## **Purdue ECE Senior Design Semester Report**

## **(Team Section)**

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| **Course Number and Title** | ECE 47700 *Digital Systems Senior Design Project* |
| **Semester / Year** | Fall 2022 |
| **Advisors** | Phil Walter and Shreyas Sen |
| **Team Number** | 5 |
| **Project Title** | Metaporter |

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| Senior Design Students – Team Composition | | | |
| **Name** | **Major** | **Area(s) of Expertise Utilized in Project** | **Expected Graduation Date** |
| Jehan Shah | CompE | Software, Hardware | Dec. 2022 |
| Manav Bhasin | CompE | Software, Mechanical Design | Dec. 2022 |
| Sen Wang | CompE | Software, PCB Design | Dec. 2022 |
| Kris Kunovski | CompE | Software, Hardware | Dec. 2022 |

**Project Description:** Provide a brief (2-3 page) technical description of the design project, as outlined below:

1. Provide a general description of the product to be delivered by this design project.

## Metaporter is a handheld, plugged-in 3D scanning and reconstruction tool. With Metaporter, users can scan still objects and get a dense 3D mesh for it within minutes. Metaporter creates accurate 3D models by fusing multi-modal sensor data from a camera and an IMU and estimating the volumetric radiance-and-density fields using neural networks. However, it has some limitations, and the quality of the reconstruction depends on the quality of data collection including the amount of data acquired. Metaporter may also have a limited ability to reconstruct certain types of surfaces and may not work under certain lighting conditions. Users will use a keypad matrix to select modes and interface with the device. A display on the device will show useful information such as the system state and the data recording time. The reconstruction will be viewed on the host machine.

1. What is the purpose of this product? For whom is it intended?

## The purpose of Metaporter was to create a hand-held reconstruction tool that would be able to create accurate 3D models, that can be viewed in a few minutes. 3D reconstruction tools have many applications in various fields such as video games, medicine, archaeology, AR/ VR and more. One example application of Metaporter would be in a video game as many video games exist where players can create their own characters to play with. However, it is often impossible to create a realistic or similar looking character to the player, making the game feel less immersive. We hope that Metaporter can provide a solution for scenarios such as these.

1. Describe how the engineering design process used to create your product was utilized in this project. Include how you were able to develop and conduct appropriate experiments, analyze and interpret data, and use engineering judgment to draw conclusions related to the development of your product.

## We started our project by determining the overarching problem to be solved. This allowed us to set the objectives for our project and understand the requirements. During synthesis, we started by designing the low-level software and hardware. By comprehending how we wanted the microcontroller and other peripherals to operate, we were able to begin construction, and we tested each component individually to ensure a smooth integration. For the IMU sensor and keypad, we used a UART connection to a laptop with a terminal emulator to test and debug both components. Using a technique, we learned in ECE 362, we used a logic analyzer to conduct the proper tests on the LCD’s SPI connection and the IMU’s I2C connection. Once the desired functionality of the embedded hardware and software was achieved, we were able to synthesize and create the appropriate high-level software to produce our 3D reconstruction. At this time, we were also finalizing our product packaging which was comprised of laser-cut acrylic with suitable holes for mounting components. We ran numerous tests on different featureful objects with our device in order to determine the best 3D reconstruction conditions with Instant NGP NERF. We came to the conclusion that the subject needs to be well-lit and have a background with at least some features. In addition, having at least 30-45 seconds of camera capture produced a much clearer reconstruction than shorter durations.

1. Describe the design constraints, and resulting specifications, incorporated into your product (list a minimum of 3).

## The first major design constraint we had to account for was the size of the device itself. Since we intended metaporter to be a hand-held device we had to ensure that all our components fit into a package that could easily be held by an adult. This constraint led us to creating a multi-plate packaging design. We mounted components on a front, middle and back sheet of acrylic in order to conserve space. The final product had a size of 5 X 6.75 X 6. inches making it rather easy to hold with two hands. The second major design constraint we were faced with was the compatibility of certain libraries and technologies with the hardware we had available to us. For example, ROS2 Humble only has native support on devices that had Ubuntu 22.04 LTS as the operating system. Unfortunately, our Jetson Nano only had Ubuntu 18.04 LTS and we were unable to upgrade this any higher. In order to get around this problem we decided to containerize our entire software stack. This allowed us to utilize various docker images which were built on Ubuntu 22.04 and therefore compatible with ROS2 Humble. Furthermore, the portable nature of our design meant that our device should run under low voltages with minimum heat dissipation. As the result, our device operates on 5V and 3.3V power lines with the total package consumption of less than 10Watts.

1. Describe how each of the following factors influenced your design specifications and constraints.

## **Public Health, Safety, and Welfare:** In order to ensure the safety of our potential users we designed the packaging and PCB with the idea of reducing the risk of injury as much as possible. For instance, our packaging and PCB design are implemented without any sharp edges that could potentially hurt the end user. Furthermore, the packaging material (acrylic) is electronically insulated, and therefore it isolates the end user and the internal electronics from each other.

## **Global Factors:** We believed that Metaporter’s usage is not limited to an audience within the United States. International business and content creators can make use of metaporter like anyone in the US would. In order to be marketed in Europe we will make sure that Metaporter meets out the standards set out by RoHS

## **Cultural Factors:** When we were first discussing our project, the topic of the Metaverse and virtual reality gaming were prevalent. We thought that metaporter and related 3D reconstruction technology could play a role in this.

## **Social Factors:** We understand that privacy related to cameras and image data has become a bigger and bigger social issue over the past few years. When we designed the product, we made sure that it was very clear to the user that the cameras were in use. Since the image data is being stored on a server we wanted to ensure that the provider we used was secure. We chose AWS S3 because it supports both server-side and client-side encryption.

## **Environmental Factors:** One environmental factor that we considered was the usage of batteries. Batteries are considered hazardous waste as they consider many harmful chemicals such as sulfuric acid and cadmium. By making our device powered from an outlet we avoid contributing to this harmful waste.

## **Economic Factors:** The design process considered the demand for a lower cost 3D reconstruction tool. Many commercial software solutions have extremely high licensing costs, so Metaporter offers a cheaper alternative to these.

1. Describe the appropriate engineering standards incorporated into the creation of your product.  
     
   We ensured that all the individual electronic components that we used were reputable and legitimate. The main engineering standard that we followed were the FCC standards. For our product to be FCC certified each of the individual components that emitted any EMF must be certified. Therefore, we had to make sure that our Jetson Nano is up to the correct standards, which it was. We also made sure to follow RoHs standards by not using any lead-based solder while soldering our PCB.
2. Describe the final status of your product.

The final product was able to meet most of the specifications that we laid out in the beginning. We were able to gather data from an IMU and transfer it to our compute unit using direct memory access (DMA) and UART. Additionally, we were able to create a simple user interface using an LCD and a keypad for user input. We were also able to generate a 3D reconstruction using NERF based on the image data from the camera. Unfortunately, we were not able to incorporate the data from the IMU into the reconstruction because we were only able to find one SLAM package that used both camera and an IMU. This package required stereo camera input but because of poor documentation for the stereo-camera we purchased, we were unable to write a compatible ROS package to use with the SLAM package and use the IMU.

1. Describe the makeup of your project team and how you were organized to establish goals, plan tasks, and meet the objectives of this project.

## Our team was comprised of a team lead (Jehan), a hardware engineer (Sen), a software engineer (Manav) and a systems engineer (Kris). In order to facilitate the development of this project we attempted to follow an agile workflow. This means that we would have weekly meetings to discuss our goals and plans for the week and use JIRA [1] to help track these goals. We also communicated regularly through discord to share updates of our progress.

[1] https://metaporter.atlassian.net/jira/software/projects/MET/boards/1

1. Did your project require the production of any written documentation other than this document (i.e., manuals, educational materials, etc.)? If so, describe the types, composition, and nature of the audiences for whom these materials were intended.

## Our project requires the creation of a detailed user manual that simplifies the description of our device. Since we want anyone to be able to use our product, we made our user manual tailored to a wide range of audiences with less technical terms for clear instructions on operating Metaporter. The legal analysis, safety and reliability analysis, and ethical and environmental analysis are all professional reports that use technical terminology and elaborate on our project’s impact for each area. These reports are created for the curious consumer, other engineers, and engineering design boards that evaluate our product before it is released to consumers. In addition, we created a software overview, electrical overview, mechanical overview, and software formalization. These reports were very technical with numerous engineering concepts broken down in order to detail the operation of our project for each sector. They are written in technical detail with the audience in mind, and the people meant to read and understand these reports are other engineers.

1. Describe the types, composition, and nature of the audiences in attendance for the final oral design review. Discuss how you prepared for this audience.

## We expect our audience for the final oral design review to be comprised of students, professors, and TAs. As with the midterm design review, we will practice our presentation several times as a team. This allows us to give feedback to each other and ensure that we are all on the same page. Since all of our audience members come from an engineering background, our presentation will involve technical terminology to explain our project and individual contributions. If time allows, we will rehearse our presentation and setup in the senior design studio where the final design review will take place. This helped us learn the projector and document camera operation prior to our midterm design review.

## **Purdue ECE Senior Design Semester Report**

## **(Individual Reflections Section)**

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| **Course Number and Title** | ECE 47700 *Digital Systems Senior Design Project* |
| **Semester / Year** | Fall 2022 |
| **Advisors** | Phil Walter and Shreyas Sen |
| **Team Number** | 5 |
| **Project Title** | Metaporter |

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| Senior Design Student Completing This Section | | | |
| **Name** | **Major** | **Area(s) of Expertise Utilized in Project** | **Expected Graduation Date** |
| Jehan Shah | CompE | Software | Dec. 2022 |

**Individual Reflection:** Provide a brief (1-2 page) individual reflection of the design project, as outlined below:

1. Describe your personal contributions to the project.

## I proposed this project and designed most of the software architecture used for this project. When we were initially considering using a LiDAR, I programmed the microcontroller to read distance measurements from the LiDAR using I2C. I worked with Kris to receive data from the IMU and debug the program using a logic analyzer. I integrated the Keypad so that pressing keys triggered the necessary actions such as starting data collection from the IMU. I also integrated the LCD to display the status whenever it changed as well as to show the time elapsed during data collection. Since we needed to containerize our application, I wrote a Dockerfile and other shell scripts to build a Docker image with all the required dependencies for our system. I debugged the camera and wrote a custom GStreamer pipeline to be able to read data from the camera. I extended that to a python script that used OpenCV to capture video from the camera. I also wrote a separate script that we could use to record and save video from the camera. Finally, I worked with Manav on the initial design of the product packaging.

1. Describe how your contributions to this project built on the knowledge and skills you acquired in earlier course work.

## A large part of our codebase is in C, which we learned in ECE 159 and 264. I used a lot of the knowledge and skills learned in ECE 362 such as an understanding of I2C to interface with sensors. I was also able to use debugging skills such as visualizing the protocols on a logic analyzer to write correct programs. I used my knowledge of design patterns and experience from previous class projects to design the software architecture for this project.

1. Describe how you acquired and applied new knowledge as needed to contribute to this project. What learning strategies did you employ to do so?

## There were many new things that I had to learn during this project. To gain a conceptual understanding of some of the computer vision concepts, I relied on textbooks and online lectures from other universities. To learn tools such as Docker I used their documentation, Youtube videos, and example Dockerfiles from other projects. I started by building a simple Dockerfile to get familiar with it before moving to more advanced features.

1. Discuss your ethical and professional responsibilities as they relate to this engineering design experience.

## As an engineer, it is my responsibility to thoroughly test the product for correctness and reliability. I prepared a testing plan for each software component and presented it in the software formalization. It is also my responsibility to ensure the safety of the user when using this device, such as from electrical shocks and provide clear warnings and usage instructions which I did in the user manual. Finally, it is my responsibility to cite all work that is done by someone else and used by us in our product. We use external software packages for parts of our project which I discussed in our software formalization. Furthermore, whenever I used any code snippets from other sources, I made sure to cite those.

1. Consider what the impact of the product of this engineering design experience could have in economic, environmental, societal, and global contexts. Discuss how you would make (or did make) an informed judgement as to your product’s impact in each of these four contexts?

## This product can have applications in many industries and provides many economic opportunities. It could be used to create life-like avatars for video games or create 3D housing tours. Globally, it can be used to capture historic or tourist sites for digital tourism and enable more immersive experiences than is possible using just photos. Easy 3D content creation can also change how we store memories as a society. It can enable people to store memories such as an old home in a more immersive way. Finally, these can also help reduce the environmental burden from transportation by allowing more lifelike interactions remotely. We also consider the environmental footprint of the device itself. Since we use mostly discrete components, the product should be repairable if some component breaks. We use acrylic for packaging our product prototype, however, if such a product should go to market, we would want to make the packaging recyclable and/or biodegradable. **Purdue ECE Senior Design Semester Report**

## **(Individual Reflections Section)**

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| Senior Design Student Completing This Section | | | |
| **Name** | **Major** | **Area(s) of Expertise Utilized in Project** | **Expected Graduation Date** |
| Manav Bhasin | CompE | Software, Hardware, Mechanical Design | Dec. 2022 |

**Individual Reflection:** Provide a brief (1-2 page) individual reflection of the design project, as outlined below:

1. Describe your personal contributions to the project. The first major contribution I made this semester was related to our LCD display. In order to interface with the display, I had to use the SPI protocol. Once the basic communication bus was set up, I created timers that would end up being used to record how long video capture was ongoing. Another contribution I made was the packaging of the project. I designed the packaging in AUTOCAD and created a multi-plate package which would be used to house all of our electronic components. Once the design was finished, I collaborated with the TAs at the Bechtel design center to laser cut acrylic sheets to the specifications in my design. Once the sheets were cut, I worked with Sen to mount and assemble the final packaging. I also worked on the automation of our 3D reconstruction library NERF. This included developing scripts that leveraged AWS S3 cloud storage to transfer images from the jetson nano and download them onto our host machine. We then developed scripts that would run NERF with the images that were downloaded on the host machine. I also spent a significant amount of time developing a transformation script which would take the pose and orientation outputs from a ROS subscriber node and transform them into 3 x 4 pose arrays that could be utilized by NERF.
2. Describe how your contributions to this project built on the knowledge and skills you acquired in earlier course work.

## I’ve utilized knowledge from previous courses such as ECE 362 to aid in the development of the embedded portion of this project. Python programming fundamentals were also very important in this project, and I gained many of the required skills from ECE 20875.

1. Describe how you acquired and applied new knowledge as needed to contribute to this project. What learning strategies did you employ to do so?

## From this project I gained experience with many different new technologies. Some of these included ROS, AWS S3 services, and mechanical CAD design. For me, I personally learn best by watching videos and in-depth tutorials before I start utilizing a new technology. This allows me to gain a solid foundation and reduces the number of growing pains.

1. Discuss your ethical and professional responsibilities as they relate to this engineering design experience.

## The biggest ethical concern we had to consider was the usage of the camera. Anytime a product uses a camera users may have concerns about their privacy and security. Therefore, we made sure that the camera is only collecting data when the user explicitly says so. We also made sure to use AWS S3 buckets to securely transfer images.

1. Consider what the impact of the product of this engineering design experience could have in economic, environmental, societal, and global contexts. Discuss how you would make (or did make) an informed judgement as to your product’s impact in each of these four contexts?

## In terms of economic impacts, I think that our product offers a lower cost solution to the 3D reconstruction market. Many other 3D reconstruction software have licensing fees that can exceed 1000 dollars a year. In terms of environmental impacts, our device is powered directly from a power outlet. This ensures that we do not introduce any batteries which are one of the biggest contributors to electronic waste. We also understood that socially that data privacy is a huge issue which is why we took extra care to make sure that it was very clear to the user when the camera was recording. We also designed our product so that it could be used in countries outside the United States. We followed all the RoHs standards so that our product could be marketed in Europe as well.

## **Purdue ECE Senior Design Semester Report**

## **(Individual Reflections Section)**

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| **Advisors** | Phil Walter and Shreyas Sen |
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| **Project Title** | Metaporter |

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| Senior Design Student Completing This Section | | | |
| **Name** | **Major** | **Area(s) of Expertise Utilized in Project** | **Expected Graduation Date** |
| Sen Wang | CompE | Software & Hardware | Dec. 2022 |

**Individual Reflection:** Provide a brief (1-2 page) individual reflection of the design project, as outlined below:

1. Describe your personal contributions to the project.

I've committed several contributions to the project. For one, I designed and prototyped circuitry that is our power circuit, microcontroller layout, and various communication channels interfacing with the keypad, display, Jetson Nano, IMU, and debugger. I also did the soldering and assembly of the PCB as soon as we received it. Furthermore, I also implemented some embedded software, namely the keypad. I helped Kris with the integration of embedded software. On the top-level software, I worked on testing and integration of the host machine software pipeline, namely SLAM, NERF algorithms, and the ROS subscriber. On top of these, I also assisted Manav with the packaging and helped on various Linux-related issues regarding our software.

1. Describe how your contributions to this project built on the knowledge and skills you acquired in earlier coursework.

Prior to this project, I had taken both microprocessor and embedded system software courses (ECE362 and ECE40892) that guided me in the development of microcontrollers and their respective embedded software. Furthermore, the OS, Compiler, and Network courses I've previously taken also enabled me to conduct system-level analysis and be able to troubleshoot the various issues we've encountered during our project development.

1. Describe how you acquired and applied new knowledge as needed to contribute to this project. What learning strategies did you employ to do so?

My personal strategy to go about learning and applying new knowledge is to use an iterative approach that empowers rapid prototyping. I would start by learning the concepts and creating an initial prototype. I would then modify from the existing prototype based on the problem, concerns, or new knowledge I acquired through research and create new iterations that would improve from previous iterations. A prime example of it would be my PCB design, since I had no prior PCB design experience, it took me four design iterations and three major revisions from scratch to finish.

1. Discuss your ethical and professional responsibilities as they relate to this engineering design experience.

During our project development, I quickly realized the potential intrusion to our end user's privacy as our devices take records of personal images and exchange image intrinsic using the cloud. Therefore, the software and our design are as transparent to the end user as possible while making sure that any data collected by the device is only accessible to the privileged user.

1. Consider what the impact of the product of this engineering design experience could have in economic, environmental, societal, and global contexts. Discuss how you would make (or did make) an informed judgement as to your product’s impact in each of these four contexts?

In terms of social impacts, I believe that Metaporter has shed light on an emerging way of socializing in the metaverse. The nature of this portable 3D reconstruction device enables a more immersive gaming and social experience by personalizing each character and virtual objects. In an economic context, our versatile product also opens a wide possibility of emerging businesses such as virtual reality games while offering a more cost-effective solution. On a global and environmental context, we also contributed to following the RoHs standard to ensure our product is environmentally safe and contributes to less harmful electronic waste produced by the humankind.

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| Senior Design Student Completing This Section | | | |
| **Name** | **Major** | **Area(s) of Expertise Utilized in Project** | **Expected Graduation Date** |
| Kris Kunovski | CompE | Software, Hardware | Dec. 2022 |

**Individual Reflection:** Provide a brief (1-2 page) individual reflection of the design project, as outlined below:

1. Describe your personal contributions to the project.

## I was in charge of the UART data transmission from our microcontroller to the Jetson nano using DMA. After this setup was complete, I worked on the IMU sensor data collection with Jehan and ran tests using a logic analyzer to ensure we were receiving appropriate data. I also remapped the IMU axes and enabled calibration to guarantee an accurate camera pose and sensor data for our VSLAM algorithm. In addition, I wrote the low-level software for a debounced 4x4 matrix keypad which will be our user's main interface for interacting with our device. Once all the embedded hardware and software was made and tested individually, I was also in charge of their integration. This was crucial for ensuring all components worked together properly before finalizing our PCB. After all embedded hardware and software was complete and integrated, I started work on the camera software for capturing images with our stereo camera on our Jetson nano. I wrote the ROS2 publisher node for capturing camera images using some external scripts for help. Once the images were published to their respective ROS2 topics, I wrote a ROS2 subscriber to save these images to a directory for integration with the NERF software to make a 3D reconstruction. In the end, we ditched the VSLAM package, ROS2, and Docker in an effort to simplify camera capture, and I fixed compatibility issues with our Jetson Nano and the Raspberry Pi Camera we decided to use in place of the stereo camera. Lastly, I integrated the nano operations with the embedded components by triggering camera capturing on the keypad press for starting data collection.

1. Describe how your contributions to this project built on the knowledge and skills you acquired in earlier course work.

This class allowed me to explore concepts that were previously only touched on in earlier courses. ECE 362 covered the basics of microcontrollers and embedded software development. The past lectures and labs for this class proved to be very useful for refreshing my understanding of embedded hardware and software basics, and I was able to use the tools and strategies taught in this class to build on Metaporter. This project helped me branch out by understanding how to interface with external sensors using the communication protocols taught in ECE 362. I was able to read component documentation effectively and integrate numerous parts together using knowledge from previous courses. I built on my knowledge from my basic circuitry labs by more confidently understanding how to wire electrical components and solder on a PCB. This project also taught me how to research and gain new information more effectively for problem-solving.

1. Describe how you acquired and applied new knowledge as needed to contribute to this project. What learning strategies did you employ to do so?

The internet is one of the most useful modern tools for acquiring new knowledge and skills. I used the internet and YouTube quite often when I was faced with a task that was unknown or difficult. YouTube has a number of free tutorials and lectures that analyze any concept or technology in an understandable manner. Due to the plethora of available videos, there was always an instructor or expert with explanations that helped me gain new knowledge and grasp the material. When I needed to explore particular concepts further, simply searching the internet yielded various sources and discussion boards with helpful answers or similar situations. As with many complicated problems, breaking it down into smaller issues and steps help to work through the larger matter at hand. When a subject matter was completely foreign to me, I would tackle smaller tasks and research to get more familiar with concepts before approaching the major obstacle. In addition, examining previous labs and coursework proved to be incredibly useful for understanding the proper procedures to take when tackling a large problem.

1. Discuss your ethical and professional responsibilities as they relate to this engineering design experience.

As an engineer, it is my responsibility to disclose any and all ethical and safety concerns with our device. Our team's ethical, environmental, safety, and reliability reports all detail any threat or concern our product poses to consumers and the environment. We were incredibly detailed in each area to ensure that consumers and regulators are accurately informed. Since our project requires video recording of a subject, there are certainly privacy concerns with user data. Our device records this video on the Jetson nano and stores it in an AWS S3 bucket. The video is automatically deleted after each new run, and this process will be elaborated on in the user manual for full clarity of consumer data use and storage. In addition, as an engineer, it is my responsibility to give credit to others when using their work or information during product creation. Any software developed from third-party sources or inspired by other engineering work is clearly credited. Information from other research papers or scholarly journals was appropriately cited in IEEE format and given credit in every report.

1. Consider what the impact of the product of this engineering design experience could have in economic, environmental, societal, and global contexts. Discuss how you would make (or did make) an informed judgement as to your product’s impact in each of these four contexts?

Economically, while this device may have a higher cost for some, it can be a useful tool for businesses and video game creators. The ability to make 3D reconstructions to enhance marketing strategies or personalize video game characters could prove to be a huge economic benefit. This device would easily attract more customers and would benefit local or international businesses. The versatility of our device would allow it to be a success in global markets as well since there is a wide range of international content creators and companies. Environmentally, there are various non-biodegradable electrical and plastic components incorporated in our device that could have a very negative impact. If our product ever went to production, we would have to ensure that we use clean energy facilities for manufacturing and more biodegradable components. In addition, having a recycling program to minimize the negative environmental impacts of our product would greatly help. Societally, this would give people another tool to express themselves and take their creative freedom to the next level. It may also help researchers and scholars with studying their subjects more accurately using our product's 3D reconstruction capabilities.