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Space Force Spacecraft Hull Inspection: Creation of a Process to Inspect, Compare, and Fault Detect on the Surface of a Spacecraft Hull

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Space Force Hull Inspection and Fault Detection

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Abstract

The University of Akron, in collaboration with the Air Force Research Laboratory (AFRL) and the University Consortium Research Opportunity (UCRO), is creating a new modular system to inspect and repair the surface of a spacecraft whilst on-orbit and in-situ. This system will be small enough to fit in a small portable package and will act as a repair kit. The kit will consist of a small mobile robot able to make scans and required repairs, along with a 3D printing station, and various repair tools.

Our project focuses on 3D scanning a prebuilt model hull, comparing original undamaged hull scans to damaged hull scans, finding these damages, and creating a repair decision process. Once these have been done manually, an effort to automate the process using Python will be made.

This summer's team started 3D scanning the model hull, as shown in the pictures, created damages to scan and compare against the undamaged hull. They also found various open-source software packages for the comparison of the two scans. They also started finding software for a finite element analysis for the creation of a repair part. The new design team will continue with these software packages and possibly any others that are found to produce better results. They will use these software packages to streamline the inspection and repair process for the larger project and automate the process using Python.

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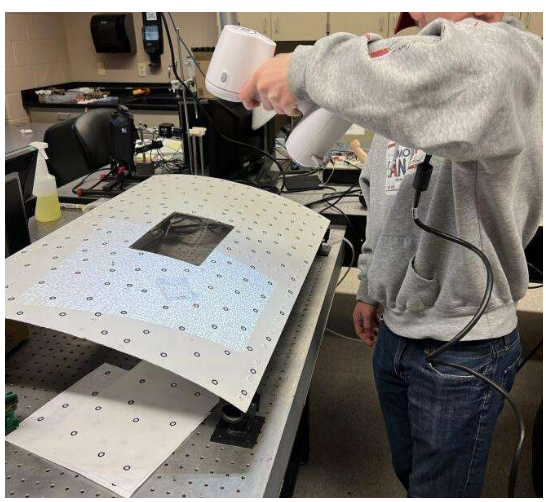
1. Problem Definition

In this project, the group is tasked with implementing a process to scan the hull of a spacecraft in order to identify defects and repair any defects found. This is to be implemented to the U.S. Space Force for use on future satellites and space stations. The scope of our group is to create the scanning process, while a sister team creates the robot that will be performing the scan.

2. Scanning

3D scanning is a technology that involves capturing the shape and appearance of real-world objects or environments to create digital 3D models. This process is commonly used in various fields, including manufacturing, engineering, design, healthcare, entertainment, and archaeology. The primary goal of 3D scanning is to accurately represent the geometry and texture of physical objects in a digital format. 3D scanning has a wide range of applications, including quality control in manufacturing, reverse engineering, creating digital archives of cultural artifacts, virtual reality content creation, and even in medical fields for creating patient-specific models for surgery planning and simulation. This technology continues to evolve, providing more accurate and efficient ways to capture the physical world in digital form. The way that our scanner and other similar scanner works is by emitting light and collecting the data from the light that is reflected back towards the scanner. There are many different types of light scanners, but the most common ones are white light, blue light, and laser scanners; all of which have different benefits and setbacks. We chose to use a blue light scanner because we determined that we could get high quality scans with it, and it is much more cost effective than a laser scanner. A picture of our scanner completing a scan can be seen in the following image.



2.1. Scanner

The scanner that is in use is the Creaform Academia 10 light scanner. The specifications of the scanner are listed below. [1]

Specification	Value
Part Size Range (Recommended)	0.3 – 3.0m (1 – 10ft)
Accuracy	Up to 0.250 mm (0.01 in)
Mesh Resolution	0.500 mm (0.020 in)
Measurement Resolution	0.500 mm (0.020 in)
Measurement Rate	550,000 measurements/s
Volumetric Accuracy	0.500 mm/m (0.006 in/ft)
Scanning Area	380 x 380 mm (15.0 x 15.0 in)
Stand-Off Distance	400 mm (15.75 in)
Depth of Field	250 mm (10.0 in)
Light Source	White Light (LED)
Texture Colors	N/A
Texture Resolution	N/A
Positioning Methods	Geometry and/or Targets
Weight	850 g (1.9 lb)
Dimensions (LxWxH)	96 x 140 x 258 mm
Connection Standard	1x USB 2.0
Operating Temperature Range	5 – 40°C (41 – 104°F)

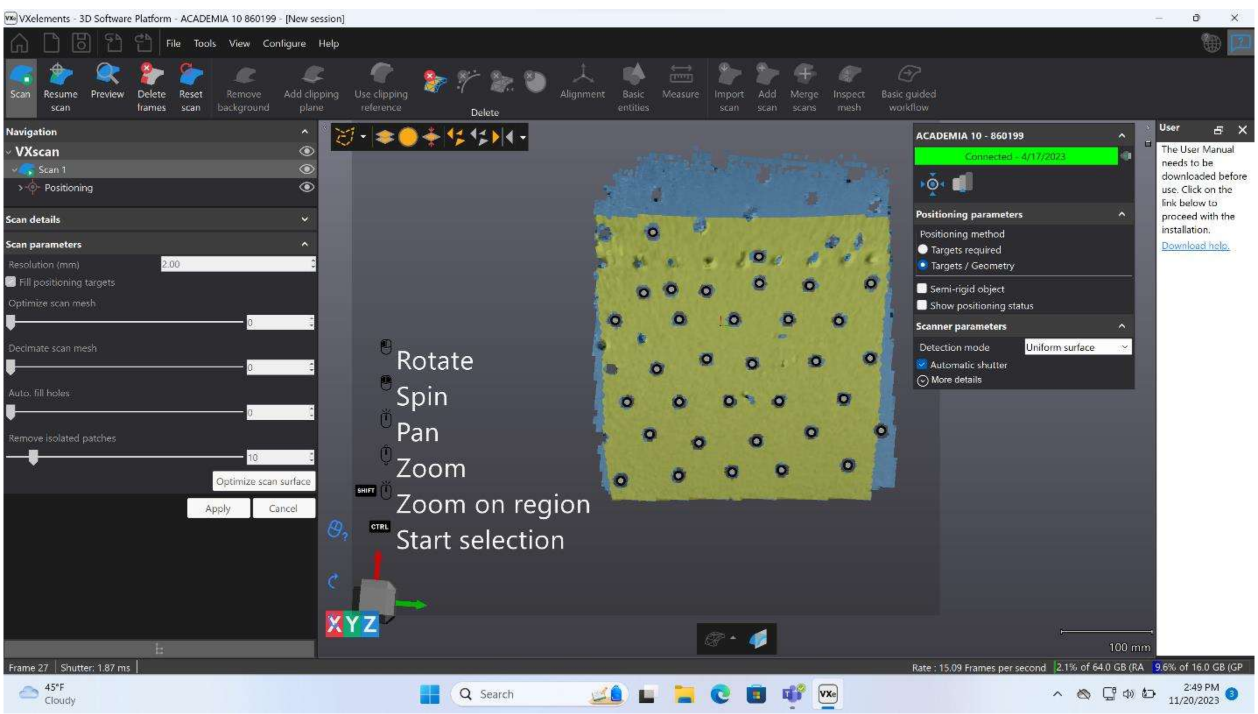
The Creaform Academia 10 light scanner is a relatively small, lightweight, handheld device. The scanner can be seen in the figure below.

2.2. Scanning Software

For scanning, we are utilizing the software VXElements. This is the software recommended by Creaform.

VXelements is a powerful integrated 3D scanning software platform that works in complete synergy with the entire fleet of Creaform's 3D measurement solutions. It combines both acquisition and application modules into the same simple, easy-to-use interface, providing a complete solution rather than a simple measurement device alone. Included with all of Creaform's 3D measurement technologies, VXelements acquisition modules produce superior accuracy and data quality from 3D measurements and provide real-time visualization. VXelements guarantees you optimal user experience, seamless interaction with your device, and the shortest time to usable mesh or 3D data—everything you need to use your Creaform optical technology to its full potential. [2]

An example of the VXelements software displaying an ongoing scan can be seen below.



2.3. Scanning Best Practices

After many trials, we have established some baselines and guidelines that should be followed or known to achieve accurate scans. They are as follows: The resolution capacity for detecting cracks is 1/8". The optimal scan height from the object surface is between 14" to 21", with the best results found at approximately 18". Targeting practices recommend a minimum of 5 targets per 42 square inches, with higher target density leading to improved scans. Targets should be placed a quarter inch away from desired features, and patterned targets yield better results. Object orientation is recommended on an opposite-colored surface, placed above that surface. Sweeping practice suggests a slow and methodical scanning approach, although no specific sweep time is required.

3. Comparisons

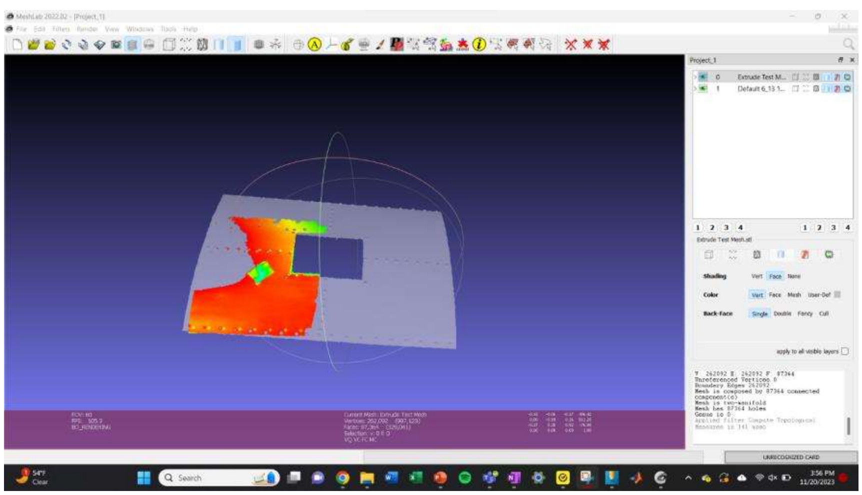
Comparisons of 3D models are essential in various industries for purposes such as quality control, design verification, and analyzing changes between different versions of a model. Several methods can be employed to compare 3D models, and the choice of method often depends on the specific requirements of the application. We are employing the method of Mesh Comparison. Mesh

Comparison is when the 3D models are represented as meshes, a collection of interconnected triangles or polygons, the vertices and connectivity of the meshes can be compared to detect differences in shape.

3.1. Comparison Software

The software we are using for the comparisons is MeshLab. MeshLab is an open-source system for processing and editing 3D triangular meshes. It provides a set of tools for editing, cleaning, healing, inspecting, rendering, texturing, and converting meshes. It offers features for processing raw data produced by 3D digitization tools/devices and for preparing models for 3D printing. Main functions include alignment, reconstruction, mapping and texturing, scaling, positioning, orienting, refinements, analysis, offsetting, and comparison. [3]

A comparison of a defective scan with an undamaged scan can be seen below.



The different colors in the scan show the warping and extrusion present on the damaged hull. The red represents a smaller defect, while the green and blue represent a larger change in dimension between the two scans.

3.2. Defect Definition

After using the comparison software, the defect can be classified using many different clarifiers defined by the end users. Defects could include cracks, bluntness, and dents, which can vary in size, depth, or thickness. Defects are classified based on their severity and impact on the product's functionality, with measures taken to mitigate or eliminate them during production.

4. Finite Element Analysis

Finite Element Analysis (FEA) is a tool used in engineering to simulate how structures and systems respond to different conditions. It's used to analyze things like stress, heat transfer, fluid flow, and more. FEA breaks down complex systems into smaller parts for analysis, helping engineers understand how the whole system behaves.

4.1. FEA Software

The FEA software that was agreed upon is CalculiX. CalculiX is an open-source finite element analysis (FEA) software package. It is used for simulating the behavior of mechanical and thermal systems. CalculiX supports a variety of analysis types, including static, dynamic, and thermal analyses. It is capable of solving linear and nonlinear problems, making it a versatile tool for engineering simulations. CalculiX is widely used in academia and industry due to its flexibility and open-source nature, which allows users to modify and extend its functionality to suit their needs.

4.2. Defect Analysis

Defect Analysis was moved from scope of project and is continued by another team that is associated with the project.

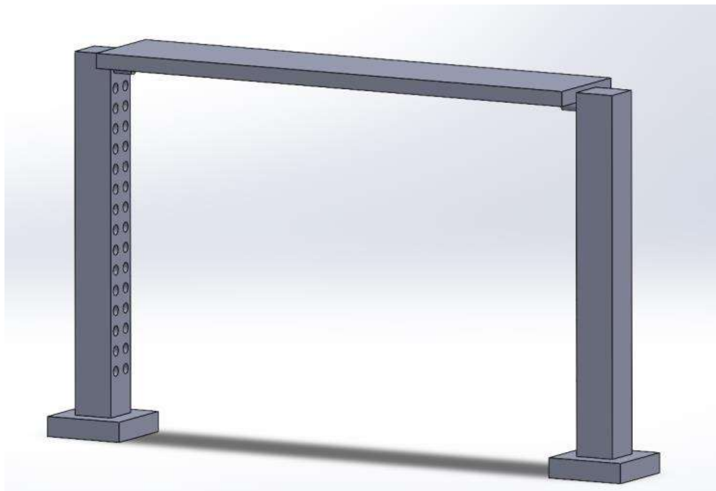
4.3. Repair

Repair solutions will be determined by end users as well as project requirements and budgets.

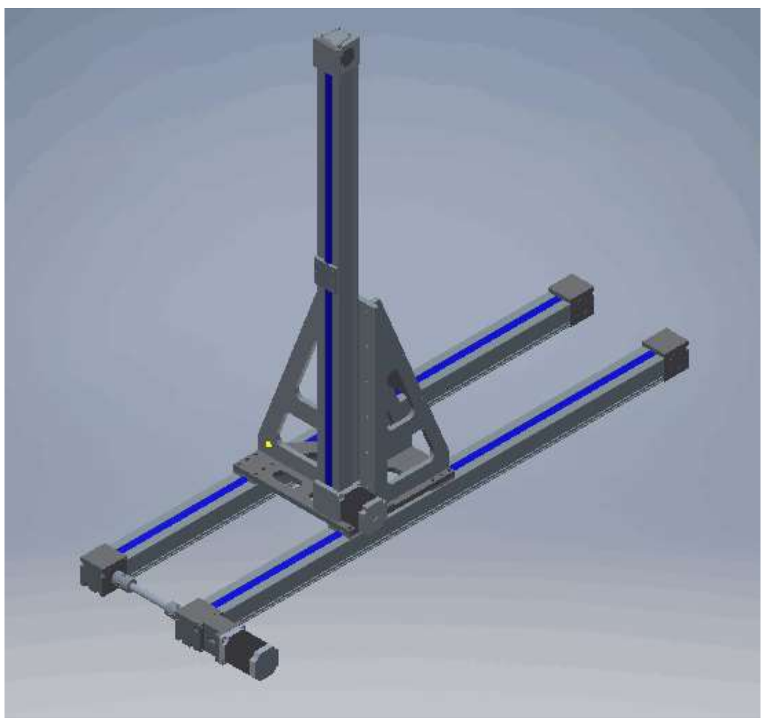
5. Test Structure

The data accrued through the series of tests outlined previously to determine the specifications of the 3D light scanner was found to be non-repeatable. This was due to the possibility of human error being introduced when scanning the hull by hand. To improve our results and ensure that they were completely accurate, the team came together to come up with design ideas for a robotic 4-axis test structure to remove any variabilities in the testing procedure.

We began by designing a basic 2-axis (x and z) test structure to remeasure the scanning parameters. Our design included two 4x4 pieces of lumber with a track in between them for the scanner to hang from. The track would be powered by servos coded by the team to provide a smooth motion accross the hull. We also planned to code several different speeds across the hull. This design can be seen below.



We ended up deciding, however, for the purpose of project cost amongst the different teams working on this project that it would be a beneficial to design and build a 4-axis test setup. This decision was made because one of the other teams was in need of a 4 axis setup for a different aspect of the Space Force project. We also wanted to ensure that the 3D scanner's parameters were the same for the x and y directions. Creating a 4-axis design was much more complicated than the simple 2-axis design. After completing some research, we decided that it would be cheaper, and more reliable to order a custom design from a third party. We sent the specifications that we found necessary to a contractor, and they provided us with the following two options to meet our needs.



After looking over the designs, we deemed the second design to not meet the requirements necessary for our test setup, as it has no x axis adjustment. Because of this, we decided to go through with the first design sent to us by the private contractor. We planned on purchasing the structure and once again testing the parameters of the scanner, but due to the time constraint, we were not able to receive the equipment before the end of the semester. Due to the time constraint, the end users will complete the final parameter testing, and compare against our previous results.

6. Conclusions and Results

In this study, we developed a comprehensive scanning process utilizing multiple software tools for 3D scanning. Our approach involved systematically evaluating the performance of each scanner by identifying their strengths and optimal parameters. Through the creation of a structured testing framework, we assessed the scanners' capabilities in terms of accuracy, resolution, speed, and compatibility with different types of objects. This allowed us to determine the most suitable scanner and parameters for specific scanning tasks. Our results indicate that each scanner has unique strengths and weaknesses. For example, a laser scanner excelled in capturing fine details but was slower compared to a light scanner, which was faster but slightly less accurate. By understanding these nuances, users can make informed decisions when selecting a scanner for their specific needs. Furthermore, our study underscores the importance of systematic testing and parameter optimization in achieving high-quality scanning results. The process of identifying scanner strengths and optimal parameters can significantly improve the efficiency and accuracy of 3D scanning projects. In conclusion, our research demonstrates the effectiveness of our scanning process and testing structure in evaluating 3D scanners. Future research could focus on expanding the evaluation criteria to include additional factors such as cost-effectiveness, ease of use, and compatibility with other software tools.

6.1. Uncertainties

Uncertainties in space projects arise from various factors such as technical challenges, budget constraints, and unpredictable environmental conditions. Technical uncertainties can include the performance of new technologies, complex mission requirements, and the behavior of spacecraft and instruments in space. Budget uncertainties stem from the unpredictable costs of development, launch, and operation, often influenced by changing economic conditions and unforeseen expenses. Environmental uncertainties, such as space weather and debris, can impact mission planning and spacecraft operations. Managing these uncertainties requires robust risk assessment, contingency planning, and adaptive management strategies throughout the project lifecycle.

6.2. Ethical Considerations

Ethical considerations in space projects encompass various aspects, including the need to minimize space debris to prevent collisions that could endanger operational satellites and spacecraft. Projects must also adhere to planetary protection guidelines to avoid contaminating other celestial bodies with Earth organisms and vice versa. Ensuring fair and sustainable use of space resources is crucial, along with maintaining transparency in activities to foster international cooperation and trust. Safety of astronauts, personnel, and the public is paramount, requiring thorough risk mitigation measures. Collaboration among nations is essential to promote peaceful and beneficial uses of outer space. Additionally, standards for safe and efficient space traffic management should be developed and followed. Open access to space data and research findings should be encouraged for the benefit of the global scientific community. Consideration should also be given to the social impacts of space activities on communities, cultures, and societies. Finally, designing space projects with long-term sustainability in mind is essential to preserve space environments for future generations.

6.3. Future Work

Future work on this assignment will be performed by future senior design projects, graduate students, and undergraduate researchers under guidance and supervision of University of Akron faculty and relevant personnel from AFRL. There are also groups that are currently working on projects that are directly related to the work discussed in this paper.

7. Acknowledgements

We would like to extend our sincere gratitude to all those who contributed to the completion of this project. Special thanks to our project advisor for their invaluable guidance and support throughout the project. Their expertise and feedback were instrumental in shaping our work. We also wish to thank the faculty members and researchers who provided valuable insights and feedback during this project. Their contributions helped us refine our ideas and approach. A big thank you to our team members for their dedication and collaboration. Their hard work and commitment were essential to the success of this project. This project would not have been possible without their support. Finally, we are grateful to all those who participated in or contributed to this project in any way. Your involvement and contributions were greatly appreciated.

8. References

https://emco.co.uk/creaform-academia-professional-grade-3d-scanner/ [1]
https://www.creaform3d.com/en/metrology-solutions/3d-applications-software-platforms [2]
https://www.meshlab.net/#features [3]