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Project Proposal

3D SCANNER

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1 Introduction

1.1 Problem

3D scanning is a cutting-edge technology that involves collecting physical object data and constructing digital 3D models for further analysis. [1, 3, 4] It has numerous applications across various industries, including manufacturing and healthcare [7, 5], where capturing accurate and detailed 3D models has become an indispensable tool.

However, one of the limitations of traditional 3D scanners is their size and portability. This is where embedding 3D scanning technology into mobile phones comes in. By embedding 3D scanning technology into mobile phones, the ability to capture 3D models becomes more accessible to a wider range of people. With the prevalence of smartphones and their widespread adoption, embedding 3D scanners into mobile phones could democratize 3D scanning technology, making it more accessible to individuals, businesses, and organizations of all sizes. Another issue with traditional 3D scanners is the time it takes to process and render a 3D model. This can be especially problematic for larger or more complex objects. Designing apps that can process data more quickly could improve user experience and increase the practical applications of 3D scanning on mobile devices.

While many traditional 3D scanners have made strides in simplifying the scanning process, there is still room for improvement. Some techniques require specific settings or lighting conditions to work properly, which can be frustrating for new users. [4] Designing a more intuitive and user-friendly 3D scanner could help make 3D scanning more accessible to a wider audience.

1.2 Solution

Our proposed solution involves designing an autonomous system that utilizes a mobile phone's camera to capture multiple angled photos. These photos are then used to generate 3D models from various 2D images taken at different positions. Additionally, a remote-controlled mechanical device will be implemented, which will allow the mobile phone to rotate 360 degrees and move the object up and down on the platform. The system will enable the user to scan objects within a specific range of volume using their phone's camera, and generate highly accurate digital 3D models in a short period.

Regarding the software component of our proposed solution, our plan is to create a program that will enable the camera on a mobile phone to capture images at predetermined intervals and subsequently transmit them wirelessly to a designated server. On the server side, we intend to develop an algorithm with the capability of transforming the 2D images captured by the mobile phone into digital 3D models. By doing so, our solution aims to provide a user-friendly and accessible means of creating 3D models for individuals who do not have access to traditional 3D scanning equipment.

In terms of the hardware component, we plan to design and construct a mechanical device that consists of a platform with height adjustment capabilities and a phone holder that is adjustable and equipped with wheels at the bottom. The phone-holder can rotate around the platform via remote-controlled motors, while the platform can be raised or lowered to adjust the height of the object being scanned. Through these mechanical functions, our solution aims to provide users with a versatile and adaptable means of capturing 3D images using their mobile phones. The technology has the potential to be used in various fields, including product design, archaeology, and cultural heritage preservation. [7] With the increasing accessibility and affordability of mobile phone technology, our proposed solution provides a promising and cost-effective alternative to traditional 3D scanning equipment.

1.3 Visual Aid

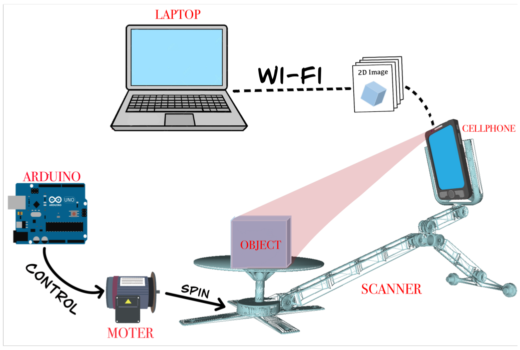

Figure 1: Visual Aid of 3D Scanner

1.4 High-level Requirements List

① The 3D scanner should be able to capture data from a wide range of object sizes, from small objects to large structures, and be able to scan objects in 360 degrees

② The 3D scanner should be user-friendly and easy to operate, requiring less than 30 minutes of training.

③ The mechanical device should take the phone and the holder to rotate 360 degrees continuously. One rotation takes 10 seconds on average.

2 Design

2.1 Block Diagram

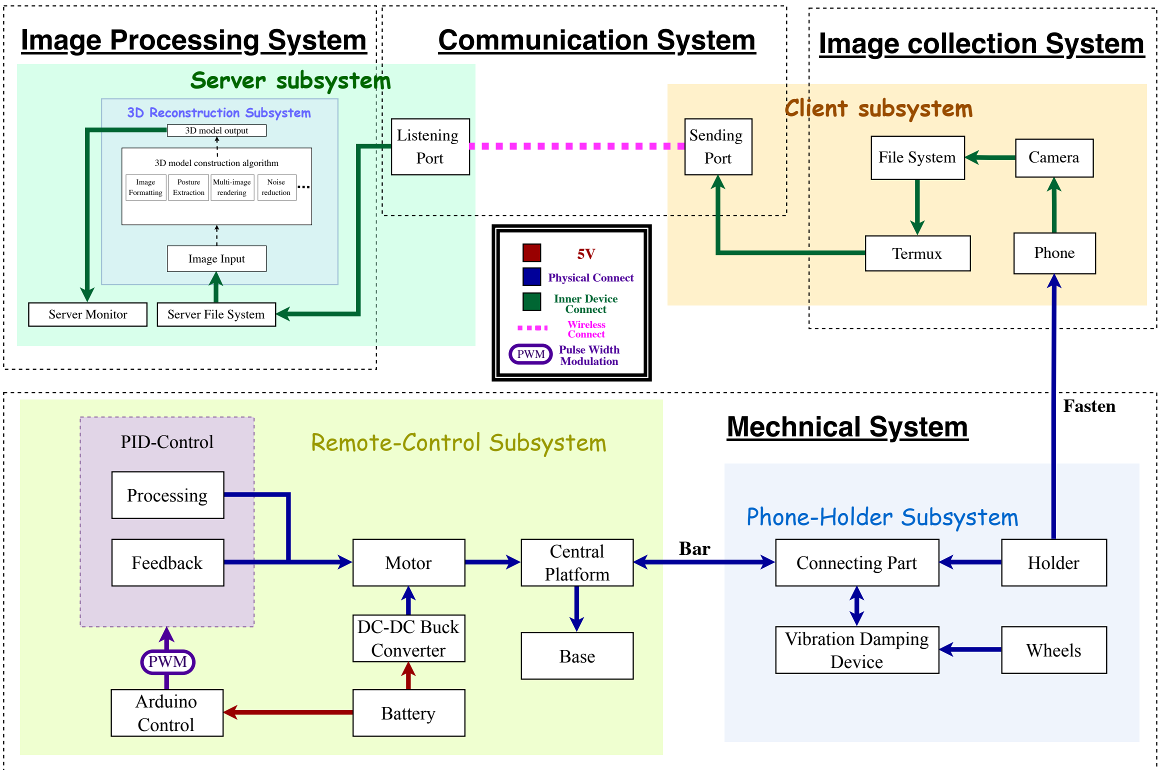

Figure 2: Block Diagram of 3D Scanner

2.2 Subsystem Overview

★ **Image collection subsystem**. Image collection subsystem is supported by a mobile phone with Android 7.0+ and a specialized software application that will allow for the precise control of a camera's settings and enable it to capture images at predetermined time intervals. Through the wireless communication protocols, these images will be sent to a designated server in real-time. This program will provide a convenient and efficient way to remotely collect and transfer 2D images at different angles.

★ **Image processing subsystem**. Image processing subsystem is a key component in the development of a autonomous system that can transform multiple 2D images into a high-quality 3D model. This subsystem takes the images collected by the image collection subsystem as input and uses advanced algorithms to analyze and process them. The image processing is composed of image formatting, posture extraction, multi-image rendering and noise cancellation. Image formatting is to format the input images in a way that is suitable for the 3D reconstruction. This may involve correcting for lens distortion, adjusting color balance, and removing any artifacts or inconsistencies that could interfere with the reconstruction process. The algorithm also performs posture extraction, which involves identifying key features in the input images and using them to create a point cloud that represents the 3D structure of the object or scene being captured. Multi-image rendering involves combining the information from multiple images to create a more complete and detailed 3D model. Noise cancellation, on the other hand, involves removing any unwanted noise or artifacts from the images, further improving the quality of the 3D model.

★ **Phone-holder subsystem**. Phone-holder subsystem is a purely mechanical part containing four parts that are connected together by bolted joints. The connecting part connects the holder that holds the phone at the top and a vibration damping system along with two wheels at the bottom. The phone-holder subsystem is connected to the central platform of the remote-control subsystem by a long bar.

★ **Remote-control subsystem**. Remote-control subsystem is to control the position of the central platform and it is connected with the phone-holder subsystem by the bar. For the remote-motor control, we use arduino to control the motor. The arduino generates PWM signal to give a PID control to the system. After processing the signal to motor, the control system will give a feedback to the control device. For powering the device, we use a battery to generate power, and use a DC-DC buck converter to change the voltage to the motor.

2.3 Subsystem Requirements

✔ **Image collection subsystem**. Image collection subsystem is required to ensure the quality of the 2D images captured for the scanned object. To this end, the image collection subsystem must be capable of obtaining high-quality multi-view 2D images of the scanned object under varying lighting conditions, different distances from the camera, and in the presence of potential shaking induced by the slow rotation of the phone-holder. Furthermore, it is essential that the subsystem ensures fast and reliable image transmission to the server, i.e. the image processing subsystem.

✔ **Image processing subsystem**. The image processing subsystem is tasked with ensuring the quality of the 3D models reconstructed from multiple 2D images, which is a challenging undertaking. As such, the subsystem must be designed with robust algorithms that can effectively handle issues such as occlusions, noise, and variations in lighting and texture, which may significantly impact the quality of the 3D models. Furthermore, the subsystem must be capable of achieving accurate and consistent reconstructions from multiple viewpoints, as well as integrating the reconstructed 3D models into a coherent whole. Additionally, the subsystem should be designed to enable real-time 2D image processing to facilitate prompt feedback on the quality of the images being captured and processed.

✔ **Phone-holder subsystem**. Phone-holder subsystem should have a solid connection with the remote-control subsystem, meaning the bar and its joints need to at least tolerate a torque of 1 $N \cdot m$. The holder should be able to sustain a weight of 240 g, which is the weight of the heaviest iPhone for now, and the bolted joints should not loose under such conditions. The range of rotation angles of the connecting part needs to be larger than 90 degrees. The friction coefficient between the wheels and a typical table surface should be around 0.3.

✔ **Remote-control subsystem**. Remote-control subsystem should control the motor's rotating speed to control the position of the platform up and down for 20 cm. The subsystem can help adjust the position of the platform where the object is place. This will help the phone to take photos for the object in a clear and convenient way. The motor is controlled by sending a series of pulses through the signal line. The frequency of the control signal should be 50 Hz or pulse every 20 ms. The pulse width determines the angular position of the motor, and these types of motors can usually rotate 180 degrees Moreover, the remote-control system should also have solid connection with the phone-holder subsystem by a bar and its joints need to at least tolerate a torque of 1 $N \cdot m$.

2.4 Tolerance Analysis

✘ **Failure of Wireless transmission**. During wireless communication between the image acquisition subsystem and the image processing subsystem, occasional interruptions may occur, potentially resulting in the image processing subsystem missing some of the images sent by the image acquisition subsystem. In such cases, it is essential that the algorithms in the image processing subsystem are capable of achieving high-quality reconstructions even when individual 2D images from certain viewpoints are missing. To address this issue, the image processing subsystem should be designed to incorporate robust algorithms capable of handling missing data effectively. One possible solution is to employ reconstruction algorithms that can effectively interpolate missing data from available 2D images, such as interpolation techniques based on spatial or temporal consistency. Another possible approach is to leverage machine learning techniques, such as deep learning, to generate plausible missing data based on available images. Furthermore, to prevent such wireless transmission failures, the subsystems should be designed to incorporate appropriate error handling and recovery mechanisms, such as **TCP** retransmission protocols, to ensure that all images are successfully transmitted and received.

✘ **Failure in the Reduction of Vibration**. During the rotation of the phone holder subsystem around the central platform on two wheels, vibrations are inevitably generated, which can have a detrimental effect on the imaging process and potentially lead to errors in the digital model construction. To mitigate this issue and ensure accurate imaging, it is crucial to reduce the amplitude of vibrations in the subsystem. One feasible approach to achieve this is to install springs above the wheels to serve as a shock absorber and dampen the vibrations generated by the rotational movement of the subsystem. The effectiveness of this approach is largely dependent on appropriate design considerations, such as the material and stiffness of the springs, their placement and orientation, and the load-bearing capacity of the subsystem.

- ✘ **Failure of the remote-control out of range**. In some cases, motors may be outside the control range of the remote control, which may be due to various factors. For example, the environment in which the motor is located may affect the transmission and reception of signals, such as buildings, obstacles, or interference from other electronic devices. In addition, the functionality and capabilities of the motor itself may also affect its distance from the remote control's operating range. For example, if the motor requires higher power output or higher sensitivity to perform specific tasks, it may need a closer operating range to achieve precise control.

3 Ethics and Safety

3.1 Ethics

Our project is aimed at designing an autonomous system that uses a mobile phone to take multiple angle photos and generates 3D models from multiple 2D images taken at various positions. Using 3D scanners, 3D models of human bodies, objects, and environments can be easily scanned and reconstructed, which can violate the privacy of others. For example, using a 3D scanner to scan someone's face, body and personal belongings may reveal someone's personal information. Therefore, privacy is of great importance to our project.

In the IEEE Code of Ethics, term 1: "To hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment" [6]. Also, in the ACM code of Ethics, 1.6, it talks to respect privacy. "Computing professionals should only use personal information for legitimate ends and without violating the rights of individuals and groups." [2] So for our project, we need to carefully collect the information we get and make sure the information is not leaked to others and made to other uses.

At the same time, for our project, the 3D scanner also has intellectual property issues: 3D models of items can be easily scanned and reconstructed using 3D scanners, which may violate intellectual property rights. Using a 3D scanner to scan copyrighted artwork or design drawings, for example, could violate Copyrights and trade secrets.

In the ACM code of Ethics 1.5, " Respect the work required to produce new ideas, inventions, creative works, and computing artifacts." [8] For the objects that has intellectual property, we need to respect all the objects, and we should not upload what we scanned on the Internet. In the process of manufacturing and using 3D scanners, relevant laws, regulations and ethical guidelines should be complied with to ensure that they do not violate the intellectual property rights and privacy of others. Security, privacy and intellectual property issues should be taken into account, and corresponding technologies and measures should be taken to minimize the risk of violating others' privacy and intellectual property rights.

3.2 Safety

- ! Electrical Safety: Since the 3D scanner involves electronics and electrical components, there is a potential risk of electrical shock. It is important to ensure that all electrical components are properly insulated and grounded, and that appropriate safety protocols are followed when working with electricity.

- ! Mechanical Safety: The 3D scanner may include moving parts that could pose a risk of injury. It is important to ensure that all moving parts are properly enclosed and that appropriate safety protocols are followed when working with these parts.

! Environmental Safety: The 3D scanner uses materials like lithium battery that can be harmful to the environment, which contains toxic chemicals or heavy metals, it is important to ensure that appropriate measures are in place to prevent contamination and to dispose of these materials properly.

! Data Privacy: The 3D scanner may capture and store sensitive data, such as personal or confidential information. It is important to ensure that appropriate security measures are in place to protect this data from unauthorized access or theft [8].

! User Training: To prevent accidents and injuries, it is essential that all personnel involved in the project are properly trained on the safe operation of the 3D scanner and understand the potential hazards and safety protocols.

References

[1] Agudo, A., and Moreno-Noguer, F. A scalable, efficient, and accurate solution to non-rigid structure from motion. *Computer Vision and Image Understanding 167* (2018), 121–133. 1.1

[2] Anderson, R. E. Acm code of ethics and professional conduct. *Communications of the ACM 35*, 5 (1992), 94–99. 3.1

[3] Cui, Y., Schuon, S., Chan, D., Thrun, S., and Theobalt, C. 3d shape scanning with a time-of-flight camera. In *2010 IEEE Computer Society Conference on Computer Vision and Pattern Recognition* (2010), IEEE, pp. 1173–1180. 1.1

[4] Daneshmand, M., Helmi, A., Avots, E., Noroozi, F., Alisinanoglu, F., Arslan, H. S., Gorbova, J., Haamer, R. E., Ozcinar, C., and Anbarjafari, G. 3d scanning: A comprehensive survey. *arXiv preprint arXiv:1801.08863* (2018). 1.1

[5] Haleem, A., and Javaid, M. 3d scanning applications in medical field: a literature-based review. *Clinical Epidemiology and Global Health 7*, 2 (2019), 199–210. 1.1

[6] IEEE. Ieee code of ethics. `https://www.ieee.org/about/corporate/governance/p7-8.html`, 2016. 3.1

[7] Javaid, M., Haleem, A., Singh, R. P., and Suman, R. Industrial perspectives of 3d scanning: features, roles and it's analytical applications. *Sensors International 2* (2021), 100114. 1.1, 1.2

[8] the U.S. Senate. Cybersecurity information sharing act. `https://drexel.edu/it/security/policies-regulations/fed-laws/`, 2014. 3.1, 3.2