertical angles as shown in Figure 10, this generates a slightly different perspective of the point, call it P2. Knowing the change in the camera angle, it is possible to calculate not only the depth of the object, but now, also the height. With the combination of these two shots, an accurate depth and height can be calculated.

In order to completely survey the large area covered by the glide path a specific series of images should be achieved. From each site, five pictures, namely 0 degrees, 15 degrees, 30 degrees, 45 degrees and 60 degrees (see Figure 10) should be obtained. If it is impossible to take the top-down (0 degrees) image, the angle of the first picture should be as small as possible. While the images are being saved the matching GPS information of the shooting locations must be recorded.

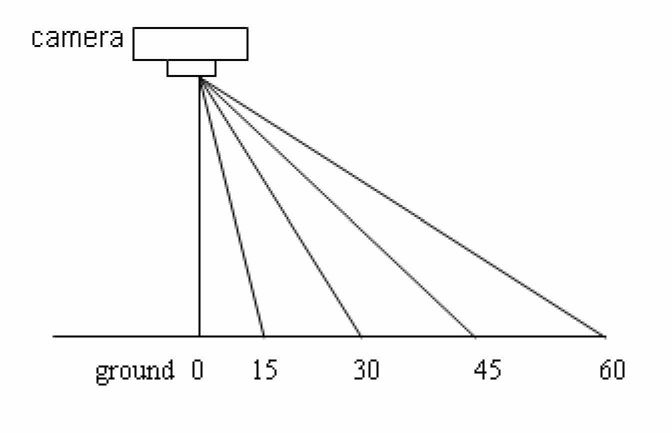


Figure 10: Aerial photograph angle illustration

After the first series of images is saved, the unit should move the camera to 4 or 5 different sites. The distance between the neighboring two sites should be around 20 feet, however the height should be the same is possible. Then the camera should repeat the same series of photos at the respective angles. With both series of images and GPS data saved, the principles of stereo imagery can be applied.

This is an extremely complex model and will require a custom-built software algorithm. If the acquisition unit cannot take images simultaneously or at the same altitude this will create a significant computational issue for the algorithm.

SELECTION OF RADIO CONTROLLED AIRCRAFT

Helicopters and Blimps

Aerial images are widely used all over the world. The research team can acquire aerial images from many sources, for example: airplanes, helicopters, air balloons, radio-controlled (R/C) helicopters, R/C blimps, among others. From previous discussions with NJDOT, it was agreed that the use of aerial images technology for the airport obstruction research project would be the most ideal. The search was then focused on the use of radio controlled flying crafts in order to achieve our goals. We minimized the search to two crafts: R/C blimps and R/C helicopters.

Several contacts, discussion, and Internet searches were conducted to obtain a clear understanding of the abilities and limitation of both technologies in order to select the best one to use in this project. Many advantages and disadvantages were presented for both technologies.[12]

R/C Helicopters:

Advantages:
- It can be carried anywhere without any significant expenses or handling.
- Can fly in difficult weather conditions like moderate winds.
- Can fly at high altitudes.
- Can fly at high speed, so it can enter and exit sensitive airspace quickly.
- Only fuel is required for operation.
- Higher payload capacity.

Disadvantages:
- Pro- R/C helicopters that are made especially for aerial photography are expensive.
- Not very stable in the air. Tilt and roll of the helicopter, and the shaking due the fuel engine require constant operator correction and oversight.
- Difficult to fly and control, it requires special training schools and programs.
- May have a vibration issue due to the gasoline engine.

R/C Blimps:[13]

Advantages:
- Very stable in the air, can acquire pictures for the whole site from the same altitude.
- Easy to fly and control.
- No significant tilt and roll problem.

Disadvantages:
- Due to the payload requirements, the photography system will require a 30 foot blimp. This is extremely large when inflated and hard to mobilize from site to site. Deflated is much easier to carry but inflating it with helium on every site is logistically and financially unreasonable.

- The blimp cannot fly when wind speed exceeds 13-15 mph.
- Payload capacity of a reasonably sized blimp is rather low.

Blimp Supplementary Information

A 20 ft blimp will use about 800 cubic feet of Helium and can lift an additional 10 lbs (that is 10 lbs after taking into account the gondola, radios, etc). The 10 lb working weight based on preliminary information would be border line for this application. A large 5 ft tall cylinder holds about 300 cubic feet and will cost roughly $51 per cylinder, thus the cost of filling the Blimp will be under $150.[14] Also, it should be noted that it is expected that the hull can potentially lose 1% of its helium per day and that every three months the helium should be completely replaced because the helium loses purity as it ages.[15] Therefore the cost of the helium is not necessarily the concern but the large quantity (3 big tanks) and storage of such a large (20’ long x 8’ round) blimp becomes a practical usage issue. If the system is drained after each flight it would take three large cylinders to fill the blimp again and the storage of a filled blimp does not seem practical for this application. The research team verified with five radio-controlled blimp manufactures and with the exception of the one from Southern Balloon Works (which has the 20’ outdoor blimp) all the outdoor blimps are 30’ or more.[15]

Also a tethered balloon was considered, but this only provides one point to take images from. For this application and based on the analysis from the Glide Path and Area to be Surveyed section of this report, more than one reference point is needed and tethering would most likely be ineffective.

Initial Field Verification

After further review and analysis it was decided that a remote controlled helicopter was the best option and best suited the needs of the project. A demonstration was given and aerial pictures were acquired to show the feasibility of such a system, sample pictures are shown in Figure 11.

Figure 11: Aerial test photos of tree canopy.

Using a laser range finder ‘truth data’ of actual tree heights of a select number of trees was collected. The laser range finder allows the user to measure the height of a selected tree one at a time. It proved extremely challenging to correlate a specific tree from the image with a field verified height. The research team had to look for color variations in trees or identify trees right on the edge of a clearing in order to match the tree to its counterpart from the aerial image. Some of these field verified heights are shown on the image in Figure 11.

After the analysis of the pictures shown in Figure 11, they were digitally enhanced using the software to obtain virtual heights of the objects, in this case the trees and even the individuals standing in the grass areas. A side by side comparison of one of the images from Figure 11 can be seen in Figure 12.

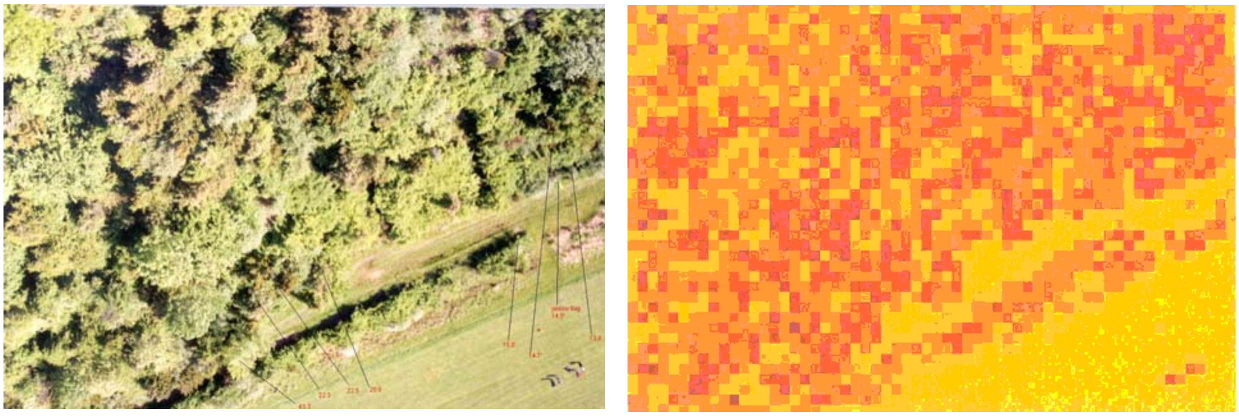


Figure 12: Side by side comparison of field image and computer analyzed tree height model. (Note the accuracy: the system could detect the height of people standing in the bottom right corner of the image).

The data was analyzed and compared against “truth” data. There was a high degree of correlation between the manually collected data and the computer generated analyzed data. However, with the limited amount of aerial images collected, individual trees could not be isolated. As shown in Figure 12 elements may appear pixilated, this was a direct result of the data limitations and camera resolution. The research team decided that these obstacles would be dealt with in the next phases of the research and decided to proceed with the radio controlled helicopter for aerial image collection.

Radio Controlled Helicopter and Payload Considerations

The research team decided to use a radio-controlled helicopter mounted with a high-resolution digital camera and GPS unit to accurately obtain geometry and spatial data on suspect vegetation. It was anticipated that the most difficult component to select would be the GPS.

Initial findings indicated that the GPS unit would be a significant issue; the GPS needed to be accurate, the more accurate the GPS the heavier the unit, if the unit was too heavy it could exceed the lifting capacity of the helicopter. The GPS needed to be lightweight, accurate within less than a meter, and cost effective for this project.

After reviewing many different possibilities for the purchase of radio controlled helicopter systems the process was narrowed down to two different options. These were a semi-commercial system and a custom built system.

Helicopter Selection

After reviewing many numerous R/C helicopters the options were narrowed down to two systems. The first being a complete system built by Floatograph, a company that specialized in radio controlled devices and photography. This system had total cost around $50,000 and included all of the major components. However, after careful review of the individual components necessary, as discussed in the following section, it was determined that the system was not cost effective or accurate enough for the projects needs. [13]

It was decided that a home built system would better suit the project needs. This option, even though more challenging than using an off-the-shelf unit, was the only way to meet the technical needs of the project. One of the main concerns with competitive systems was the choice of GPS unit. The unit that was specified in the Floatograph system had very low accuracies. These accuracies would be unacceptable for this project since mapping trees will require accuracies less than one meter. Thus, the Floatograph system would have required the purchase of another GPS, increasing the price of the overall unit. More importantly, changing the GPS unit could result in the overall system exceeding payload capacities.

The home built system would include a helicopter purchased from Bergen R/C, purchasing the required components individually, and the use of a consultant to integrate the system. The helicopter chosen by Bergen R/C was the Industrial Twin. The Industrial Twin's main advantage was power; and consequently it having the highest payloads available of any commercially available unit thereby maximizing the payload and giving the research team the most amount of flexibility when specifying the various mapping components. Choosing the Industrial Twin enabled the research team to broaden the search for the GPS unit, camera, and other onboard systems.

Following careful review of each system, it was determined that the custom built system would be a better fit and was far less expensive than the semi-commercial system. Another advantage of building the system was that it could be customized to the projects exact needs thus avoiding "generic" equipment with the potential for low accuracy.

Listed in Table 3 are the specifications for the Industrial Twin helicopter from Bergen R/C, and shown in Figure 13 and Figure 14 is a general image showing the base R/C helicopter.

Table 3: Industrial Twin Specifications[16]

Length	59 in.
Height	22 in.
Weight	18 lb.
Rec. Main Blades	810mm V-blades
Rec. Tail Blades	120mm
Gear Ratio	6.43:1:4.67
Fuel Tank	32 oz.
Engine	Zenoah G-23

Figure 13: Image of the Industrial Twin radio controlled helicopter manufactured by Bergen R/C

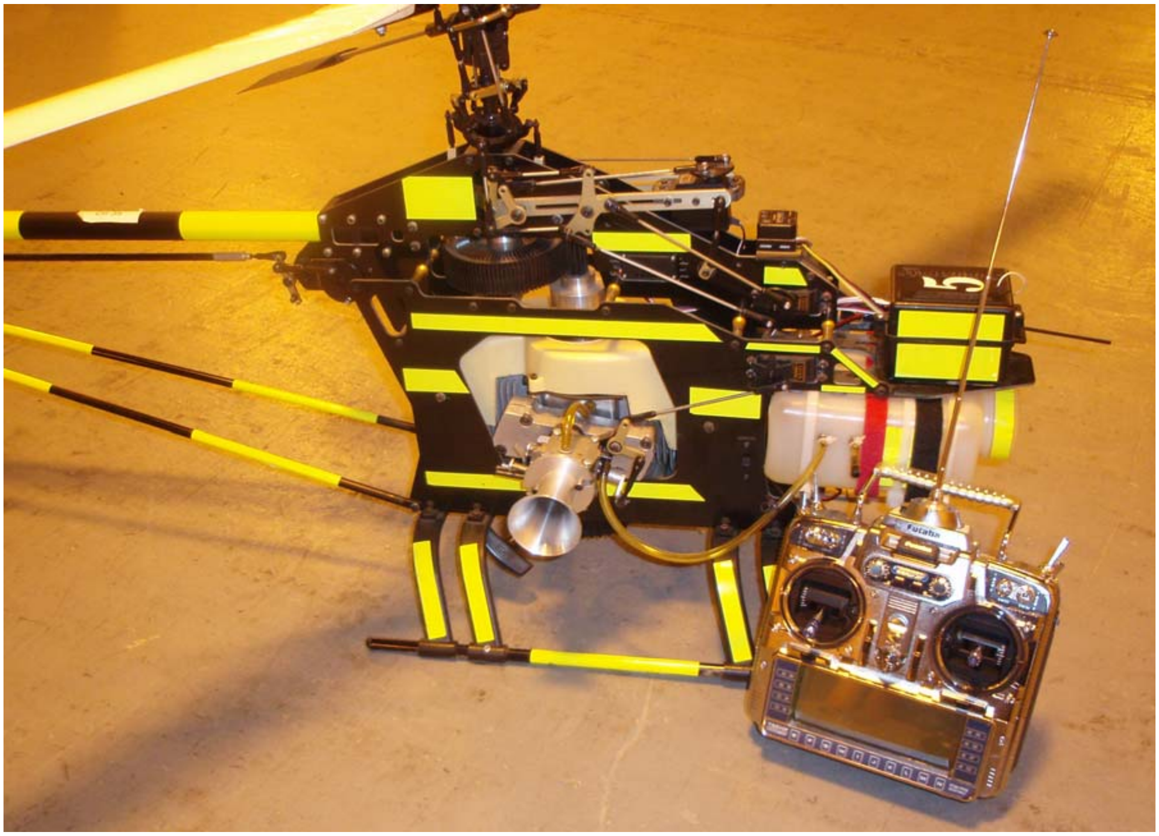


Figure 14: Image of the Industrial Twin with radio controller.

Industrial Twin System Information

The Bergen R/C Industrial Twin is capable of lifting a 20 lb. payload for one half hour on a tank of gas. The Industrial Twin uses a twin cylinder engine manufactured by Bergen R/C utilizing components from Zenoah G-23's, producing about 4.5 horsepower. A single carburetor manifold is used for ease of mixture adjustment. A large, high efficiency fan is in place to provide cooling for the engine.[16]

Power is transmitted through a heavy-duty double clutch and clutch bell to a twin main gear. A fully hardened 10mm hollow main shaft turns the all aluminum head and fully ball raced aluminum blade grips. Symmetrical 810 mm V-Blades are included to provide the lifting power for the helicopter. The landing gear is doubled to handle the weight of the helicopter, and G10 frames are used to provide the strength to hold it all together. The Industrial Twin features an aluminum torque tube to transmit power to the aluminum tail gearbox with metal gears and 120 mm tail blades.[16]

Helicopter Components

Camera:

After reviewing many different digital cameras, the Olympus E-20N digital SLR camera as shown in Figure 15 was selected. The E-20N, 5 mega pixel digital SLR, is a professional quality digital camera. Some of its features include a body built for durability; a lens designed for high quality image results, the ability to shoot in Interlaced and Progressive scan modes, and many other advanced features. The E20-N also has two different digital media card slots for Compact Flash, Smart Media, or IBM Micro drive removable media. The E20-N is also compact in size, which will enable easy integration into a bracket to be mounted beneath the helicopter. Some other important features are that the camera can operate between 0-40 degrees Celsius and between 30 and 90 percent humidity. The camera also only weighs 37 ounces. The low weight allowed more of the remaining balance of the weight to be used for other components namely the GPS unit.[17]

At the time when the camera was purchased the camera was state-of-the-art, however by the time this report was published the 5 mega pixel resolution has been far surpassed with cameras offering 10 mega pixel at a fraction of the cost.

Figure 15: Olympus E-20N

Video Downlink:

A reliable video downlink is essential for the helicopter since it is being controlled from the ground. Also, the use of monitors, goggles, or another device may be required to control the video downlink along with a radio control for the pan/tilt of the video link. A second individual, other than the pilot flying the helicopter will control this apparatus.

Transmitter and Receiver:

The transmitter and receivers are required for the video downlink and the digital camera. Video is transmitted directly to the ground and can be recorded for future analysis.

Vibration Control:

The necessary steps to control vibration depend on what type of vibration is being generated. The model with a model helicopter is rather complex. The vibration sources are the engine, tail rotor, and primarily the main rotor. Frequency, softness, and mass affect the vibration isolation of the system. There is a limit to the amount of softness desirable. The camera will start to swing about, making aiming difficult and potentially introducing motion blur. A compromise must be reached. Where the appropriate compromise is depends on the camera's weight. For example, someone flying a light point-and-shoot camera will need a very soft, flexible attachment method to stop vibration. At the other extreme, if using a heavy medium format camera with a pan/tilt/roll mount and video assist, things are a bit different. This is why the camera and its weight is an important part of the system.

Servo:

The servos will be specially made for the project; the software expert recommended that they build, or the company providing the R/C helicopter build a servo that tilts for a series of angles (30,75, and 90 degrees) every time activated. The result will be a group of pictures for the same location taken at different angles, it will be helpful and much easier to process such images.

Pan and Tilt System:

To ensure that the camera will be able to take pictures at the appropriate angles and withstand all vibrations, a specialized pan and tilt system was purchased for the underbelly of the aircraft. The ri-200 system from Remote-I was selected for the needs of the helicopter. Remote-I developed a CamMount system that is reliable, flexible, simple, and is high quality. The ri-200 series CamMount System is constructed of Computer Numeric Control machined aircraft aluminum and carbon fiber for lightweight and durability. The use of belts, pulleys, and high-torque servos provides smooth and precise rotation of up to 360 degrees. The vibration dampers ensure crisp, clean, and shake free images.[18]

The design allows the ri-200 to be mounted in the front or on the belly of the helicopter. An image of the ri-200 is shown in Figure 16.

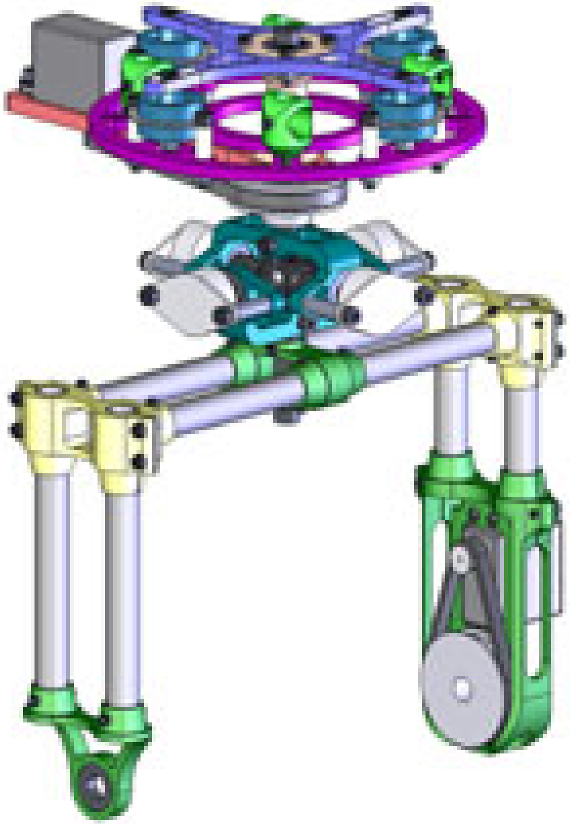


Figure 16: Remote-I Pan and Tilt System[18]

Accessories:

Different radios, cables, batteries, and chargers for various hardware components are required. Each system and subsystem has its own radio, cables, and sub-accessories.

GLOBAL POSITIONING SYSTEM (GPS)

This section will discuss the choice of an appropriate GPS device for the helicopter. The GPS selection has been the longest and most complex part of this project to date. The three main objectives for choosing the appropriate unit were the weight, accuracy, and the cost. The unit must be small enough to be mounted on the helicopter along with the other components. It also must provide accuracies that are better than 1 meter. This is one of the most important aspects. To map the tree locations effectively, a system with sub-meter accuracy is needed. The last aspect is cost, as with any project, it is important to get the best cost to benefit ratio.

In general, for most GPS units it was found that the height error (or z component) was typically twice that of the x-y error.[19] So an error of a meter could result in a two meter height error (approximately 6 feet). The idea of identifying a tree as an obstruction is binary, either it is or is not an obstruction. A two meter error could not only cause the analysis to yield false positive but false negatives. Therefore the accuracy of the GPS unit is critical to the success of the project.

Table 4 lists six units that were identified and studied as possibilities for use with the system. Although many of them satisfy one or even two of the above components, five of the six were determined be ineffective for this project.

Table 4: GPS Unit Comparison[20]

Unit	Company	Accuracy	Weight	Cost
GS-20	Leica Geosystems	< 1 m	1.44 lb.	$3,668
GS-50	Leica Geosystems	< 1 m	4.5 lb.	$6,375
ETrex Vista	Garmin	3 to 5 m	5.3 oz	$250
AgGPS214	Trimble	< 1 m	2.25 lb.	$35,000
SF2040	Navcom	15 cm	5.5 lb.	est. $10,000
SF2050	Navcom	15 cm	5.5 lb.	$9,831

The following is a brief explanation regarding each unit, and more detailed information regarding the GS-20, as shown in Figure 17, the unit that was ultimately chosen:

Leica GS-50: This unit was similar in accuracy to the GS-20 but is much heavier. It required the use of a backpack unit as a beacon and was determined not to be feasible.

ETrex Vista: This unit, although extremely inexpensive, does not provide the accuracy needed for this project. An accuracy of three to five meters when mapping trees will not meet the project requirements.

AgGPS214: The Ag GPS is a unit used for agricultural purposes. It has the right components for this project, and has good accuracy and low weight. The main problem with this unit is the cost, which was determined to be too high for this project.

SF2040: The 2040 is an all in one GPS unit that uses Navcoms Starfire satellites to provide accuracies far better than any of the other GPS units. The only reason the 2040 was not reviewed in depth is because the 2050 has an antenna with better mobility. Other than that, the units are identical.

SF2050: The accuracies in the horizontal are 15 cm, which is idea for this project. It provides 3D capabilities to the project and should do the best job out of the GPS units selected. It also has very small lag times, meaning that if a signal is lost, the unit can reacquire the signal very quickly. However, the downside to this unit was the high cost and reliance on a subscription based service that would incur additional yearly costs.

Leica GS-20: The final choice for this project was this unit. It provides the most accurate readings, a weight in which the helicopter can handle, and a cost that is appropriate for this study. This unit is an extremely small handheld all-in-one device. The cost, weight, and accuracy were all excellent for the scope of this project. A picture of the unit can be seen in Figure 17.[21]

Figure 17: Leica GS-20 shown with case and accessories.

After extensive research, contacts, vendor meetings, and other means of gathering information a choice was finally made. The unit chosen, the GS20 from Leica Geosystems, best satisfies all of the requirements.

GPS Technical Issues

There were many GPS issues that became evident as the team investigated various equipment models. For example, to acquire the accuracy that the study requires a beacon antenna and support equipment would also need to be purchased for the GPS unit so that the equipment can acquire the quoted accuracy of about 80 cm in 20 seconds. Also, the GPS provides only half the accuracy in the z dimension so the resulting accuracy would be within 160 cm in 20 seconds. It would need to be verified if this degree of accuracy will suffice to provide the required degree of accuracy in the 3-D maps.

The GPS requires a clear view of the sky which leaves mounting of any unit as an issue. Cloud cover and tree canopy as well as the interference of the main blades can affect the GPS signal. It may be possible to gimbal an external antenna but this would need to be fabricated and analyzed with the units center of gravity. If the main rotor blades produce enough interference, it is not certain how long these side trusses would need to be but a starting point could be mounting the antennae out as far as the blade's span.

It would be beneficial if the GPS unit was mounted in a metal enclosure to shield it from the electromagnetic interference generated by the ignition coils of the engine and metal to metal contact of the helicopter drive train.

At the time that the GS20 from Leica Geosystems was purchased it was considered state-of-the-art. The unit uses GPS L1 with quoted accuracies of 30cm with post processing. However, many published studies now show that the GPS signal frequency L1 was found to be around 1.1 meter.[22] Previous accuracies of approximately 100 meters were limited by Selective Availability (SA) a precision restriction which was rescinded in 1998 and removed in May 2000. The submeter accuracies that many vendors claimed were obtained using corrections technologies and post processing. According to Leica the GS20 was the first and only handheld at the time using proven correction technology to provide submeter accuracy. Using either real-time corrections or post-processing to collect submeter data without a backpack system; this was a critical reason why this unit was selected.[21] The first satellite carrying the new L2C (the next generation of signal frequency for civilian users) was launched on 12/16/05 followed by the second on 9/25/06. In 2008 it is anticipated that an entirely new signal will be launched referred to as L5 frequency; all of which means that the level of accuracy of GPS receivers continually gets better.[22]

Also, one technology that was not discussed is the Inertial Navigation System (INS). INS is widely used to determine a receivers position and orientation. Basically INS allows a system to be more robust and substitute missing GPS data as well as reducing time to reacquire a satellite link; not to mention trajectory processing. New receivers are integrating INS and PS together resulting in better performance of collection sensors such as LiDAR, digital imagery, and other remote sensing technologies such as was developed in this project.[22]

INTEGRATION

The integration of the Bergen R/C Industrial Twin unit and mapping systems proved to be extremely complex. The complete system needed to be heavy duty to withstand the vibrations generated by the engine, however it also needed to be soft enough to dampen those same vibrations so the images would not be blurred. Also, in the event of a crash the system needed to be modular so components could be swapped out and replaced without significant downtime. Fabrication of a custom mount with replaceable joint connections was one of many integration obstacles.

The process to connect the mount to the helicopter was more complex than just bolting the two together. There were many concerns to be addressed

- modular design in the event of a crash
- modular design to allow upgrades
- system balance for easy of flight
- center of gravity for vibration control
- overall vibration for image quality
- weight restriction due to payload capacity
- system durability, too soft leads to resonant vibration

This was an extremely complex task, as these issues are in direct conflict with each other. For example, the more durable the system is constructed typically the more rigid the connections, the more rigid the connections the blurrier the photos. If you make the system too soft then the entire unit shakes and the result is either failure or once again blurry photos.

The mounting system consists of two primary systems, a pan-tilt system and the main framing system. During the operation of the camera it is expected that the camera will need to rotate to various angles to acquire photos all the while withstanding dynamic vibrations.

The research team began with a commercially available specialized pan and tilt system as a starting point. The ri-200 system from Remote-I was selected for the needs of the helicopter. The ri-200 series CamMount System is constructed of machined aircraft aluminum and carbon fiber for lightweight and durability. The system comes complete with vibration dampers to help ensure crisp, clean, and shake free images.

The complete integrated mount system was designed to dampen vibration for the camera and GPS systems, as shown in Figure 18. This system needed to be mounted under the helicopter as close to the units' center of gravity as possible. By mounting the unit near the center of gravity this "balances" the unit and thus makes it much easier for the pilot to fly, otherwise the result would be similar to driving a car with extremely bad alignment. In addition, similar to a tuning fork, as the unit vibrates the oscillations become exceedingly more rhythmic which could cause the unit to oscillate about its primary axis. If the entire system is balanced the unit becomes more stable like a gyroscope, however any imbalance will lead to catastrophic failure.

Figure 18: Mount with dampers to allow softness to limit vibration effects on images.

The actual frame connecting the mount, helicopter, and skids was custom fabricated. The research team decided against welding an undercarriage together in order to make the unit more modular. Thus, due to a modular design and no welds, in the event of a crash or needing to modify the design, changes can be made. A modular design increased the level of complexity but since it was still unknown if the system would function as expected the research team felt the need to keep everything as flexible as possible to allow major and minor changes to the design.

Vibration and oscillation were not only a concern to the flying of the unit but the durability as well. The primary mount material used was aluminum (which is susceptible to wear), the connections needed be rigid to avoid vibration that could grind the connections and round out the joints and cause failure. Given that the connections must be rigid and the fact that the unit is not permanently welded together; it was decided to use aluminum tubing with custom aluminum compression knuckles to fabricate the undercarriage. This should provide a lightweight frame that is both modular and durable. Weight distribution is also a factor in the design and must be correct in order to minimize vibration in the overall unit. The complete custom mount and vibration damping undercarriage can be seen in Figure 19.

Figure 19: Custom mount and vibration damping undercarriage.

The final prototype with mounting system is shown in Figure 20.

Figure 20: Helicopter with final vibration damping undercarriage.

Vibration and Accuracy

As previously discussed under the previous section, vibration directly correlates to image quality and therefore accuracy. The camera mount that was purchased had to be modified. The pan servo was removed and the pan axel was set screwed in place so that the camera will always point straight in the direction of the helicopter. The tilt servo had to be modified so that it could respond to angular inputs instead of rate inputs. A modified servo mount was fabricated to attach an external servo gearbox and potentiometer. This new installation supplies greater torque and has 180 degrees of position sensitive travel on the tilt. This allows predefined tilt angles to be programmed into the radio, which can be activated and switched between using the 3-button switch. This also allows for the future automation of the image capture sequence using a servo programmer that was purchased. The routine could be activated remotely and a sequence of tilt angles and images captured at each angle would occur. The camera mount was fitted with Gentled camera remote control LED shutter and zoom control transmitters. These microprocessed LED’s provide the same functioning as the RM-1 remote control that comes with the digital camera, however these can be controlled by the radio receiver. The camera mount was completed and allows full remote functioning of tilt, shutter, and zoom as well as being set up for a feedback downlink from the camera which will allow the camera operator to watch on a small monitor on the ground exactly what the camera is recording.

Orientation and Heading

Experimentation and research was been done on methods of recording the helicopter’s orientation and heading in flight which would be correlated with each image. The GPS will supply (x,y,z) coordinates of the helicopter, but the heading and orientation of the camera for each image is required in order to process the set of images to generate 3-D maps. The image processing is very sensitive to these angles.

One option to find the headings was to assume that the helicopter camera mount remains parallel with the ground at all times, although the helicopter could be banked several degrees during image acquisition. The physical angle that the camera is tilted for each programmed tilt setting would have to be measured as well as the alignment of the pan axis so that the camera is aligned with the helicopter. This could also provide several degrees of error. Measurement of the heading of the helicopter would require a sensor to reference the earth’s magnetic field. Even so, in the best case scenario such sensors provide only one degree of accuracy. Additionally, they are subject to interference by the helicopter moving metal parts as well as the ignition coils. This idea was not feasible because it produced several degrees of error on orientation measurements which would translate into several errors in linear dimensions of the objects being mapped.

A more promising option would be to use several registration marks on the group and each picture taken would require that at least two of these marks be identifiable images. Each registration mark must have its physical (x,y,z) coordinates measured. Then an algorithm would use the coordinates of these two marks as well as their relative location in the image in addition to the helicopter's physical (x,y,z) coordinates to calculate two unit vectors in space, one pointing in the direction of the camera's exact view (direction normal to the plane of the image) during image acquisition, and the other pointing in the physical direction corresponding to the horizontal axis of the image. The algorithm has been developed and is being tested.

This could be a significant drawback of the system. The users would need to establish a reference point on the ground that would be captured in the aerial images during a flight. Without these registration marks any software algorithm would be unable to even determine which direction is North. Thus the data would not be usable and would have to be recollected. There are more advanced GPS units that can provided higher degrees of accuracy and such heading, roll, and tilt data but given current GPS technology, the weight would make such equipment not viable.

HELICOPTER MAPPING SYSTEM COST

Table 5: Rutgers Cost To Date of Home Built System

	Price
Base Helicopter	$ 4,500.00
Additional Add-On Components	
Futaba Radio-9Zap Transmitter	$ 999.99
4 Servos Futaba 9151	$ 399.96
Module	$ 59.49
Gyro Futaba 401 w/Servo	$ 249.99
Receiver	$ 199.99
Crystal	$ 17.99
Extension	$ 8.99
Power Backer	$ 120.00
Co-Pilot	$ 100.00
Video Down Link	$ 549.00
Shipping	$ 75.00
COST	$ 7,280.40
Project Specific Additional Equipment	
Camera	$ 1,264.80
GPS	$ 3,668.40
Remote I Pan and Tilt System	$ 1,295.00
Servo with presets (estimate)	$ 200.00
Labor for Advanced Integration	$ 3,500.00
Training (est. 40 hours @ $35/hour)	$ 6,000.00
Practice Helicopters (2 @ ~$1,358 each)	$ 2,716.93
TOTAL COST	$ 25,925.53

HELICOPTER TRAINING

One of the most important parts of this project is the training of DOT personnel to operate the radio-controlled helicopters. Two training helicopters were purchased for this purpose. The goal of the training is to have the DOT personnel become proficient enough to operate the helicopters by themselves, fly to a specified height above the trees (most likely 200-300 feet high), and be able to hover the helicopter in position to acquire the images to be used in the post processing. For the training, a large field on the campus of Rutgers University was used. The field was cordoned off with cones along with small areas created to fly the training helicopters.

To date, their have been 15 training sessions comprised of practical field training, the use of a computer simulation program, hands on maintenance, and the use of an indoor practice trainer unit. To conduct the training session, Rutgers used the assistance of two remote controlled helicopter specialists, who are highly knowledgeable and well known in the field. Rutgers enlisted the services of Chuck Wildey, who has been flying radio-controlled helicopters for 15+ years. He began using radio-controlled helicopters in 1988 while visiting a local hobby shop that specialized in R/C helicopters and quickly formed a local club with another radio-controlled enthusiast. The club, The Hudson Valley Airscrews, quickly became the largest group of this discipline in the tri-state area. As an active member and president for 4 years, several contests, fun fly's and clinics were incorporated as a service to the radio-controlled helicopter community at large. He has also worked through the competition levels and currently competes at the expert level in Academy of Model Aeronautics (AMA) sanctioned events.

In August 2000, Chuck formed AirVision 360 LLC. The company is involved with aerial photography, along with still and video photography. Training is also part of the AirVision's portfolio. Most of the company's time is devoted to the advancement of aerial photography and the training of new pilots. Some of the project participants that AirVision has brought to this project specifically include Bergen R/C, Futaba, and Morgan fuels, all of which are leaders in the radio-controlled helicopter field.

The second trainer, Paul Papandrea, has been involved with radio-controlled aircraft since 1975. Since then Paul has been building and flying numerous types of radio-controlled aircraft including helicopters. He began full-scale flight training in 1992 and has earned his Private Pilots license, Instrument Rating, Commercial Pilot, and Multi-Engine ratings. He followed these certifications with a Flight Instructors Rating with both an Instrument and Multi-Engine Instructor qualifications. In 1998 Paul began flying Learjets and currently flies for Meridian Air Charter in Teterboro, New Jersey. Along with a type rating in Learjet aircraft he currently holds an Airline Transport Pilot Certificate with 5000 hours of flight time.

Between 1998-2003 Paul was a field representative for Bergen Helicopter, a company that designs and builds radio-controlled helicopters for both Industrial and hobby applications. He has had the opportunity to help and train many aspiring radio-controlled pilots with both fixed and rotor models as well as being a check airman at a local flying field. This experience has enabled Paul to become a proficient instructor regarding radio-controlled helicopter flight and setup. He continues to actively build and fly radio-controlled helicopters and airplanes and hopes to help many more aspiring pilots in the future.

During each training flight, the DOT trainee would fuel the aircraft, start the aircraft, and perform all other pre flight checks. The remote controls were then buddy boxed together so both the student and trainer would have control of the helicopter. This was an essential part of the training system, as it enabled the trainer to easily make corrections and minimize the danger of flying the helicopters while the trainees were first starting. This was also important because it greatly reduced the risk of losing control of the helicopter and avoided potential crashes, thereby avoiding costly accidents and increasing the training rates. Each flight lasted approximately twelve to fifteen minutes and each trainee averaged about four flights per training day depending on the number of trainees attending each session.

Also, for initial training sessions training gear was used so the trainees could better see the aircraft and it made for smoother take offs and landings. For the first few training sessions, a laptop computer was also used while trainees were waiting their turn to fly. On the laptop was the simulator program that the trainees had been using prior to any training sessions. This ensured minimal down time during the training sessions and helped keep all personnel fresh and ready to fly.

A detailed list of the training sessions from July 2003 to April 2004 follows. It contains the trainer for the day and a list of the DOT personnel and Rutgers personnel who participated in each session. There are also some notes regarding each session when appropriate along with reasons for cancellations.

July
22nd: Trainer- Chuck Wildey
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT), Greg McDonough (DOT), Ed Kondrath (DOT), Pat Szary (Rutgers), Matt Zeller (Rutgers)
-This was a simulator only training session. DOT personnel were able to get techniques and learn more about the helicopter before actually flying in the field.

August
5th: Cancelled due to inclement weather
12th: Trainer-Chuck Wildey
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT), Greg McDonough (DOT), Ed Kondrath (DOT), Pat Szary (Rutgers), Matt Zeller (Rutgers)
-This was the first outdoor training session.
19th: Trainers-Chuck Wildey, Paul Papandrea
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT), Pat Szary (Rutgers), Matt Zeller (Rutgers)
26th: Moved to 28th and subsequently cancelled (DOT conflict, would have minimal turnout)

September

4th: Cancelled due to inclement weather

11th: Trainer- Chuck Wildey
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT), Matt Zeller (Rutgers)

18th: Cancelled due to inclement weather (Hurricane Isabel)

25th: Trainers- Chuck Wildey, Paul Papandrea
Attendees- Bart Ritorto (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT)

30th: Trainers- Chuck Wildey, Paul Papandrea
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT)

October

7th: Trainers- Chuck Wildey, Paul Papandrea
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT), Ron Harbist (DOT)

14th: Trainers- Chuck Wildey, Paul Papandrea
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Ron Harbist (DOT), Greg McDonough (DOT)
- The radio controlled helicopter referred to as Rutgers 1 was involved in a crash while Todd was flying solo. The helicopter needed to be repaired and was ready for flight within a week.

21st: Cancelled due to wind forecast, winds were in excess of 30mph.

28th: Trainers- Chuck Wildey, Paul Papandrea
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT), Ron Harbist (DOT)

November

6th: Cancelled due to Rain.

10th: Trainers-Chuck Wildey
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT)

18th: Trainers- Chuck Wildey, Paul Papandrea
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT), Ron Harbist (DOT)
-Bart and Todd are flying on their own and have taken radio-controlled helicopters back to DOT. This represents significant progress in the training program.

25th: Cancelled- Thanksgiving week, conflicting schedules.

December

4th: Trainers- Chuck Wildey
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Gerry Leipfinger (DOT)

9th: Cancelled due to snow cover.

17th: Cancelled due to snow cover.

April

19th: Trainers-Chuck Wildey, Paul Papandrea (1/2-day)
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT), Ron Harbist (DOT)

20th: Trainers- Chuck Wildey, Paul Papandrea (1/2-day)
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT), Ron Harbist (DOT), Karen

21st: Trainers- Chuck Wildey, Paul Papandrea (1/2-day)
Attendees- Bart Ritorto (DOT), Bob Draper (DOT), Todd Kropilak (DOT), Gerry Leipfinger (DOT), Ron Harbist (DOT), Karen

Photographs of the training sessions can be seen in the following section. Figure 21 illustrates the use of the buddy box system. As you can see, the instructor pictured on the left is head trainer Chuck Wildey and DOT trainee Bob Draper on the right. The buddy box system allows the instructor to have ultimate control of the helicopter, in case the unit begins to drift or lose control.

Figure 21: Training photo showing the use of the buddy box system.

In Figure 22, DOT trainee Bart Ritorto can be seen preparing the blades for one of the training helicopters. A large portion of the training consists of non-flight training, such as startup, takedown, safety precautions, and other helicopter preparations that are necessary for safe operation. This can also be seen in Figure 23; from left to right, Chuck Wildey, Gerard Leipfinger (DOT), and Greg McDonough (DOT) help fuel the Raptor during the first outdoor training session.

Figure 22: Training photo of blade preparation and pre-flight check.

Figure 23: Training photo of pre-flight preparation and check of aircraft.

Figure 24: Training photo showing poor weather conditions, students were taught how to handle the unit in inclement weather.

Since the outdoor training sessions are seasonal and can be limited by scheduling and weather (worsening weather conditions can be seen during training in Figure 24), they were supplemented with indoor training activities. The first was a computer simulation program called Real Flight. This simulator can be run on any personal computer and comes with controls similar to those found on the outdoor training helicopters. The Real Flight system was given to the DOT trainees prior to flying the real system to provide them with a feel for the helicopters and to accelerate the learning curve. The simulator also provided good practice for the trainees in between training sessions. The Real Flight controller also has the ability to interface with the regular outdoor unit to provide the users with the exact same controller. A photograph of the Real Flight controller with the interface can be seen in Figure 25.

Figure 25: Real Flight Computer Simulator

The second system used for training during the winter months and adverse weather conditions was a tethered indoor helicopter, the Hoverfly. The Hoverfly is a simple to use electric indoor helicopter that requires little space and short setup/takedown times. This unit allowed the DOT trainees a more realistic indoor trainer that responds similarly to the outdoor training unit. The Hoverfly enabled the DOT personnel to practice without elaborate equipment or formal training sessions with an instructor present, thus enabling “learn at your own pace” training. The Hoverfly has a flight performance that closely resembles conventional radio-controlled models. It is light, and employs a slow rotor speed, making it safe, and ideal for indoor operation. The Hoverfly can be seen in Figure 26.

Figure 26: Hoverfly Indoor Trainer

The R/C helicopter was not as easy to fly as originally anticipated. The research team underwent extensive training to learn the basics of flying R/C units. Many of the individuals trained became quite proficient by the end of the project.

Post Processing Software

This section represents an abstract of the report written by Darrin Hanna, the full text of which can be found in Appendix 1.

Aerial photographs are widely used in tracking the types and number of trees for different plots and stands in forestry. Some methods that require field-based approaches, such as using a global positioning system and foot-canvassing a plot and recording the tree types one-by-one have not gained popularity in field applications. However, processing digital images, a method which is much less time consuming, has received a great deal of attention. Thus far, individual tree-counting techniques that have been studied have yielded fairly accurate results. In many cases, local adaptive binarization techniques combined with local maxima methods improve the accuracy of processing these digital images, see Figure 27.

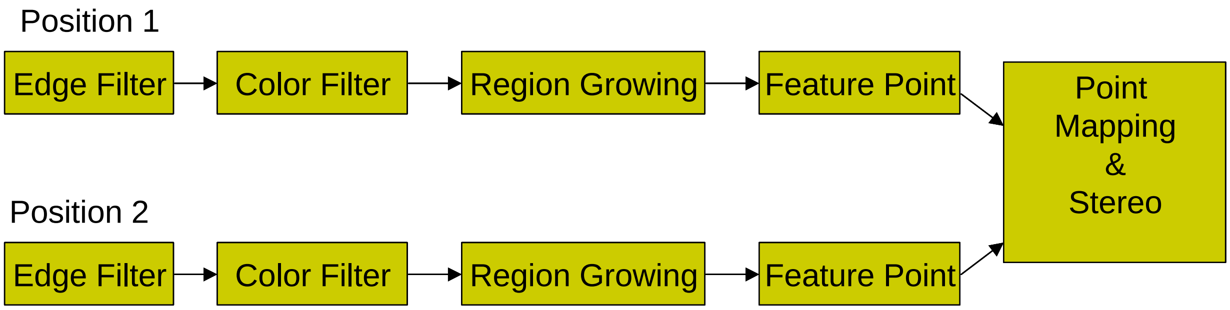


Figure 27: Flowchart showing process to develop stereo image.

Unfortunately, for individual tree detection this post-processing step tends to remove some components that should be counted as trees. This may or may not be within tolerable limits. Experiments were conducted, the algorithm worked well (435 trees detected out of 500). However the same algorithm with a less dense threshold/resolution detected over one thousand trees.

In general, this method was found to be very unstable for individual tree detection. The algorithm was heavily dependent on the threshold choice. This suggests that the results might be fairly inconsistent from picture to picture.

In the binarized image, using 8-connected segmentation, 383 trees were detected (best) using a specific model. This is 76.6% accurate. A summary of the results can be found in Table 6. The difference in results may have been due, in part, to obtaining a derivative image instead of the same exact image used in the experiments.

Table 6: Algorithm experimental results

Method	Trees Found	Hanna's Overall Accuracy	Pitkanen's Overall Accuracy	Notes
Mode	383	76.6%	79.2%	Used Mode *1.6 to achieve best result
Niblack	375	75.0%	82.9%	K=1.3
Otsu	377	75.4%	81.6%	
IIFA	435	87.0%	82.8%	Using T=0.075
IIFA	1217	243.4%	82.8%	Using T=0.4 (comparable to Pitkanen's 50)

In Pitkanen's experiments, he used an area for Stand 2A with 530 trees in it. The only image the research team was able to obtain from him was a derivative image with 500 trees in it. Additionally, the image Pitkanen sent me was 343 x 172 resolution and he eluded that the image that he used in the paper was a slightly higher resolution.[23]

In experiments, the Mode method of binarization seemed to work the best. However, the standard mode was not used, rather the mode-multiple that maximized the number of components in the binarized image. However, the post-processing algorithm was not applied. Without the post-processing algorithm (and quite possible even with the post-processing) IIFA was fairly unstable for this application. Changes in the manually chosen threshold parameter yielded large changes in the number of trees detected by the implementation. Also, it actually overestimated the number of components in some cases (grossly overestimated). Overall, the modified mode method, Niblack's method, and Otsu's method yielded good results and were reliable. Even though functionality of using locally adaptive binarization verses binarization methods (that use global parameters) cannot be conclusive determined; an analysis on a single image was used performed.

A visual representation of the steps undertaken in the software development and testing can be seen in Figure 28, Figure 29, Figure 30, Figure 31, and Figure 32.

Figure 28: Image acquired using radio-controlled helicopter.

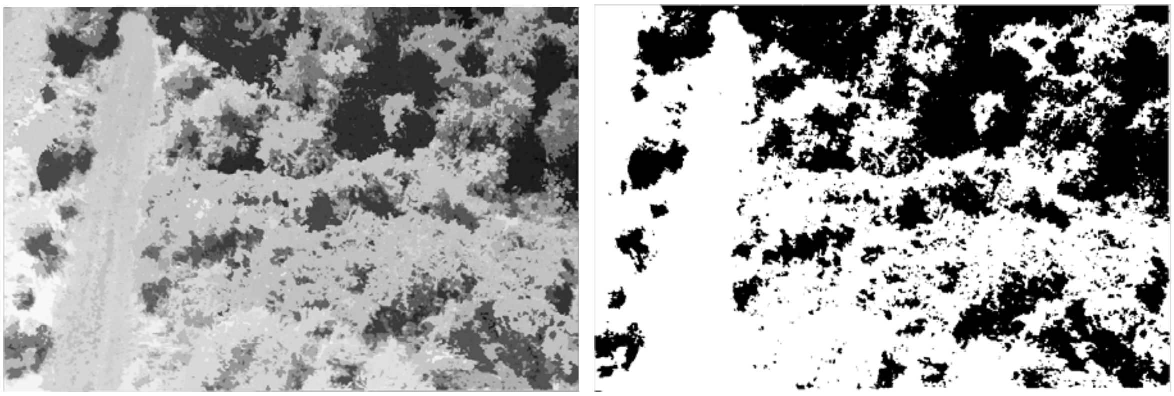


Figure 29: Gray level image followed by threshold analysis.

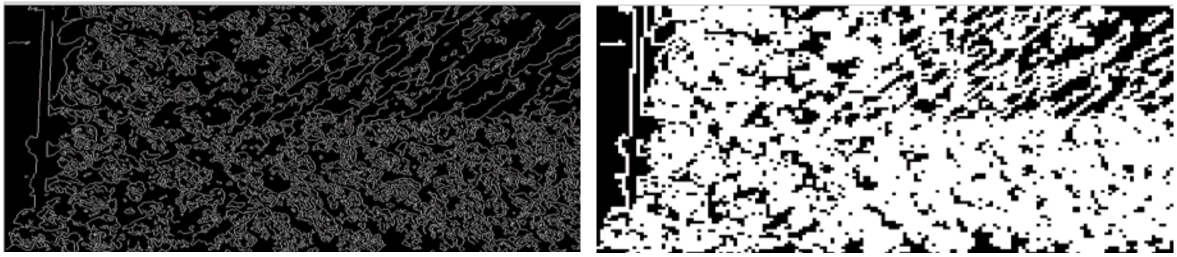
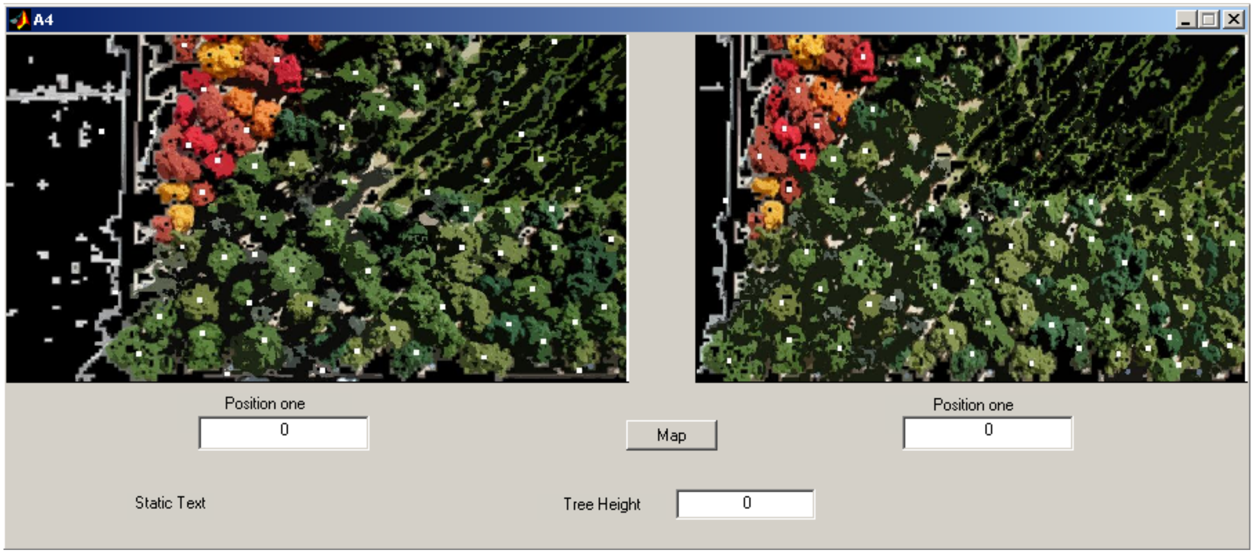


Figure 30: Edge detection image followed by edge and color filters.

Figure 31: Analysis of growing region leading to feature identification and tree top obstruction detection.



Position one 0

Position one 0

Tree Height 0

Figure 32: Selection of regions of interest and modeling of the image based on stereo approach.

Field Data Collection

Due to the extended time frame for the integration portion of the helicopter unit, it was necessary to integrate a small unit for preliminary data collection. In lieu of the integration on the primary unit, a secondary unit, comprised of Chuck Wildey's Observer aircraft, was prepared so that test pictures with the camera unit and smaller GPS can be taken and used in the computer analysis. This unit was comprised of the Observer helicopter and a small Garmin GPS unit. The helicopter was then flown at a test site, pictures of trees near site were acquired as well as GPS readings recorded. This was done to allow for a preliminary beta test to be done by the software side of the research team.

The Garmin unit was tested for use in the initial field data collection for Chuck Wildey's helicopter. Various methods to either save the waypoints where photos would be taken or downlink the data while in-flight were attempted. Embedding the data directly into the photo image was preferred by the research team to ensure correlation of data. However, the simple Garmin unit does not have sufficient output capabilities. Also tried was a real time data downlink using a small transmitter/receiver setup with a camera focused on the Garmin screen. This proved useful but there were concerns over blurriness and vibration as well as the fact that the Garmin unit does not have an all-inclusive screen, with all the data displayed. Therefore it was decided to use the Garmin unit as both a GPS and a data logger where it would track the unit every ten seconds. Then at the completion of each test the unit was interfaced with a computer on the ground to download the GPS data log. The data was then to be manually cross-referenced with time stamped photos to the GPS x, y, and z data.

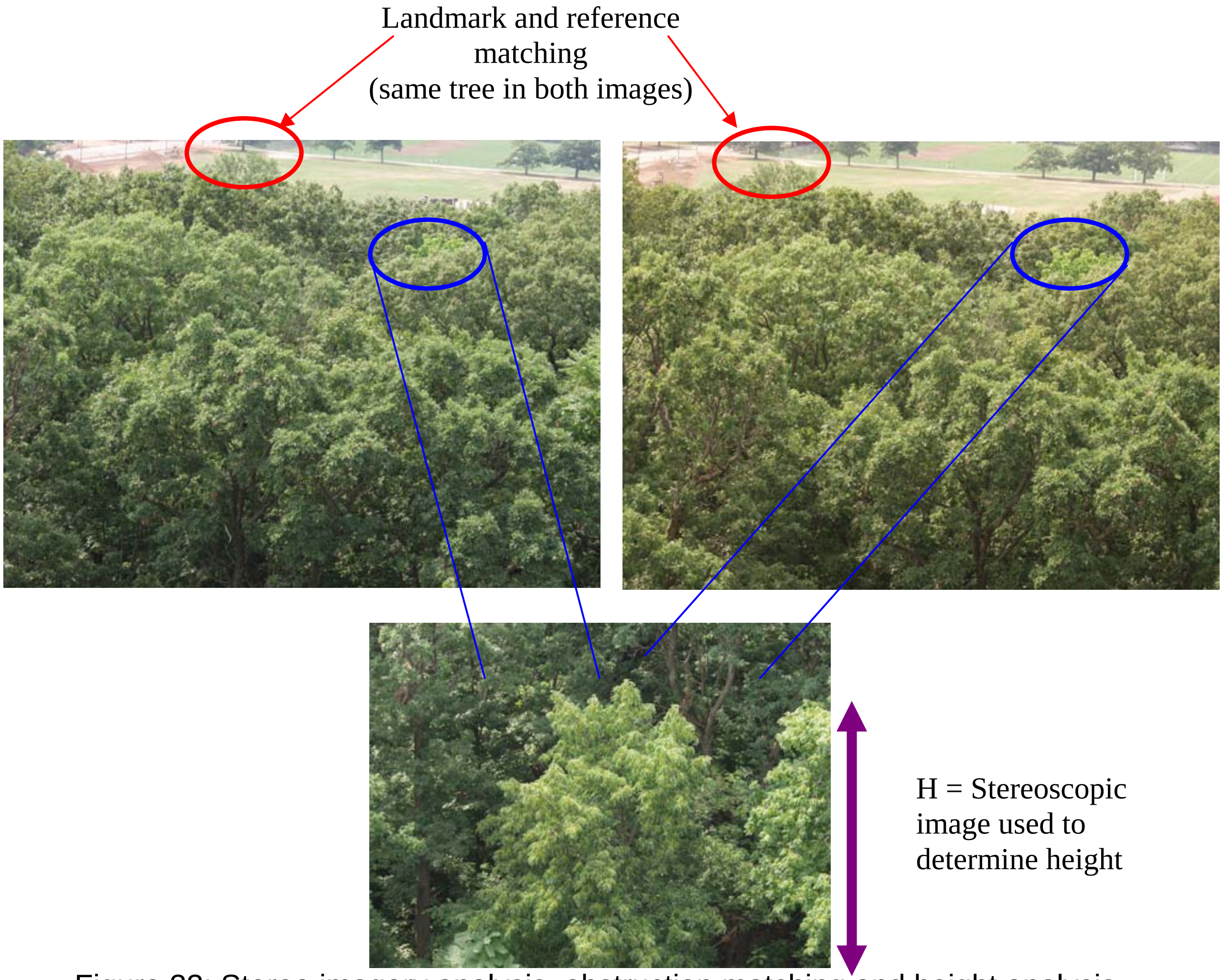


Figure 33: Stereo imagery analysis, obstruction matching and height analysis.

Helicopters have absolute negative stability, meaning that the can move in any direction having complete freedom of motion. In a helicopter measuring the roll, pitch, altitude, heading, etc requires an extremely fast refresh rate as conditions change instantly. To maintain a heading the operator needs to constantly make corrections as opposed to a fixed wing aircraft that will typically glide on the same heading and altitude. Thus for the helicopter the image acquisition is extremely more intricate. As show in Figure 34 even when the camera (focal point) is relatively stationary small changes in roll and pitch can significantly affect the image analysis.

For example, a one degree pitch of the helicopter at an image collection elevation of 200 ft for an object that is observed at 15 degrees would result in approximately a 13-15 ft error. This analysis was conducted using a fundamental 2D analysis employing basic tangent calculations. This is an extremely simplified example, but in this example the object would have been extremely close only 54 ft away in the horizontal direction. The further away the object, the more the error increases; taking into account GPS error as well as the other degrees of freedom the net error can be substantially greater.

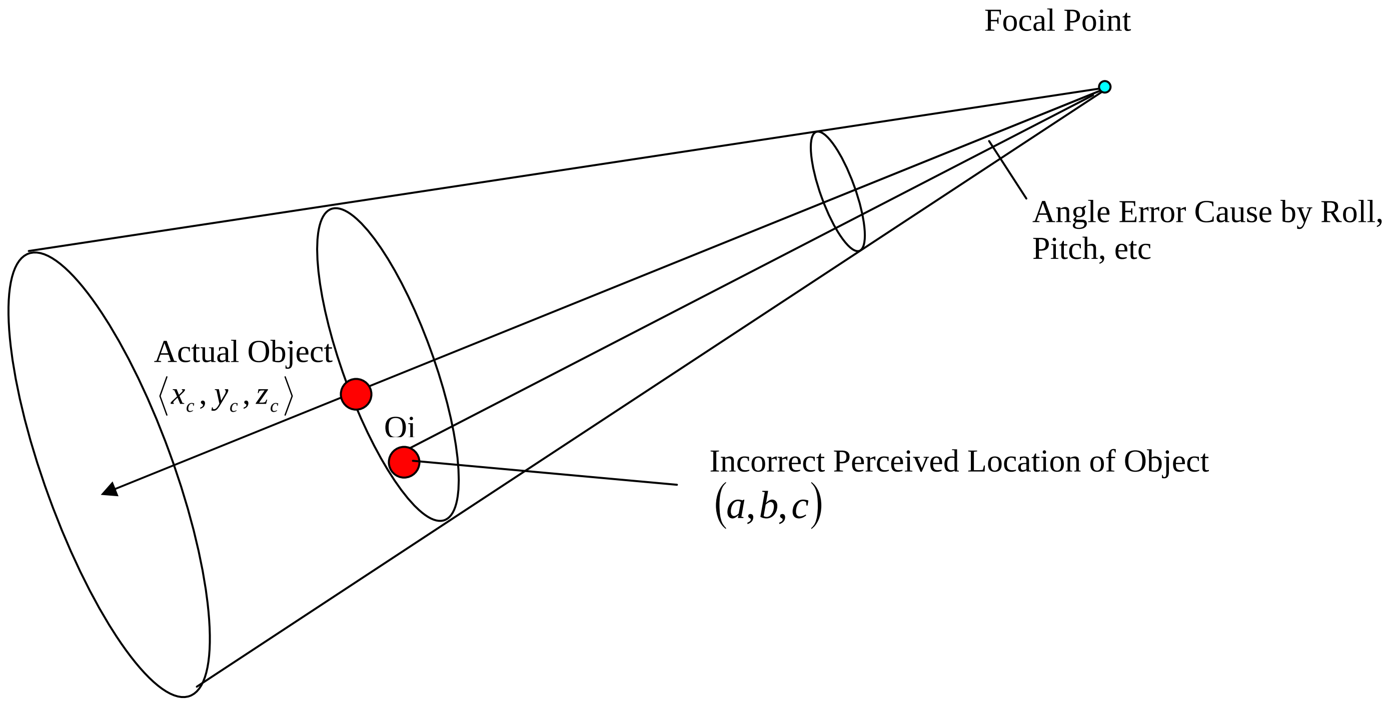


Figure 34: Compounded error during image collection due to rotation, roll, and pitch.

Lessons Learned

Stereo imagery, one of the fundamental concepts of the image post processing required the collection of stereo images. The software component of this project was to analyze two near identical photos acquired by the aerial mapping system and determine the precise height of each tree. Two problems encountered were:

- Due to a weight concern two cameras were not mounted, instead it was decided to use a single camera and acquire multiple photos from similar locations. It was later found that a radio-controlled helicopter drifted very rapidly and the acquisition of the second set of photos was nearly impossible.
- It was decided during the research phases that this would be a operator controlled flight, in order to mimic flight paths much more closely it would have been beneficial to have used some type of autonomous flying mode. This would have been a significant departure from the intent of the study and would have required a complete redesign of the system.

Numerous studies throughout the world have shown that aerial surveys conducted using radio-controlled helicopters have significant potential. The ability to fly near the survey area is one of the most important aspects. However, there are many problems that continually plague the units these include vibration, wind effects, and difficult in flying (operating) the helicopter. The units are not able to survey large areas, roughly half a square-mile of coverage would be about the limit of existing technology. Augmenting a unit with an advanced navigation system would significantly increase the overlap of images and allow for better coverage. The pilot of the helicopter is limited by the line-of-sight, if they cannot see the unit they cannot judge the orientation. This is a significant limitation for large areas.

The camera mount used for vibration dampening was not sufficient to completely eliminate vibration effects; also the pan and tilt pulley system should be upgraded, as well as the servos. It was absolutely critical to balance the camera exactly in the center of gravity. The dampers may not have been the best ones suited for this application and the frequency ranges experience by the helicopter.

In general, for most GPS units it was found that the height error (or z component) was typically twice that of the x-y error. So an error of a meter could result in a two meter height error (approximately 6 feet). This level of error was discussed with Leica, solutions proposed were to switch to a static observation for a minimum of 20 minutes which clearly would not have meet the project goals of having the unit onboard a helicopter which cannot be held statically for more than a second or two; or to switch the GPS receiver to one that uses dual frequency resulting in 20cm x-y and 40-60 cm in the z direction.[19] At the time the GPS unit was purchased a dual frequency unit was either not available or not considered. A model such as the Leica GS1220 available at the time this report was written has this dual frequency capability. However, the receiver, controller, antenna, and battery would weight over 5lbs; 3.5 times as much as the unit currently on the helicopter. Technology is a moving-target, and this is a clear example of how technology is progressing and how the research team could not achieve the required level of accuracy due to limitations at the time the study was undertaken. [19]

Many of the technical issues experienced by the research team are the same issues others are having worldwide. For example “The tests in Switzerland showed that the sued camera platform was not sufficient for our purposes, because vibrations were not absorbed and the camera could not be aligned straight to the ground…..test flights showed also, that in manual mode it is not possible to keep the predefined waypoints….the main problem of a mini model helicopter is still the vibration of the system, and the payload capability and integration of all the sensors” [24]

Conclusions

As shown from the previous sections, the choice of components for the system was not straightforward; no one system immediately stood out to solve the technical problems. Each technology and alternative had many advantages and disadvantages for use in this project. Changing of one variable many times created another issue, which then needed to be overcome.

The one significant problem that seems to be universal in similar research projects around the world is the system vibration. Use of a radio-controlled helicopter for mobile mapping is a reality. However, the vibration of the system during flight still creates numerous obstacles. The cause of the vibration is the engine (a standard combustion engine similar to what one might find on a weed wacker). Blurry images, loss of GPS satellite tracking, and line of sight while flying the unit are all very real problems that need to be addressed in future work. Use of vibration dampers and “auto-pilot” automatic stabilization units helped but did not completely eliminate the errors.

The aerial mapping system developed during this project was comprised of a radio-controlled helicopter mounted with a camera and GPS unit to accurately obtain images of suspect vegetation. The most difficult component, as previously discussed, was the choice of the GPS. This had to be lightweight, accurate within less than a meter, and cost effective for this project. After extensive research, contacts, and other means of gathering information a choice was finally made. The GS20 from Leica Geosystems was selected because the research team believed it to best satisfy a majority of the technical requirements. This research project began in 2002, by 2005 entirely new generations of GPS technologies were available, and now by 2008 L5 frequency signal is projected to bring even higher levels of accuracy that were not previously attainable. Technology available and used during this study proved intrinsically prone to error, as the receiver moves, the system generates position estimates and this creates error upon error growth thus making the data unreliable.

New Jersey DOT personnel were extensively trained on the radio controlled helicopter equipment. The DOT trainees have made great strides in training that would have ensured the proper operation of the system.

The image post processing software component was being developed by partners on this project working from Oakland University outside Detroit, Michigan. With the use of the software package and the data obtained from the helicopter flights, accurate locations of the obstructions was to be easily obtained and action (such as trimming of trees) was to be taken. The limitation in GPS data and blurry images caused by vibration prevented the research team from completing this phase of the project. However, preliminary results showed that even if these had not been such significant issues that the overall accuracy of the software algorithm was at best 75-87% accurate.

The development of an airport obstruction identification system utilizing low altitude mapping technologies is an extremely promising technology. Once fully developed, it can enable NJDOT to accurately identify, map, and remove trees that are currently posing a danger to arriving and departing aircraft at various airports within New Jersey. It will also enable the DOT to remove the suspect vegetation from property the first time, without missing any obstructions. The technology used within this project has the potential for use in many different future applications. Other uses for this technology include the possibility of use with DOT’s search and rescue operations and accident investigations.

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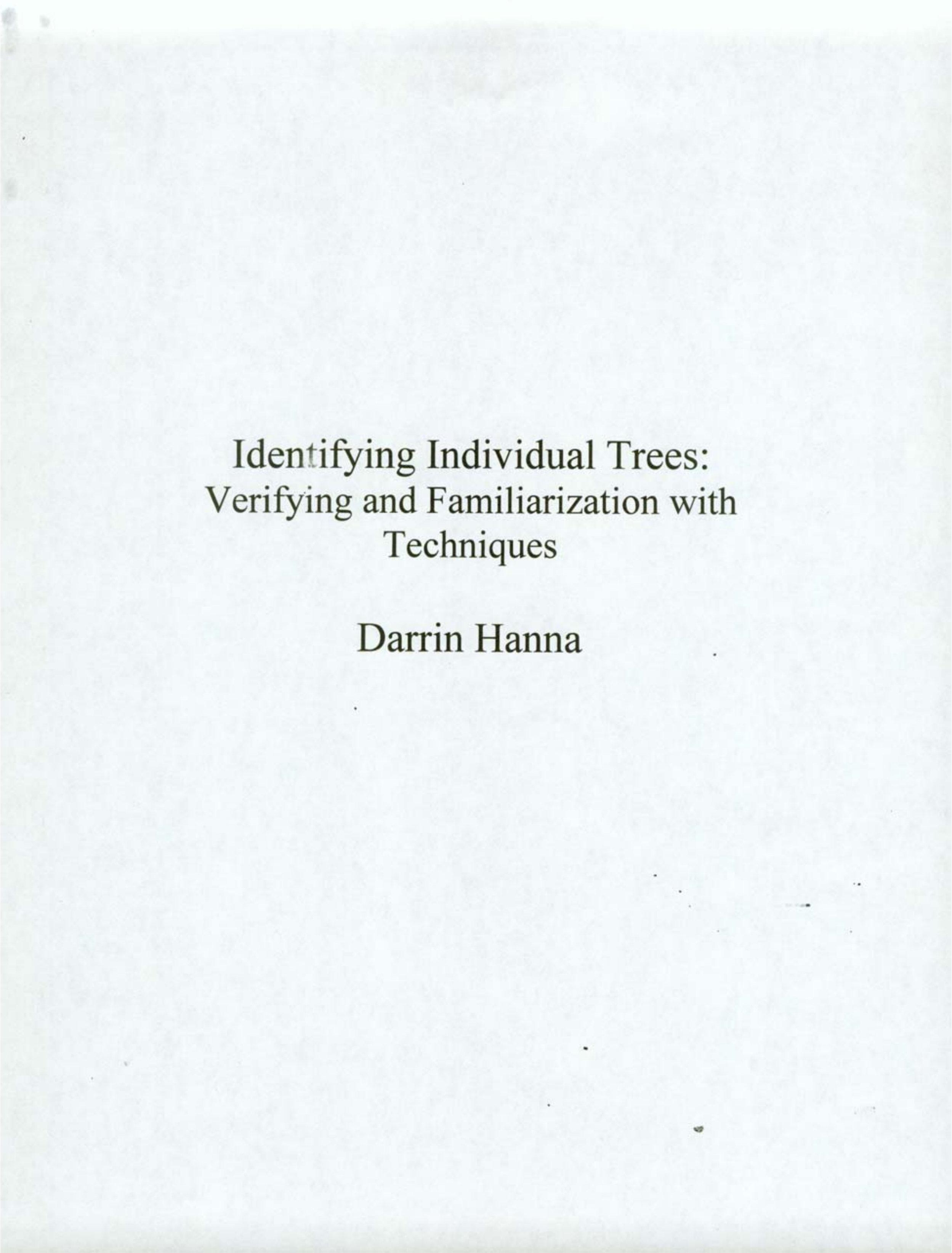
APPENDIX 1: IDENTIFYING INDIVIDUAL TREES: Verifying and Familiarization with Techniques



Identifying Individual Trees: Verifying and Familiarization with Techniques

Darrin Hanna

Identifying Individual Trees
Darrin Hanna

Aerial photographs are widely used in tracking the types and number of trees for different plots and stands in forestry. Some methods that require field-based approaches, such as using a global positioning system and foot-canvasing a Plot and recording the tree types one-by-one have not gained popularity in field applications. However, processing digital images, a method which is much less time consuming, has received a great deal of attention. Thusfar, individual tree-counting techniques that have been studied have yielded fairly accurate results. In many cases, local adaptive binarization techniques combined with local maxima methods improve the accuracy of processing these digital images. In general, individual tree detection can be described by the system shown in Figure 1.

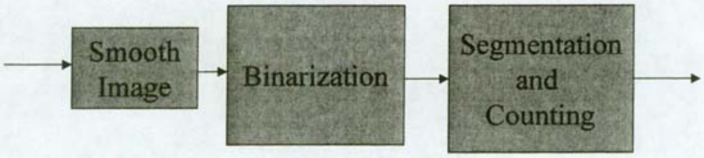


Figure 1: Individual Tree Detection

The input image was taken using a camera with three CCD sensors of 380,000 pixels each. Two of the CCDs capture the green light and the third captures the red and blue light by stripes. One of the CCDs that captures the green light is positioned so that the pixels captured are diagonally shifted a half pitch from the other. These are interpolated so that the final green image has four times the number of pixels as an individual CCD. The green band was used for these experiments because it has the best spatial resolution. The images that the author took were taken under varying conditions. During the photographing session, the weather was changing and a thunderstorm was moving in. The images taken were of several different plots that were each divided into different Stands as shown in Figure 2 [4]. Experiments presented in this paper used Plot 2 Stand A. This is the main section discussed in the paper and one of the two plots that I was able to obtain from the author.

Preprocessing: Smoothing

The input image can be preprocessed using smoothing before performing binarization. In most cases, smoothing the input image increases the accuracy of the final tree count. In this case, we used a two-dimensional Gaussian kernel obtained from

$$G_{ij} = \frac{1}{2\pi\sigma^2} e^{-\frac{i^2+j^2}{2\sigma^2}}$$

with a window size equal to 2[trunc(3σ)] + 1 where trunc stands for truncating to the integer towards minus infinity. In these experiments, we chose σ=0.6. Other values of σ were experimented with but had no significant results overall.

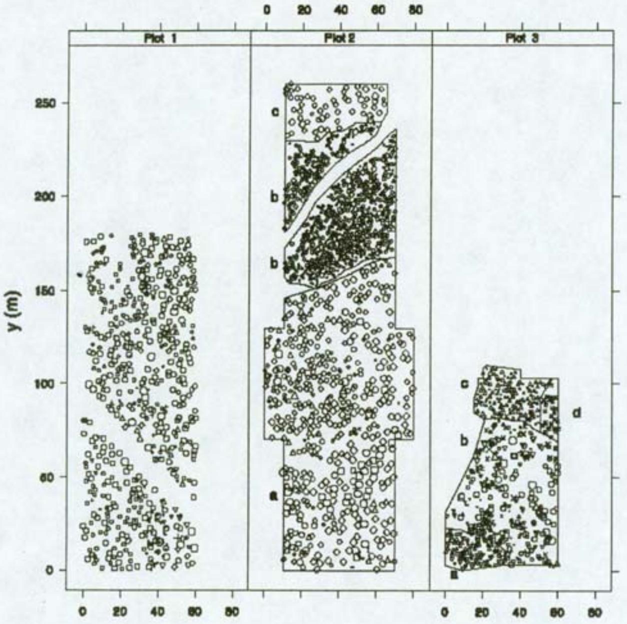


Figure 2: Plots and Stands

After smoothing, the next step is to binarize the preprocessed image. This is where different methods have different vices and rewards. Juho Pitkanen experimented with using locally adaptive techniques for binarization compared with techniques whose parameters are global.

Binarization Techniques and Observations

In 1996, Dralle and Rudemo used mode binarization to estimate the number of stems in an aerial smoothed image. In this method, the most common grey level (the mode) is used as the threshold. Pixels with a grey level equal to or above the mode are labeled as object pixels and the rest are labeled as background pixels. This method is relatively simple and is a global method since the mode is taken over the entire image.

For this paper, the mode thresholding algorithm was implemented and mode multiples were also used, including mode*1.2, mode*1.5, mode*1.6, mode*1.7, mode*1.75, and mode*1.8. A better result was achieved by mode*1.6 overall. This suggests that the mode may serve as a potential threshold point to maximize the result using neighborhood thresholds. Since trees can be very close together and appear as a single tree, individual tree detection tends to underestimate the number of trees in the image. For this reason, we would like to obtain a threshold that ultimately yields a maximum number of components. Table 1 shows the number of trees as a function of mode multiplier for the experiments conducted with Plot 2 Stand B.

Table 1: Mode multiplier vs. Tree Count

Mode Multiple	Tree Count
1.2	301
1.5	314
1.6	383
1.7	378
1.75	367
1.8	331

Another method given by Otsu in 1979 selects a threshold by maximizing the separability of resulting classes of grey levels over all possible candidate thresholds. In Juho Pitkanen's paper [4], he describes this method incorrectly. There are several missing terms. In Otsu's 1979 paper [3], the method described is a cluster-based method. Otsu defince the *variance-within* as shown in the equations below:

$$\sigma^2_{\text{Within}}(T) = n_B(T)\sigma^2_B(T) + n_O(T)\sigma^2_O(T)$$

$$\begin{aligned}
n_B(T) &= \sum_{i=0}^{T-1} p(i) \\
n_O(T) &= \sum_{i=T}^{N-1} p(i) \\
\sigma^2_B(T) &= \text{the variance of the pixels in the background (below threshold)} \\
\sigma^2_O(T) &= \text{the variance of the pixels in the foreground (above threshold)}
\end{aligned}$$

Figure 3: Otsu's Variance Within

Computationally, this method is intense. In this case, we would computer the variance within of every possible threshold and choose the threshold that *minimizes* this variance. However, the computation becomes more manageable if you consider the opposite variance defined as the *between variance* given below.

$$\begin{aligned}\sigma^2_{\text{Between}}(T) &= \sigma^2 - \sigma^2_{\text{Within}}(T)\\ &= n_B(T)\left[\mu_B(T)-\mu\right]^2 + n_O(T)\left[\mu_O(T)-\mu\right]^2\end{aligned}$$

Figure 4: The between variance

This can be rearranged as

$$\sigma^2_{\text{Between}}(T) = n_B(T)n_O(T)[\mu_B(T)-\mu_O(T)]^2$$

Figure 5: Reduced between variance

which is convenient for implementation. Now, all we need to do us compute the number of background pixels and object pixels given the candidate threshold and the mean pixel value in each set. After computing this for each possible threshold value, the threshold desired is the one that *maximizes* the between variance.

In this project, this method was also implemented. The simple recurrence relation gives a method of updating the required values for high-speed computation rather than computing them over and over again for each possible threshold.

$$\begin{aligned}n_B(T+1) &= n_B(T) + n_T\\ n_O(T+1) &= n_O(T) - n_T\\ \mu_B(T+1) &= \frac{\mu_B(T)n_B(T) + n_T T}{n_B(T+1)}\\ \mu_O(T+1) &= \frac{\mu_O(T)n_O(T) - n_T T}{n_O(T+1)}\end{aligned}$$

Figure 6: Recurrence relation for Otsu's method

I experimented with this method and found that it was incredibly slow. The results were as good as the other techniques, particularly locally adaptive techniques.

- Another method used by Niblack in 1986 was to use a local mean and standard deviation. The threshold at pixel (x,y) s calculated as

$$T_N(x,y) = m(x,y) + ks(x,y) \qquad \text{Eq (1)}$$

where m(x,y) and s(x,y) are the mean and standard deviation in the local area of the pixel and *k* is a free parameter. In Pitkanen's paper, he used k=-0.1. I found that slightly better results were obtained from k=+1.3. The neighborhood that I used was a window size of 31 pixels. Pitkanen experimented with windows of size 21, 31, 41, and 51 and found little difference. I experimented with these windows and smaller-sized windows and found no significant different in results. Table 2, below shows the results obtained at different values of k for Plot 2A.

Table 2: Niblack's method

Number of Trees	% Accuracy	k
9	1.8	-0.5
74	14.8	0
241	48.2	0.5
355	71.0	1.0
374	74.8	1.2
375	75.0	1.3
255	51.0	2.0

Finally, the last method used was the improved integrated function algorithm (IIFA) introduced by Trier and Taxt in 1995. This was a modification from the algorithm presented by White and Rohrer in 1983. Both methods were originally designed for detecting letters and numbers in optical character recognition. This method is an activity-based method. The activity operator, A(x,y) is defined below.

$$A(x, y) = \sum_{n=-1,0,1} \sum_{m=-1,0,1} a(x+n, y+m)$$

where the change activity for one pixel is

$$a(x, y) = |\mathrm{d}x(x, y) + \mathrm{d}y(x, y)|$$

and the derivatives in terms of grey level values, u, are

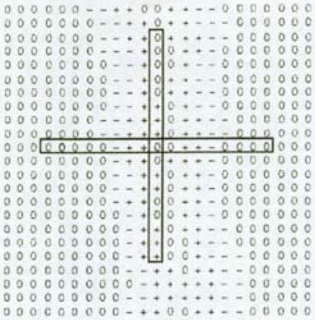
$$\mathrm{d}x(x, y) = u(x-1, y) - u(x+1, y)$$

$$\mathrm{d}y(x, y) = u(x, y-1) - u(x, y+1)$$

A manually chosen threshold must be chosen. For pixels equal to or below this threshold, T, a label of 0 is assigned. For pixels above this threshold, a label is assigned according to the sign of the following LaPlacian operator:

$$\begin{aligned}\mathrm{dd}\,xy(x, y) = {} & u(x+2, y) + u(x-2, y) \\ & + u(x, y+2) + u(x, y-2) - 4u(x, y)\end{aligned}$$

If the LaPlacian operator of the pixels is positive or zero, the pixel is labeled with a plus sign (+) otherwise it is labeled with a minus sign (-). All plus regions are labeled as object pixels and minus regions are marked as background.



```
0 0 0 0 0 0 - - + + 0 0 + + - - 0 0 0 0 0 0 0
0 0 0 0 0 0 0 - - + + 0 + + - - - 0 0 0 0 0 0
0 0 0 0 0 0 0 - - + + 0 + + + - - 0 0 0 0 0 0
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```

Figure 7: Labeled pixels during binarization using IIFA

For pixels marked with zeros, the pixel is considered an object pixel if the majority of the four-connected pixels are marked plus otherwise the pixel is considered a background pixel. An example of a block of an image after labeling the pixels is shown above in Figure 7.

A post-processing step was introduced by Yanowitz and Bruckstein in 1989. The main steps to the post processing algorithm are given below:

1. Smooth the image by a 3 x 3 mean filter to remove noise.

2. Calculate the gradient magnitude image of the smoothed image, using Sobel's edge operator.

3. Select a value for T_p.

4. For each four-connected object region, calculate the average gradient of the edge pixels. Edge pixels are object pixels that are four-connected to the background. Remove regions that were previously considered objects that have an average gradient below the threshold T_p.

The original papers show the results for optical character recognition and the post-processing technique removes erroneous objects nicely. An example from the original papers is shown in Figure 8.

Unfortunately, although Pitkanen doesn't mention it, for individual tree detection, this post-processing step tends to remove some components that were previously counted as trees. This may or may not be a desirable effect. In my experiments, For T=0.075 the algorithm worked well (435 trees detected out of 500) and for T=0.5 (which is analogous to the threshold of 50 used by Pitkanen) the algorithm detected over one thousand trees although I did not implement the post-processing algorithm for this project which would in principle eliminate some of the unwanted object pixels.

Original Image

Binarized with original method
introduce by White & Roher (1983)

Binarized with IIFA

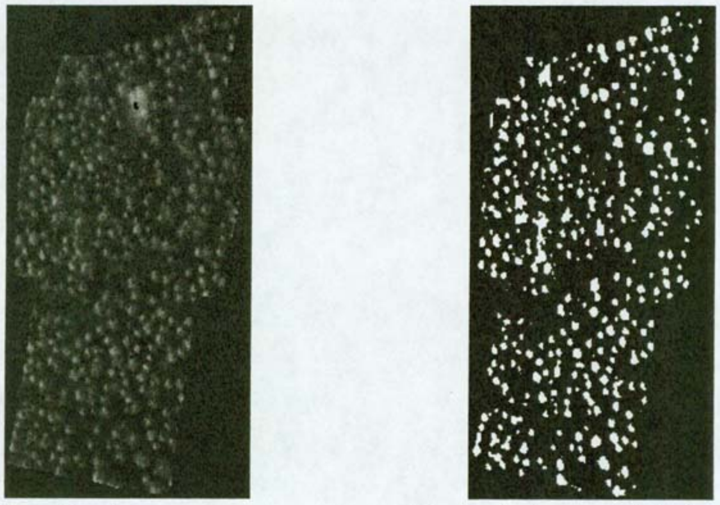
IIFA and postprocessing
intoduced by Yanowitz & Brickstein (1989)

Figure 8: Original IIFA results in optical character recognition

In general, I found this method to be very unstable for individual tree detection. The algorithm was heavily dependent on the threshold choice, *T*. This suggests that the results might be fairly inconsistent from picture to picture. The author, however, claims to have had some luck with this approach and in some cases IIFA yielded close to the best results in his experiments.

After binarization, the binarized image must be segmented into components. This can be done several ways. One method, also used by Pitkanen, is to use 8-connected segmentation. That is, a component is a collection of pixels that are 8-connected. The input image used (a derivative of Stand 2A – actually containing 500 trees reported by the author who sent me this image) and the binarized output using mode segmentation are shown below in Figure 9.

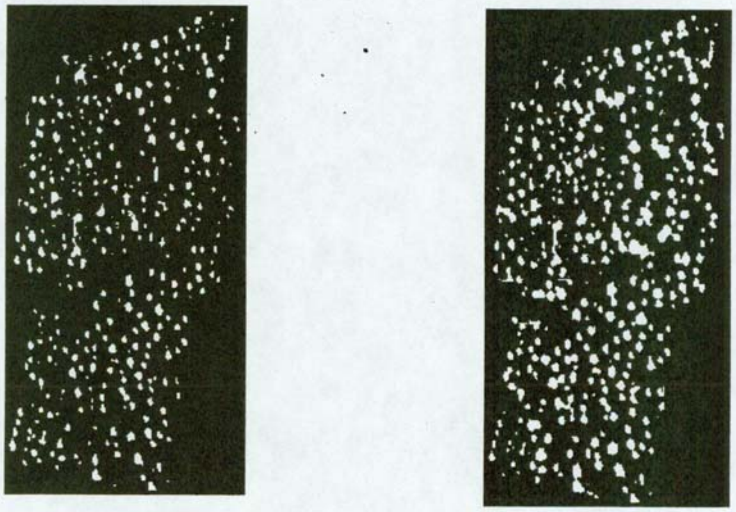
In the binarized image, using 8-connected segmentation, 383 trees were detect (best) using the mode*1.6 as previously discussed. This is 76.6% accurate. Pitkanen describes his results in terms of trees found and nontree maxima based on the original GPS data that accompanied the images. I was unable to obtain this data and therefore can not compare my results in the same manner. I could only assume that the trees counted are actual tree crests.



Smoothed Image Binarized using mode-binarization

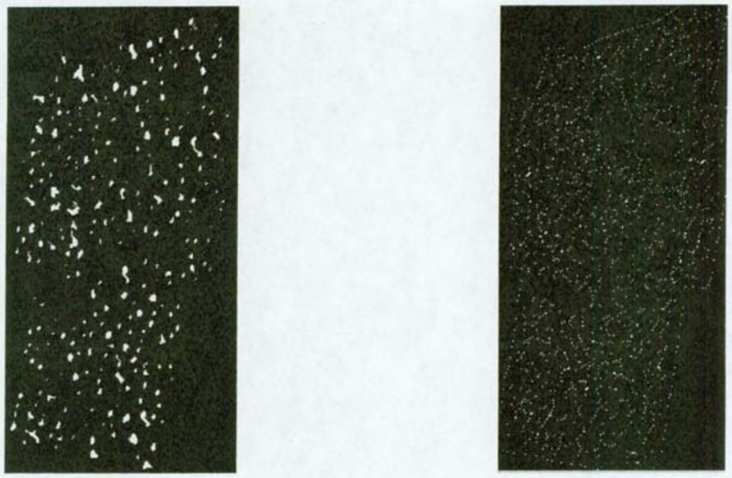
Figure 9: Smoothed image and binarization using mode method

Results using a global mean threshold (Niblack's method with window size = N and k = 1) and a threshold obtained by local averaging using a window size of 31 and k=0.1 are shown below in Figure 10.



Global Averaging Local Averaging W=31

Figure 10: Binarization using an average thresholding (Niblack's method)



Otsu's method

IIFA *T*=0.4

Figure 11: Binarization using Otsu's method and IIFA

Binarization using Otsu's method and IIFA are shown above in Figure 11. The threshold used for IFFA, *T*, was 0.4 (which is approximately equivalent to Pitkanen's 50 out of 255) and counted 1,217 trees (far too many).

Table 3 below shows the results for the Plot 2 Stand A derivative image (500 actual trees) obtained from the author compared to his results for the slightly larger Plot 2 Stand A he used in his experiments.

Table 3: Experimental Results

Method	Trees Found	Hanna's Overall Accuracy	Pitkanen's Overall Accuracy	Notes
Mode	383	76.6%	79.2%	Used Mode * 1.6 to achieve best result
Niblack	375	75.0%	82.9%	k=1.3
Otsu	377	75.4%	81.6%	
IIFA	435	87.0%	82.8%	Using T=0.075
IIFA	1217	243.4%	82.8%	Using T=0.4 (comparable to Pitkanen's 50)

Discussion on Experimental Results

The difference in results may have been due, in part, to obtaining a derivative image instead of the same exact image used in the experiments. In Pitkanen's experiments, he used an area for Stand 2A with 530 trees in it. The only image I was able to obtain from him was a derivative image with 500 trees in it. Additionally, the image Pitkanen sent me was 343 x 172 resolution and he eluded that the image that he used in the paper was a slightly higher resolution.

Conclusion

In my experiments, I found the Mode method of binarization to work the best. However, I did not use the standard mode, I used a mode-multiple that maximized the number of components in the binarized image. The highest accuracy, as shown in Table 2, were obtained by the IIFA method. However, I did not implement the post-processing algorithm. Without the post-processing algorithm (and quite possibly even with the post-processing) IIFA was fairly unstable for this application. Changes in the manually chosen threshold parameter yielded large changes in the number of trees detected by the implementation. Also, it actually overestimated the number of components in some cases (grossly overestimated). Overall, the modified mode method, Niblack's method, and Otsu's method yielded good results and were reliable. I can't make a particular comment on the utility of using locally adaptive binarization verses binarization methods that use global parameters since I only had a single image to experiment with. Pitkanen suggests, however, that in *most* cases, locally adaptive binarization outperformed binarization techniques that used global parameters.

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