**EE480 Senior Design I**

**Laser-Based Wireless Power Transmission**

**Initial Circuit/Code Design Review**

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**1 INTRODUCTION**

1.1 PROBLEM DEFINITION

The current methods for wireless power transmission focus mainly on transmitting shorter distances. The project addresses the challenge of delivery of optical energy from a transmitter laser source to a PV cell and the conversion of the optical energy to electrical energy; For higher-precision accuracy of laser beam-to-PV cell contact, the project includes an experimental and design element whereby the transmitter functions with an optical gimbal, closed-loop laser tracking algorithm, and image-processing methods while the receiver functions with the thermoelectric plate circuit for maximization of dissipated heat to electrical power conversion and thermal sensing and regulation.

1.2 PURPOSE OF THE DOCUMENT

The purpose of this document is to explain in detail the various project aspects. On the transmitter side, the tracking algorithm and the optical gimbal are explained in detail. The receiver end is explained as per its functionalities of thermal sensing and regulation and transmission of digital videography to the end-point PC computer. The paper demonstrates the mechanisms of the subsystem, subsystem relationships, system objectives, and represents the theoretical applications with proposed models, diagrams, algorithms, and circuit schematics.

1.3 SCOPE OF THE DOCUMENT

This document is a review of the project’s proposed designs prior to the culminating Project Design/Research Plan presentation and Refined Project Proposal report. Hence there may be further elaborations, innovations, and design changes as we meet challenges and continue research.

1.4 DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

**PV:** Photovoltaic

**VMJ:** Vertical Multi-Junction

**PC:** Personal Computer

**PCB:** Programmable Circuit Board

**TEC:** Thermoelectric Cooler

**TEG:** Thermoelectric Generator

**MPPT:** Maximum Power-Point Tracking

**MCU:** Microcontroller

**NEMA:** National Electrical Manufacturers Association

**3D:** 3-Dimensional

**IR:** Infrared

**CAD:** Computer Aided Design

**UAV:** Unmanned Aerial Vehicle

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**2 SYSTEM OVERVIEW**



The system contains a receiver and a transmitter. The transmitter end contains the optical gimbal, a camera, and the lasers. The tracking algorithm locates the moving train using the camera. It then works with the optical gimbal code to move the lasers in order to align the beams with the PV cell. The receiver end has a solar cell that harvests the energy. Then, using a DC-DC converter, the imager will be powered and take pictures, which will be sent to a PC. The receiver will have a heat sensing and regulation circuit containing a TEC, TEG, and K-type thermocouple.

**3 DESIGN CONSIDERATIONS**

3.1 DESIGN ASSUMPTIONS, DEPENDENCIES AND CONSTRAINTS

3.1.1 Time Constraints

We may need to make a schedule for next semester to know about the timing of full system integration.

3.1.2 Performance Constraints

Previously, as research shows, there was an unsuccessful attempt at implementing Bluetooth for the receiver’s temperature sensing and regulation circuit due to power consumption requirements. The performance of the Bluetooth module for thermocouple temperature data logging may be questionable.

3.1.3 Hardware Constraints

Hardware design constraints include:

**Optical Gimbal:** Wires tangling, 2 degrees of freedom, tracking algorithm interface.

**Tracking Algorithm:** Processing power which affects speed and accuracy in real time analysis.

**Receiver:**

● Circuit parts may have longer than expected lead and delivery times,

● The temperature sensor (thermocouple) may not be sensitive enough to detect highly precise changes in temperature of PV array,

● Some thermal sensing and regulation circuit subsystems must be tested on the breadboard first (but this requirement excludes the energy harvester chip due to this chip being a surface-mount PCB component).

3.1.4 Software Constraints

Using images to track the object may require estimation of the accuracy of the object (accuracy within a few pixels; for example, 1mm per pixel + offset error).

3.2 DESIGN GOALS

The goals of the Laser-Based Wireless Power transmission configuration are to track a moving object between the transmitter and receiver, move the lasers to follow the moving object, design a thermal sensing and regulation system for the receiver end, and power an imager using the IR laser beam.

**4 MECHANICAL DESIGN**

4.1 SYSTEM OVERVIEW

The basic mechanical system is composed of a frame, with a camera and optical gimbal attached to it. The frame will be made using T-slot aluminum rails, which will make the system customizable if design changes occur later on. The camera, that takes videos (max capability: 100 frames per sec), will be mounted to the frame, offset from the optical gimbal, using a simple camera mount. The optical gimbal is composed of 2 NEMA 17 geared stepper motors, a mirror cube with a dichroic mirror, one IR laser, one visible laser, 2 motor mounting brackets, and custom 3D parts.

4.2 DESCRIPTION OF COMPONENTS

**Framing:** The whole system will be enclosed using T-slot aluminum rails. Various components of the transmitter system will have to be mounted to the framing system. The frame will look similar to the one shown below, but not exactly like it.



**Camera:** The camera’s exact specifications are currently unknown. Once the camera is chosen, a simple camera mount will be purchased in order to attach the camera to the system’s frame.

**Optical Gimbal:**

* **Mirror Cube-** The mirror cube, shown below, houses the dichroic mirror. This cube will also have the lasers attached to it using the laser adapters, labeled below. The lasers will be mounted in such a way that both beams will pass through the beam focuser.



The dichroic mirror is a specialized filter. The mirror allows some wavelengths to pass through, while others are reflected. The diagram below shows how the dichroic mirror works. Our use of the dichroic mirror will allow the IR and visible lasers’ beams to be aligned. This will make our system safer, reducing the risk of burns.

* **Motors-** The optical gimbal uses two NEMA 17 stepper motors for rotation. One motor rotates the gimbal 360°, while the other tilts the gimbal up and down. The 2 degrees of freedom are needed in order to accurately and completely follow the moving train around the circular track. The motors have wires attached to them. The mechanical design does not yet account for preventing the wires from tangling as the gimbal turns. A possible solution is to include a slip ring that allows the system to spin while keeping the cords in place.
* **Motor Brackets-** The brackets, shown below, allow for the motors to be attached to the custom 3D parts that were designed. The motor’s circular shaft fits through the circular hole. It is there that the motor is attached to the bracket using the holes closest to the circle. The other holes are used to mount the motor to the custom 3D parts.



4.3 CUSTOM PARTS

**Adapter 1:** The first adapter, shown below, attaches to the motor that tilts the mirror cube up/down. It will be attached directly to the motor cube as well, using four screws. The bigger hole in this custom part accounts for the laser adapter. The laser adapter is attached to that side of the cube as well. The custom part is attached to the back of the mirror cube to prevent accidental rotation. It does this by utilizing four screws, instead of one. If the custom part were attached to the cube from the bottom, the screw could become unwound, causing the whole system to lose accuracy. The use of a set screw where the motor’s rotating shaft will be will cause the cube to tilt up/down depending on the code.



**Adapter 2:** The second adapter, shown below, is attached to both motors. The first motor is attached using the bottom part of the motor mounting bracket with four screws. The second motor’s shaft goes through the tapered circle hole, held in place with a set screw. That second motor allows the gimbal to rotate 360°. The part is not a solid block on the left to reduce material cost and weight of the whole gimbal.



4.4 3D MODEL

The below pictures show the 3D model’s front and back views, respectively. The green parts are the custom parts, attached to the motors using the motor brackets. The motor on the top tilts the lasers up/down, while the motor on the bottom rotates the gimbal 360°.



**Notes:**

* This design does not account for attaching the system to the frame.
* This design does not account for the wiring of the motors, which could cause tangling issues.

**5 HARDWARE**

5.1 OVERVIEW OF HARDWARE FOR TRANSMITTER

5.1.1 PC

The specific PC that is going to be used, is currently unknown. The PC will receive live footage from the camera. The tracking algorithm will then break down the pixels into X-Y coordinates. The coordinates will then be used to move the motors appropriately.

5.1.2 Camera

The specific camera that is going to be used is unknown. The factors affecting choosing a camera include color capabilities, resolution, and field of view. The use of a colored capable camera could make the image tracking easier by utilizing distinct colors as place markers. The resolution of the camera would also affect accuracy. Field of view is described as what the camera is able to see and capture, which affects accuracy as well. If the camera is unable to see the whole track, then the gimbal will be unable to track the moving train.

5.1.3 Raspberry Pi

The use of a Raspberry Pi 4 model B is a promising option for the motor controls of the optical gimbal. The Raspberry Pi would be able to use Python code to control the motor using an open-source motor library. The code used would also be altered to account for the tracking algorithm output and use that output as an input for motor controls. The Raspberry Pi is an option because it may not be necessary for the project, as the computer that runs the algorithm would also be able to run the Python code for motor controls. The benefits of the Raspberry Pi would be alleviating processing power from the PC, as well as simplifying the mechanical design of the system.



5.1.4 Motors

Various criteria must be met to ensure the motors used will fit the project design. Due to a small target, that of the solar cell being 1 cm in diameter, requires precision movements in the motors and to ensure the laser is able to remain on the target the appropriate step angle for the motor was calculated.

In addition to the step angle, the necessary speed of the motor also had to be found to ensure the laser would be able to follow the receiver. First the speed of the train was calculated at 37 cm per second, while diameter of the track was measured at 73 cm, with this and the specifications from the motors we can calculate whether the motors could keep up with the receiver.



5.1.5 Interaction of Hardware for Transmitter

For the transmitter, the hardware being used include; the PC, the camera, potentially a Raspberry Pi, and two motors. First the camera, which is mounted on the optical gimbal, will relay frames of the receiver to the PC which is running the object tracking algorithm. The object tracking algorithm will output xy coordinates from the frames captured, this will be used in the Python code, that is either run on the PC or potentially a Raspberry Pi, which then controls the motors, effectively allowing the laser to remain on the tracked object.

5.2 OVERVIEW OF HARDWARE FOR RECEIVER

The experimental receiver includes the following elements: [1] VMJ PV cell, [2] PCB with TEG, TEC, and K-Type Thermocouple (thermoelectric plate), [3] Boron-Nitride Thermal Epoxy, Epoxy Resin, and Plexiglass, [4] DC-DC Converter, [5] ESP-32 Wi-Fi Camera, and a [6] PC. The required output voltage is 5V, as required to power the ESP-32 Wi-Fi camera. Below is the current design of the receiver’s conceptual block diagram.



Aside from the experimental PCB, the receiver will be tested with a system that is easier to apply and confirm without PCB manufacturing, to include the simple configuration of the solar cell, heat sink, DC/DC Converter, and ESP32 Wi-Fi camera. This simpler approach is necessary before the implementation of the experimental PCB, although eliminating a heat sink will significantly reduce the material weight since the system is ultimately going to be used to power a miniature microscope. 2-dimensionally, the system can be enhanced if it includes Python programming to obtain real-time voltage data converted to laser beam position “markers.” 3-dimensionally, it can be imagined that there can be made an optical engineering methodology, combined with programming, to visualize Transverse Electro-Magnetic Gaussian Cell intensities as laser illumination, possibly with the quad detector.

5.2.1 VMJ PV Array

The silicon-based VMJ PV Array, a semiconductor device fabricated to generate a voltage when solar radiation meets its surface, will receive the optical energy from the laser. The positive and negative leads of the VMJ PV Array will be connected to connectors on the thermoelectric plate circuit (PCB).



5.2.2 Experimental PCB with TEG, TEC, and K-Type Thermocouple

The experimental thermoelectric plate circuit includes a dual-function TEG/TEC control system through a DPDT relay switch, an energy harvester chip, a programmable MCU, Bluetooth module for data logging, and connectors for the external TEC, TEG, and K-Type thermocouple (MAX6675 temperature sensor). The programmable ADP5091 energy harvester chip enables MPPT and PMD configuration and has a SYS output pin to deliver output energy to the load (DC-DC Converter, ESP-32 Wi-Fi Camera, and PC). The PCB’s Bluetooth module should effectively transmit temperature sensor data to the PC computer. The delivery of Wi-Fi video data from the receiver's ESP-32 Wi-Fi Camera to the PC computer should confirm that electrical power has been sent from the laser to the load. Below is the current design of the PCB stack-up diagram. The PCB circuit schematics (whole system circuit schematic and 3 zoomed-in circuit subsystem parts) are available in the PDF attachment (See Appendix 1).



5.2.3 Boron-Nitride Thermal Epoxy, Epoxy Resin, and Plexiglass

The boron-nitride thermal epoxy glues together the VMJ PV array to the PCB. Between the electrically connected thermocouple temperature sensor, TEG, TEC, DC-DC Converter, and ESP-32 Wi-Fi Camera and the plexiglass is epoxy resin. The temperature sensor should be mirrored to the PV array in a layered approach preferably using a more reliable pad-based temperature sensor that can be configured to the PV array with epoxy.

5.2.4 DC-DC Converter

The DC-DC Converter is a separate solar charger board from Adafruit called “Adafruit Universal USB / DC / Solar Lithium Ion/Polymer charge.” This DC-DC Converter board should be wired to the ESP-32 camera.

5.2.5 ESP-32 Wi-Fi Camera and PC Computer

The ESP-32 Wi-Fi Camera has been tested with Arduino UNO R3 to be programmed to transmit camera video to a PC computer through a Cam Web Server script configured to reliant Wi-Fi name, Wi-Fi password and IP Address.

5.2.6 Interaction of Hardware for Receiver

The receiver must convert optical energy to electrical energy to power the ESP-32 Wi-Fi Camera while maximizing the efficient conversion of dissipated heat collected on the PV cell to usable electrical energy through a TEG while sensing and regulating the temperature through the thermocouple and TEC.

**6 SOFTWARE DESIGN**

6.1 OVERVIEW OF SOFTWARE DESIGN

The software design includes the laser tracking algorithm and the closed loop motor control. Image-processing methods are being used in conjunction with the DeepLabCut tool to track the moving receiver’s positions through time. Python will be used to make the optical gimbal respond to the outputs of the tracking algorithm.

6.2 TRACKING ALGORITHM

The tracking algorithm uses DeepLabCut to locate the moving object by making points across time. The output has an xy graphical representation of the moving object making a circle. Point estimation and prediction will be required between the outputs of the tracking algorithm as the inputs of the motor control for the optical gimbal mounted with the laser.

6.3 OPTICAL GIMBAL CONTROL

6.3.1 Overview of Gimbal Control

The optical gimbal control will be characterized by the output of the tracking algorithm and using that as a reference and input for the motor controls. To achieve this, a Python code will be created that can interface with the tracking algorithm, by utilizing the xy coordinates, while controlling the motor positions to consistently follow the object that is being tracked. A part of the open source code library includes positional data and how to manipulate motor positions. The starting point with the Python code will be finding positional points for both motors that would move the laser in roughly the same shape the receiver moves in. After getting more familiar with the motor controls we can prioritize improving accuracy and efficiency, as well as using the tracking algorithm output in the Python code. Ultimately a conversion table that takes xy coordinates from the algorithm and manipulates the gimbal to real world positions is the end goal for the controls.



6.3.2 Kalman Filter

Due to the high precision tracking required for this project, mainly the small surface area of the solar cell, we must look into and account for the delay in the systems of the tracking. A promising option is the Kalman Filter, an algorithm that can process information from the system and predict the delays, this can then be compensated for in the controls. Getting an understanding of the Kalman filter now is important, however actual implementation of the Kalman filter will come later, after the tracking system and Python code is more developed.



**7 TOOLS AND LIBRARIES**

7.1 CREO

CREO is a high tech 3D CAD modeling software. CREO allows you to design, optimize, and validate models. There is also no need to have separate software for slicing the designs. CREO has it built-in, therefore your designs can be sent straight to any 3D printer.

7.2 EAGLE

Eagle, a PCB design software, is used for circuit schematic and PCB wiring and stack-up designs. It is used as a system to generate and export the fabrication outputs including Gerber and NC Drill files, BOM, pick-place file, and assembly drawing(s) for the PCB manufacturer to use for electrical components pick-and-place, PCB printing, and assembly. External imports of non-standard component libraries are necessary to have the schematic symbols and associated 3D PCB models of PCB components. SnapEDA files and files directly downloaded from component distributor sites may be available for access to external component libraries or individual components. EAGLE will be used for the experimental PCB.

7.3 DeepLabCut

DeepLabCut is an open source software package for reading posture information.

**8 TIME PLANNING**

8.1 Semester 1 GANTT CHART



8.2 Semester 2 GANTT CHART



**9 CONCLUSION**

Our current analysis and design includes the mechanical 3D models of the optical gimbal, an algorithmic trace graph of the receiver’s positions over time, descriptions of the requirements of the transmitter’s motor control programming, and circuit block diagram with schematics for the receiver’s experimental thermal sensing and regulation PCB design. Future work for the transmitter includes fine tuning the tracking and gimbal systems in order to apply the system to other applications. Other applications would include powering a UAV while it is in flight. The ultimate future goal of the project is to assist UND’s drone racing team. This means the tracking system would have to be able to follow an unpredictable pattern. Currently, our project follows a train on a fairly predictable trajectory. Future work for the receiver includes the deeper investigation of the method of the programming for the conversion of measured voltage values to the laser beam’s position, research on MPPT programming between the energy harvester chip and MCU and the data logging method between the Bluetooth module and the MCU, and the finalization of the components list to be ordered successfully to test the receiver’s experimental thermoelectric circuit wiring on a breadboard prototype. A preliminary hardware implementation of the receiver should be accomplished and tested with the IR laser and without the experimental PCB thermoelectric circuit. Application of the temperature, current, and voltage sensors with a test laser beam to obtain receiver variables affecting power conversion efficiency values can correspond with statistical analysis and models.