Comprehensive Design Documentation for 3D Scanner Project

1 Microcontroller Unit

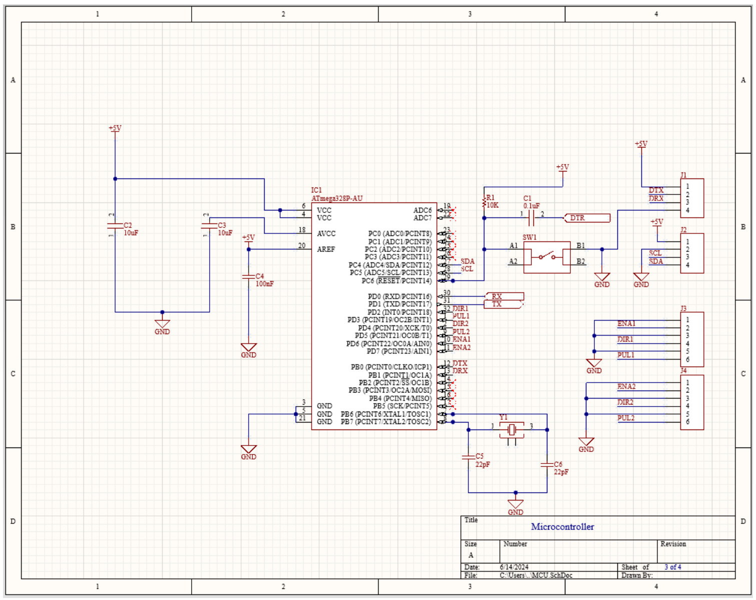

Figura 1: Micro-controller Unit

1.1 Microcontroller Selection:

For our 3D scanner project, we have selected the ATmega328P SMD microcontroller unit (MCU) due to its reliability, compact size, and capability to handle multiple inputs efficiently. The ATmega328P is a widely used microcontroller known for its robust performance and ease of programming.

1.2 Pin Configuration and Connectivity

- GPIO Pins
  - ToF Sensor Connection: The ToF (Time-of-Flight) sensor is connected to the GPIO pins of the ATmega328P. These pins are used for both power and data communication, allowing the MCU to receive distance measurements from the sensor accurately.

  - Stepper Motors Connection: Two NEMA 17 stepper motors are connected to the GPIO pins via stepper motor drivers (such as the TB6600). The GPIO pins send pulse and direction signals to control the rotation and vertical movement of the stepper motors.

- Serial Communication
  - TX and RX Pins: The ATmega328P uses its TX (transmit) and RX (receive) pins for serial communication with a computer. This communication is facilitated through a USB port, which allows for data transmission and programming of the microcontroller.
  - USB Connection: The USB connection not only powers the microcontroller but also serves as the interface for programming and data transfer. This setup ensures a seamless flow of scanned data from the microcontroller to the PC for further processing and visualization.

1.3 Programming and Operation

- Microcontroller Programming
  - The ATmega328P is programmed using the Arduino IDE, which provides a user-friendly environment for writing, compiling, and uploading code to the microcontroller via the USB connection.
  - The firmware developed for the ATmega328P handles the coordination between the ToF sensor and the stepper motors, ensuring accurate data collection and motor control.
- Data Handling
  - The microcontroller collects distance data from the ToF sensor as the object rotates and elevates. This data is transmitted to the computer in real-time through the serial communication interface.
  - On the computer, the received data is processed to generate a point cloud, representing the 3D scanned object.

1.4 Advantages of Using ATmega328P

- Reliability
  - The ATmega328P is known for its stable performance and reliability in various applications, making it ideal for our 3D scanner project.
- Compact Size
  - The SMD version of the ATmega328P is compact, allowing for a smaller PCB layout and overall system size.
- Efficient Input Handling
  - The microcontroller efficiently manages multiple inputs and outputs, ensuring smooth operation of the sensor and motors simultaneously.
- Wide Community Support
  - The ATmega328P benefits from extensive community support and resources, facilitating troubleshooting and development.

By utilizing the ATmega328P microcontroller, we ensure that our 3D scanner is capable of accurate, reliable, and efficient scanning, meeting the project's functional and technical requirements. This microcontroller forms the core of our system, enabling seamless integration and operation of all components involved in the scanning process.

2 Establishing USB Connection Between MCU and PC

To facilitate the USB connection between the ATmega328P microcontroller and the PC, we employ the CH340C IC. This section outlines the components and methods used to establish this connection, ensuring reliable data transfer and programming capabilities.

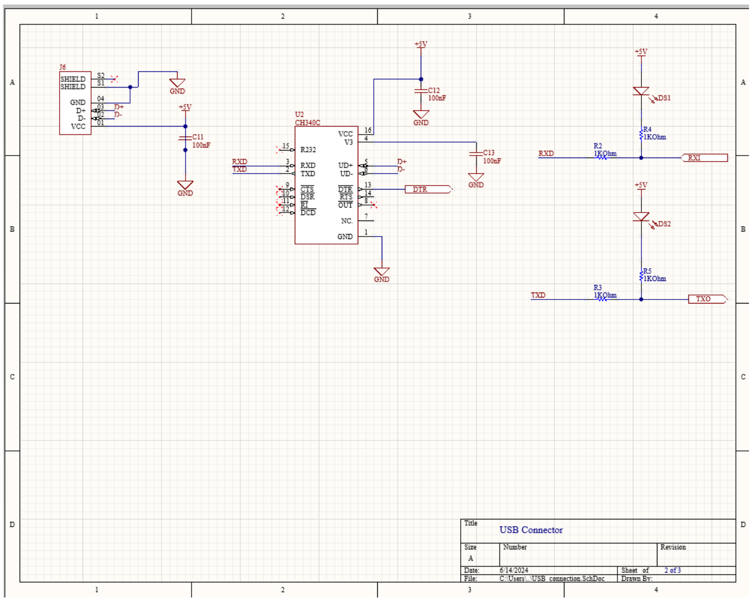

Figura 2: USB Connection

2.1 USB-to-Serial Conversion

- CH340C IC
  - The CH340C is a USB-to-serial converter IC that bridges the communication between the microcontroller's serial interface and the USB port on the PC.
  - Internal Oscillator: One of the key advantages of using the CH340C is its built-in internal oscillator, which eliminates the need for an external oscillator. This simplifies the circuit design and reduces component count.

2.2 Microcontroller Connections

- TX and RX Pins
  - The TX (transmit) and RX (receive) pins of the ATmega328P microcontroller are connected to the corresponding TXD and RXD pins of the CH340C IC. This setup allows serial data to be sent and received between the microcontroller and the PC.
  - Data Transmission: The TX pin of the microcontroller sends data to the RXD pin of the CH340C, while the RX pin of the microcontroller receives data from the TXD pin of the CH340C. This bidirectional communication is essential for both data transfer and programming the microcontroller.

2.3 USB Connection

- USB Type A Female Header
  - A USB Type A female header is used on the PCB to facilitate the physical connection between the USB cable and the CH340C IC. This standard USB interface allows easy connectivity to the PC.
  - Power and Data Lines: The USB connection provides both power to the microcontroller and the data lines for serial communication. This dual functionality ensures that the system can be powered and communicate with the PC through a single USB cable. .

2.4 Circuit Design

- Simplified Design with CH340C
  - The use of the CH340C with its internal oscillator simplifies the PCB layout, as there is no need to accommodate an additional external crystal oscillator.
  - The CH340C IC integrates seamlessly with the ATmega328P microcontroller, providing a reliable and efficient USB-to-serial conversion.

2.5 Programming and Data Transfer

- Microcontroller Programming
  - The USB connection, established via the CH340C, allows for easy programming of the ATmega328P microcontroller. Using the Arduino IDE, code can be written, compiled, and uploaded directly to the microcontroller through this USB interface.
  - Real-Time Data Transfer: During operation, the CH340C facilitates real-time data transfer from the microcontroller to the PC. This enables the continuous transmission of scanned data, which is crucial for generating accurate 3D point clouds.

By incorporating the CH340C IC into our design, we ensure a robust and efficient USB connection between the ATmega328P microcontroller and the PC. This setup not only simplifies the circuit design but also enhances the reliability of data transmission and microcontroller programming. The use of a USB Type A female header provides a standard and user-friendly interface for connecting the 3D scanner to the PC.

3 Voltage Conversion Circuit

To ensure our 3D scanner operates efficiently and safely, we use a voltage conversion circuit to step down the input voltage from 12V to 5V. This section details the components and functionality of this circuit.

3.1 Voltage Regulator

- LM7805 Voltage Regulator
  - The LM7805 is a linear voltage regulator that converts an input voltage of up to 35V to a stable 5V output.
  - Output Voltage: The LM7805 provides a regulated 5V DC output, which is essential for powering the ATmega328P microcontroller and other 5V components in our 3D scanner circuit.

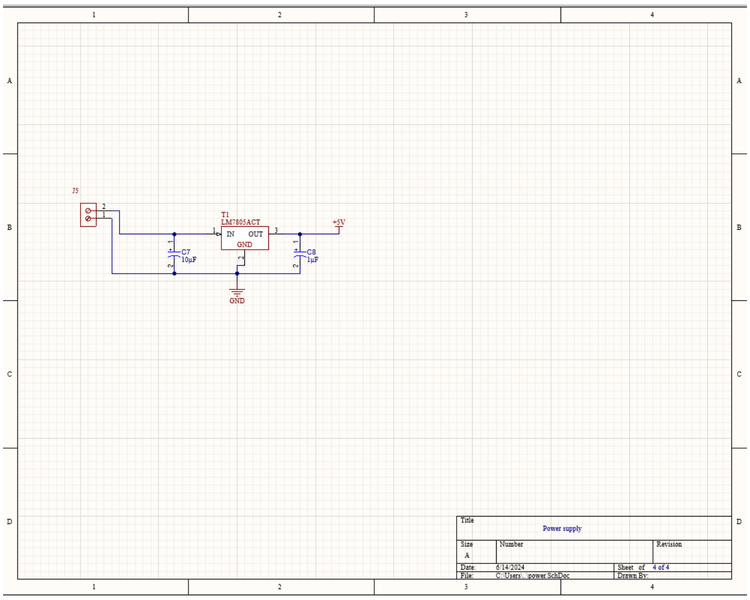

Figura 3: Voltage conversion Unit

3.2 Circuit Design

- Input Voltage (12V)
  - Our system is designed to be powered by a 12V DC input, which is common for many industrial and electronic applications.
  - Voltage Regulation: The 12V input is fed into the LM7805 voltage regulator, which then steps down the voltage to a stable 5V output.
- Component Connections
  - Input Capacitor: A capacitor is placed at the input of the LM7805 to filter out any high-frequency noise from the power supply, ensuring a smooth input voltage.
  - Output Capacitor: Another capacitor is placed at the output of the LM7805 to stabilize the 5V output and filter out any voltage spikes, providing a clean and stable power supply to the microcontroller and other components.

To ensure our 3D scanner operates efficiently and safely, we utilize a voltage conversion circuit to step down the input voltage from 12V to 5V, employing the LM7805 voltage regulator. The LM7805 is highly beneficial due to its simplicity, requiring only two external capacitors for stable operation, making the circuit design straightforward and reliable. Additionally, it includes built-in thermal protection to prevent damage from overheating, thus ensuring the longevity of the device. The regulator also features short-circuit protection, safeguarding the circuit in case of faults or shorts in the connected components.

In our 3D scanner, the regulated 5V output from the LM7805 powers the ATmega328P microcontroller, the ToF sensor, and other 5V logic components, ensuring that all critical components receive a stable voltage supply for consistent and reliable operation. The voltage conversion circuit, including the LM7805 and the associated capacitors, is integrated into the PCB layout. This compact design minimizes space requirements and ensures efficient power distribution within the 3D scanner, enhancing overall system performance and reliability.

4 SolidWorks Design Details

4.1 Turnable Table

- Diameter and Design
  - The turnable table has a diameter of 14 cm, making it suitable for scanning a variety of objects.
  - Attachment to Stepper Motor: The table is precisely mounted on a NEMA 17 stepper motor, ensuring accurate rotational movement. The stepper motor is controlled by the microcontroller to achieve the necessary 360-degree scans.

Figura 4: Turnable Table

4.2 Shafts and Coupler

- Smooth Shafts
  - Quantity: We use two smooth shafts in the design.
  - Purpose: These shafts provide stable linear guidance for the vertical movement mechanism, ensuring smooth and precise travel of the ToF sensor along the z-axis.
- Screw Shaft
  - Purpose: The screw shaft converts the rotational motion of the stepper motor into linear motion, allowing the ToF sensor to move vertically.
  - Couplers: Flexible couplers connect the stepper motor to the screw shaft, accommodating any misalignment and reducing stress on the motor shaft.

Figura 5: Shafts and Linear Slider Part

4.3 Enclosure

- Design and Materials
  - We designed a robust enclosure to house all critical components of the 3D scanner, including the PCB, stepper drivers, and stepper motors.
  - Material Selection: The enclosure is made from durable materials to protect the internal components from dust, mechanical damage, and environmental factors.
  - Connection Parts: Custom-designed parts connect the screw shaft and smooth shafts, maintaining linear motion through the z-axis. These parts ensure the alignment and stability of the vertical motion system, allowing the ToF sensor to move accurately.
- Integration
  - The enclosure features specific mounts and fixtures to securely hold the smooth shafts, screw shaft, and stepper motors in place, ensuring stability and precision.
  - Access Points: The design includes access points for USB connections and power supply, facilitating easy programming and operation.

By utilizing SolidWorks for the mechanical design, we ensured that all components fit together seamlessly and function correctly within the 3D scanner. This comprehensive design process enabled us to visualize and test the system virtually, making necessary adjustments before building the physical prototype. The detailed modeling and simulation in SolidWorks provided a clear pathway from concept to functional design, ensuring the reliability and precision of the final product.

5 Software Details: 3D Mapping and Point Cloud Generation

The software component of our 3D scanner project involves the processing and visualization of point cloud data obtained from the ToF sensor. We used numpy, matplotlib,scipy and mpl toolkt library for mapping.The process begins with loading the raw distance measurements from a text filet using numpy.loadtxt(). This file contains the distance readings obtained from the ToF sensor during the scanning process. Erroneous scan values, such as negative distances, are identified and set to zero to prevent inaccuracies in the 3D model. The delimiter 9999 is used in the text file to indicate the end of each z-height scan. These indices are located and stored to help segment the data into distinct z-layers. The raw data is then reshaped into a matrix where each row corresponds to one z-height, allowing for structured processing of the distance measurements.

Next, we perform distance calibration by offsetting the distances by the known distance from the scanner to the center of the turntable. This calibration ensures that the measurements are referenced from the turntable's center of rotation. Distances greater than a specified maximum and less than a minimum are set to NaN to exclude outliers. Values within a small threshold around zero are also set to NaN to remove noise close to the scanning origin. A theta matrix is created with angles corresponding to each column in the distance matrix, and a z-height array is generated with each row representing a specific height based on the known vertical increment. These matrices are used to convert polar coordinates (distance and angle) to Cartesian coordinates (x, y).

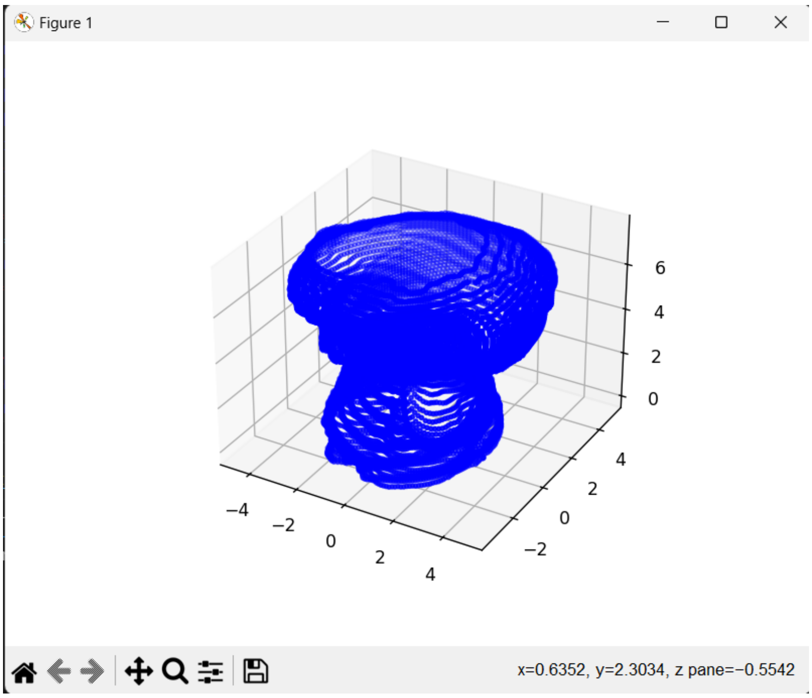

Figura 6: Example of 3D view of Scanned point cloud of a small statue

To handle missing data, NaN values in the x and y coordinates are replaced with the nearest valid neighbor value within the same height layer. This step ensures continuity in the data and prevents gaps in the 3D model. The data is then resampled to match the desired mesh resolution , reducing the data size and focusing on significant points. An average filter is applied to the x and y coordinates to smooth out noise. Convolution is used with a defined window size to average the values, resulting in a cleaner dataset.

The processed data is visualized using a 3D scatter plot with matplotlib's Axes3D, rendering the point cloud and allowing for verification of the data processing steps. The code includes a placeholder for exporting the processed point cloud to an STL file format, which can be implemented using external libraries like numpy-stl or meshio. Exporting to STL will enable the creation of a 3D model suitable for further analysis or 3D printing.

This detailed software workflow transforms the raw ToF sensor data into a structured and visualized 3D point cloud, providing a foundation for creating accurate 3D models of scanned objects. The combination of data preprocessing, calibration, conversion, and visualization ensures the reliability and accuracy of the final 3D representation.