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Optimizing Photogrammetric Techniques for Wetlands Monitoring: Southeast Texas

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Abstract Environmentalists express concerns about the health of the planet and the vital role of wetlands on Earth. Sufficient knowledge of wetland changes is becoming more crucial as loss of wetland area increases. However, an ability to efficiently map and monitor the wetland topographies requires technology advancement. Producing high resolution and high quality digital elevation models (DEMs) requires substantial investments in personnel time, hardware, and software while increasing accessibility of three-dimensional imaging methods, such as digital photogrammetry. Further refinements have highly improved the method while preserving its convenience. This study introduces unmanned aerial system (UAS) coupled with with structure-from-motion (SfM) technology as a new method in wetland mapping. The contributions of this study are aimed at maximizing the efficiency and accuracy of the data collection process for mapping the Southeast Texas wetlands and other related applications. This paper serves as a summary and evaluation of various photogrammetric and data extraction techniques.

Keywords: *Unmanned Aerial System (UAS), Unmanned Aerial Vehicle (UAV), Structure-from-Motion (SfM), Wetland Mapping, Digital Photogrammetry*

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1. Introduction

This study introduces a new approach in mapping and monitoring wetlands in Southeast Texas. Unmanned aerial system (UAS) combined with structure-from-motion (SfM) technology is able to create a new remote sensing market and open the doors to the future, where an UAS system is a necessity, not a luxury.

It has been estimated that wetlands occupy approximately 4-6% of the world's land, Southeast Texas included [1]. Wetland is a generic term used for the wet habitats impaling land that is either temporary or permanently wet. No matter to what extent human race contributes to wetland processes, wetlands are greatly beneficial for global ecology, and therefore, are valuable [1]. The study area is located on the Gulf coastal plain of the United States in Southeast Texas. Southeast Texas is located along the coast of the Gulf of Mexico and includes most of the Texas portion of the Intracoastal Waterway; it is crossed by numerous rivers and streams. The land is low, extremely flat, and often marshy - the perfect set of conditions to sustain wetlands. Along with freshwater wetlands, the area also includes salt marshes and coastal mangrove swamps that create unique ecological system in the area. However, industrial development, human factor and global warming tendencies contribute to freshwater losses of wetlands. Not only social well being, but also political development and economics are associated with the availability and distribution abilities of freshwater resources [2]. Furthermore, ground water and surface water resources are essential for livelihoods [3].

Today, a degraded wetland is not able to perform its functions fully, therefore, it's crucial to assess the status and quality of the wetlands frequently [4]. In order to monitor and map the wetland area it is necessary to meet society's expectations considering the cost of analyzing method and potential benefits of sustainable wetlands. Unmanned aerial systems (UAS) coupled with structure-from-motion (SfM) photogrammetric process have a potential to revolutionize wetland mapping processes. The proposed method is gaining significant recognition from scientists, engineers, foresters, farmers, private practitioners, resource managers, and policy makers [5,6]. Degradation of air quality, destruction of fresh water wetlands, minimal federal standard of the environment regulation: all these factors have led to an environmental crisis in the Southeast Texas area. Some environmental problems are anthropogenic rather than natural. The loss of fresh water wetlands is caused by the urban sprawl: expansion of industrial sector, forestry and agriculture; tidal wetlands and beachfront are used for residential and commercial purposes [7]. Urban heat island effect significantly contributed to the current state of natural ecosystems, such as wetlands, and put habitat fragmentation at the top of the list of environmental concerns [8]. Therefore, the matter of environmental and social implications should be discussed in a specific context before it can be generalized [9].

1.1. Wetland Function and Classification

The interdependence between wetlands and aquatic ecosystems cannot be stressed enough; wetlands in southeast Texas maintain water quality and exceptional biodiversity [10]. Wetlands are important components of the landscape: the holding capacity helps maintain flood control or act as a barrier to recharge, and reduce low flows [11]. Wetlands also act as recharge areas for groundwater. Groundwater supplies 25% of industrial water needs and serves as am important source of drinking water for more than half of the nation [12].

Substantial scientific evidence supports the claim that the wetland terrain type influences the hydrological cycle, colloquially known as the water cycle, the process in which water evaporates, condenses, and precipitates [11]. However, Dugan [13] states that there are more than 50 definitions of “wetlands” in current use. Defining whether it is a terrestrial ecosystem or a deep water aquatic habitat is exceptionally challenging due to their highly dynamic character and some limitations in evaluating wetlands conditions and their borders. Therefore, not all functions are present in the different types of wetlands, and many are unique due to particular floras and faunas. Wetlands include a complex range of ecosystems – for instance, nurseries for various species including shellfish and seasonally migrating birds.

Regardless of its effect on the area, the wetlands strongly influence the hydrological cycle. Successful water management proposes further research on which wetlands perform different hydrological functions [11].

1.2. Value of Wetlands

In the light of climate change, the impact of global warming on wetlands is not yet generalized or sufficiently investigated [14]. Without integrative environmental research and dialogue, solutions to environmental challenges will be unsuccessful and new problems will be keep on arising [15]. Economic methods, specifically cost efficiency and cost-benefit analysis, are a part of environmental policy evaluation and regulatory planning since 1983 in the United States [16]. The tools used for implementing a new environmental policy should adjust or limit economic activity [17]. The purpose of an effective appraisal work of wetland’s potential benefits to society and environment is to efficiently reduce the cost of existing wetland monitoring methods, introduce new methods and reevaluate the importance. For instance, the World Wildlife Fund reported that coastal wetlands reduced the severity of impacts from hurricanes in the United States and provided storm protection services with an estimated value of $23.2 billion per year [18]. By providing protection against the impact of hurricanes, the wetlands significantly reduce the the cost of damage repairs.

For a specific region, the value of wetlands can be measured both qualitatively and quantitatively. The value of wetlands should not only be measured by how much they contribute to the quality of life but also by how much money is associated with their functions. Despite some beliefs, assessing the value of wetlands is a complex procedure, involving a complex network of factors [1]. First, wetlands perform several processes in parallel. Optimizing for one process generally happens at the expense of another creating the need to assign a unique value to each process. Second, based off of the economic principle of scarcity, the size of the wetland area contributes to its value. For example, the practice of wetland abundance it is often viewed as a social necessity to convert the wetlands for other needs.

The value of wetlands is evaluated by how many goods it yields, its hydro geomorphic position, and its position relative to human settlements. The ability to accurately gauge the value of wetlands allows regional, national, and international government officials to make the right decisions regarding conservation and utilization.

The importance of the wetlands and their contribution to the environment and the society is clear. However, the method through which they should be mapped and monitored is open for discussion. The difficulty of monitoring wetland is finding a spatial measurement technique that encompasses numerous desirable properties, such as reliability, accuracy, low cost, and ease of installation [19]. Many methods have been implemented throughout the years that purport some of these advantages, but this study will focus on the use of photogrammetry that can be relatively inexpensive to map and monitor the wetlands [20,21,22]. In the decision-making process, especially regarding technology advancement, it is necessary to take into account possible impacts evaluated by other disciplines [23]. For example, Building Information Modeling (BIM) can be used not only to analyze site conditions, but also wetlands and protected habitats [24].

2. Introducing Photogrammetry

The use of UAS has increased over the past years to monitor environmental changes. However, wetlands are difficult to map from the ground due to their fast-changing boundaries and the diversity of species. Adaption of innovation in any industry is a complicated and extensive process – academic researchers and educators have to pay special attention to new ways to communicate new ideas to construction industry practitioners, for example [25].

The idea of photogrammetry has been in development since 1480, and as digital technologies advance, its concepts have been used to further develop its derivative technologies such as Structure-from-Motion (SfM) [26,27]. "Topographic structure from motion: a new development in photogrammetric measurement" discusses the production of topographic datasets via the structure from motion photogrammetric approach. Fonstad, Mark A., et al. produced high resolution digital elevation models of the Pedernales River in Texas from photographs acquired by a handheld helikite using an online SfM program [28]. The paper compares the SfM approach to the traditional photogrammetric approach. While the SfM approach uses a series of still images, the key difference between classical digital photogrammetry and SfM is the execution of image matching algorithms which calls for less strict requirements during the image acquisition phase. Substantiated by thorough comparisons and evaluations, the principal conclusion of the paper is that, compared to classical digital photogrammetry, the image matching algorithms of the SfM approach provide a higher level of automation and greater ease of use. Furthermore, the authors offer additional suggestions for future SfM implementation. The SfM approach is considered for the application discussed in this paper.

Regardless of the method of photo acquisition, many components contribute to the overall quality (i.e. accuracy and precision) of the data, and therefore, the method must be evaluated by several considerations. First and foremost, the method must be optimized for what is being observed. For example, if the goal is to estimate and monitor the vegetation that inhabits a wetland, then the incorporation of photointerpretation will be necessary to improve the quality of the data [29]. In the flow and erosion rates measurements algorithmic techniques and matrix conditioning can be applied in the data processing phase to reduce errors in the final model [30]. Other factors that strongly influence the integrity of the model include the quality of metric camera(s), photographs scale, scanner efficiency, resolution at ground, view angles and limitations such as surface morphology, vegetation, shadows, and atmospheric conditions [31]. Finally, the most significant and fundamental consideration is effectiveness; if the method is inadequate for the needs, then it can be dismissed. Pertinent to the scope of this paper, research has determined that digital photogrammetry can yield suitably accurate results and has a significant impact in terms of monitoring and planning for changes [32,33]. The method evaluation is complete when every factor of optimization has been considered.

This provides sufficient evidence that reinforces the necessity to map, monitor the wetlands and create a structured process for developing a method to do so. The studies explore emerging and revolutionizing technologies that are low-cost, high-quality and innovative. The use of UAS in agriculture sector alone is an emerging industry that is set to expand the next few years and become an U.S. $13.6 billion industry in the United States [34]. The research findings delivered by this review serve as a foundation for the method proposed in this paper.

2.1. Current Practice of Wetland Mapping

The practice of monitoring the wetland changes over time is crucial to port cities, coastal communities, and wildlife habitats all over the world. Monitoring the changes in the environment can allow experts to study these changes and determine the causes of many environmental shifts. They can also use the knowledge about the changes to help slow the deterioration of the wetlands which is home to many species of animals and insects. Working with the local cities, officials across the world have several options to conduct this surveying in order to secure their environment's safety and to track the changes for the scientific study of the wetlands.

In Beaumont, Texas, the city officials are concerned with the deterioration of the wetlands caused by flooding, ship traffic, strong winds, and hurricane damage. These factors play an important role in shaping the Neches and Sabine Rivers and the wildlife that call these regions home. Currently Beaumont opts for a geolocation technique in which videos are taken of specific points along the water front from an aerial position. These videos are taken as a panoramic view of the waterfront and the GPS coordinates where the video was taken is then documented. Once the videos are uploaded from the camera, they are linked to a map of the area. This interactive map takes the coordinates of the video taken and pins the video to the map for viewing. After several videos are taken at numerous points along the water front areas the map will represent a comprehensive string of videos that documents the entire river's environment for that year. In order to take the videos, researchers must fly in a helicopter each year and hover in a specific location specified by the coordinates for each video to be taken.

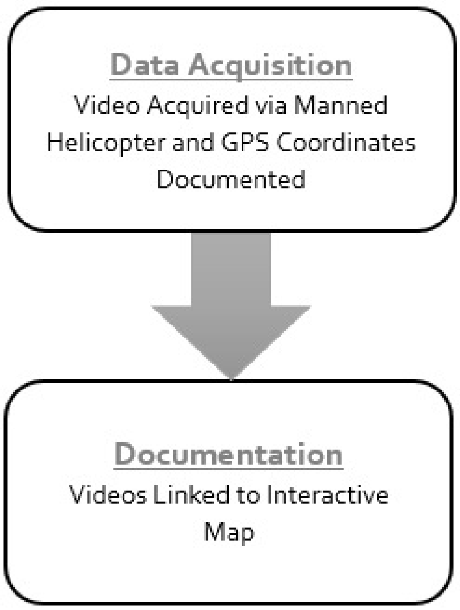

Figure 1. Scheme of current practice of monitoring vegetation and topographical changes

This process in expensive due to the cost of renting the helicopter and the fuel cost for flying (Figure 1). The videos are generally shot over the course of two days each year. These videos are uploaded to the geolocation database where the interactive map for each year shows the change in the environment over time. These maps are very useful to the city and local industries as well as the environmental agencies tasked with protection of the wildlife and recourses of the area. Although it is difficult to fly at the precise coordinates each year that were used the previous years, the team of surveyors does attempt to take data from the same vantage point each time they generate a geolocation map. The accuracy of the coordinates is estimated to be a 30-yard radius from the previous year's location. More accuracy could improve the quality of area mapping and vegetation observation. Helicopter-based GPS videography increases a risk of error, bias and pseudo accuracy assessment. The conventional method of image acquisition using planes, helicopters or satellites can collect data for large land, but can cost large amounts of money depending on the region of interest [5]. Nevertheless, it could be difficult to use these methods for a specific date due to weather conditions and flight regulations.

2.2. Proposed Method

Considering an increased awareness of wetland losses and threats to water quality, scientists recognize the importance of wetland mapping using the most advanced technology [35,36]. Researchers are in constant search for a more efficient, cost effective way to monitor wetlands. Technological advances in mapping technology have opened up new avenues for innovative methods. The methodology can be greatly improved and made much more efficient through the use of UAVs (Unmanned Aerial Vehicle), aerial photogrammetry, and model overlapping analysis. Comparing to ground-based methods and any other conventional aerial technology, UAVs are cost-efficient and smaller, providing high-resolution aerial image at low altitude [37].

The current method of the city of Beaumont does not take advantage of some of newest technology that are readily available. Instead of operating a helicopter each year to obtain videos of the area's wetlands, UAVs can be used to make the process much more cost effective and simpler. The use of a drone also makes it easier to take the video more than once a year, as it is cheaper and simplistic in comparison to helicopter usage practice. UAVs also allow for the video to be taken at a much closer distance giving a much more detailed look at the wetlands (Figure 2).

Once a video is recorded, it can be processed using a 2D or 3D aerial photogrammetry software. The two-dimensional model will be more advantageous, if erosion and the changing of the coastline location are the main areas of study, while the three-dimensional model examines the vegetation and elevation changes (Figure 3).

Figure 2. Video screenshot using UAV (Jefferson County, Texas, March 2016)

The two-dimensional software produces a map of the area videoed. This map can then be used to compare the same area of the wetlands to what it looked like in the past or how it looks in the future. For example, if the city of Beaumont used an UAV (a drone) to capture video of the same area every six months, the video could be turned into a map each time. These maps could be stored and used to compare the changes over a period of time using a method called layering in a program such as AutoCAD. Overlaying each map on one another would easily illustrate the changes in that particular area over time and also measure the exact change. It would simplify monitoring erosion and also help to alert trends of erosion happening at a more rapid pace.

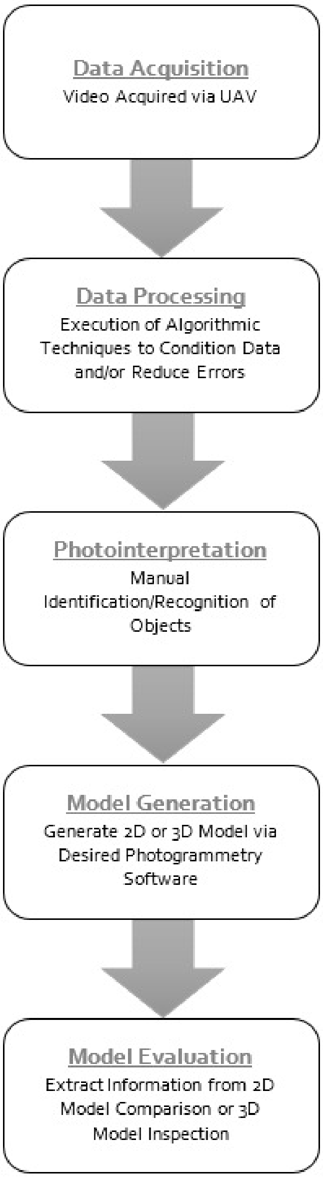

Figure 3. Current practice of monitoring vegetation and topographical changes

The three-dimensional model helps monitor vegetation and sea level changes in the wetlands. The main advantage of a 3D multi-view model is the ability to examine closely particular portion of the area at any convenience with a centimeter-level accuracy [38]. Complete control and navigation of the three-dimensional model is possible by using programs like AutoCAD. Figure 4 shows an example of created 3D model using PhotoModeler software to generate a point cloud dataset representing vegetation structure and wetland geovisualization. There are several programs that are able to convert images into useful three-dimensional data. For instance, PhotoModeler PC program is a platform that can generate dense surface three-dimensional model, get accurate measurements and scans. PhotoModeler is able to quickly capture a large scene and to model accurate volume of stockpile using the PhotoModeler Scanner. One of the most important additions to modern UAVs (unmanned aerial vehicle) is global positioning system (GPS) – now, an UAV can determine its own location in three-dimensional space and apply this to its image data. Mapping can be a costly venture – budget is usually strictly limited or may not be sufficient enough to cover suitable mapping. With the help of all these features, a complex measurement task can be greatly simplified, done quickly, and at a low cost.

Ground-based, helicopter and satellite observations do not contribute to wetland research as much as UAV practice could.

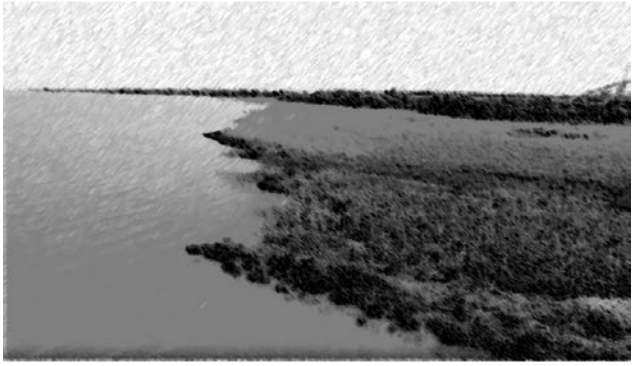

Figure 4. Sample of the created 3D model using PhotoModeler (Jefferson County, Texas, March 2016)

The process of creating two-dimensional or three-dimensional models is completely automated. Once uploaded, the software uses algorithms to detect particular features, match and mark the images, sense orientation layout, and then, produce the model using the data collected. The produced model will be a collection of point collates from the uploaded images or videos. In most cases, the model will not be entirely complete. It will be necessary to fill in the missing parts of the model, which in most cases is very minimal. This can either be done in the software were the model was created if possible, or using a program such as Adobe Photoshop.

Figure 5. DJI Phantom 3 Advanced Quadcopter Drone with 2.7K HD Video Camera

In this study we used a multi-rotor (DJI Phantom 3 Advanced Quadcopter Drone with 2.7K HD Video) to acquire high-resolution images and videos from a high angle (Figure 5). Throughout each flight, the drone sends GPS coordinates on a mobile device. The three axis gimbal stabilizes the camera even with sudden movements or wind.

3. Discussion

Extreme summer temperatures put Texas in a position when Lone Star state faces severe, multi-year drought (Figure 6). Research shows that annual economic losses from not meeting the Texas's water needs could result in $12 billion annually and over one million jobs lost. This shows the importance and need for mapping and documenting the state of the Southeast Texas surface water for making effective decisions [39].

This section will compare the current practice and the proposed method from the previous two sections based off of the following attributes: quality of the final model, method efficiency, personnel time and effort, and cost. A comparison of the two methods will provide a sufficient foundation for method evaluation.

The current practice of mapping and documenting the state of the Southeast Texas wetlands only involves videos taken from an aerial perspective. The method proposed in this paper is an extension of the current practice; it integrates the application of photogrammetric techniques into the existing method. By doing so, this method allows for a more intensive inspection of the wetland areas through the generation of three-dimensional modelling. Furthermore, the photogrammetric techniques in the proposed method can also be coupled with photointerpretation to yield greater degrees of accuracy in estimations. While the proposed method is not designed to improve the video quality, it delivers model that can be more thoroughly examined, and therefore, produces a final model higher in quality than the current method.

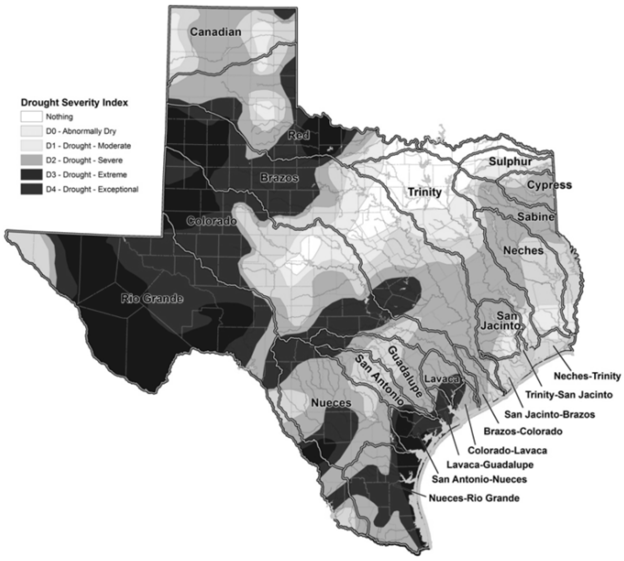

Figure 6. Drought impact on Texas surface water reported by TCEQ

The proposed method also accommodates for a more efficient process through which changes in the wetlands can be monitored. Unlike the current method, the proposed method has the ability to generate two-dimensional maps that model a specific wetland characteristic, i.e., vegetation, elevation, etc., which can then be overlaid and compared simultaneously. By overlaying two-dimensional models acquired for different dates, a more concrete comparison of the wetlands can be obtained more quickly and with less work.

Improved efficiency of the proposed method would reduce personnel time and effort, but that is without considering the learning curves associated with photogrammetry techniques, equipment, and software. Regardless, once the aforementioned learning curves have been surpassed and the method becomes a routine, the personnel time and effort will be greatly diminished.

The long-term costs required by the current method undoubtedly and significantly exceed the costs required by the proposed method. Initially, high-end photogrammetry software, equipment, and expertise must be attained with major expenses. However, the costs associated with the implementation of an UAV will be notably less than the costs associated with helicopter rentals and fuel. The reduced costs of using a UAV will also allow officials to map the wetlands more frequently, resulting in a more detailed and accurate depiction of how the wetlands change over the course of a year. Therefore, the proposed method offers long-term economic benefits which, in turn, allows officials to obtain more knowledge about the wetlands.

Limitations and optimization of the proposed method

As expected, the method proposed in this paper has several limitations. However, the number of limitations of the proposed method is less than those of the current practice. The limitations of this method affect videos that are acquired and the quality of the final product; this includes instantaneous atmospheric conditions, wetland morphology and vegetation.

The following parameters can be considered for optimization: equipment, when videos are acquired (i.e., environmental conditions, season, etc.), how videos are acquired (i.e., camera angles, distance from objects, etc.), and photogrammetry software and algorithms. These four parameters are variable; method optimization should be contingent upon what is being mapped, measured, or estimated.

4. Conclusion

Using UAS to bridge the gap between aerial mapping and ground-based measurements can highly benefit wetland research and improve economic situation in the area. Wetlands serve many purposes that are beneficial, and more often than not, crucial to humans. Therefore, the ability to accurately and efficiently monitor them is of high importance. Photogrammetry techniques provide a moderately inexpensive and efficient way through which accurate models and comparisons of the wetlands throughout time can be obtained. This allows officials to be more informed and make the appropriate and better decisions when planning for wetland utilization. The method proposed in this paper produces models that can be examined more thoroughly, is more efficient, does not require an unreasonable amount of personnel time, and is more cost efficient in the long-term. Although this method is designed to improve the practices used by officials in the Southeast Texas area, it is widely expandable and can be used to map and monitor most characteristics of any wetland area.

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