3. DESIGN APPROACH

The Milwaukee RO-T8 is engineered to gauge the rotational speed of Milwaukee fans with precision and reliability. Equipped with a high-quality sensor and Arduino microcontroller, this device ensures precise measurement of fan RPM. Its sophisticated sensor technology detects rotational motion with exceptional accuracy, providing reliable data for various applications. The Arduino microcontroller processes the sensor data efficiently, guaranteeing precise RPM readings. Furthermore, the device incorporates robust data storage capabilities, allowing users to access and analyze RPM data for monitoring fan performance over time. Designed with a focus on accuracy and data management, the Milwaukee RO-T8 is an essential tool for maintaining optimal fan operation and performance. The following sections discuss the subsystems in more detail and explain the hardware and software choices that were made.

3.1. Design Options

In the development of the Milwaukee RO-T8, the team faced a significant challenge: accurately measuring RPM values. The chosen method involves employing an infrared (IR) sensor, but some sensitivity issues were encountered with the initial sensor. To overcome this hurdle, the team opted to upgrade to a higher-quality sensor. The current iteration of the design features a microcontroller that utilizes input data from the sensor to compute RPM. Following calculation, the RPM value undergoes testing against predetermined parameters for validation. Upon completion of the test, the result is displayed on the liquid crystal display (LCD) screen, accompanied by the illumination of a light-emitting diode (LED) indicator. This design approach was selected for its simplicity and flexibility, facilitating ease of customization.

3.1.1. Design Option 1

One of the solutions the team investigated for measuring RPM is using an IR sensor. The IR sensor works by emitting infrared radiation or IR LED, seen in Figure 3-1, from a transmitter and picking up the reflected radiation using a photodiode seen in Figure 3-2.

Fig. 3-1: IR LED [1]

Fig. 3-2: Photodiode [1]

The Milwaukee RO-T8 is oriented in a way so that the sensor sits right in front of the fan. The team discovered, as visualized in Figure 3-3 and 3-4, that the black plastic parts of the fans, most importantly the fan blades, cannot be detected by the IR sensor. To combat this issue, the red grill on the back of the fan is used since the red plastic can be picked up by the sensor and allows the fan blades to break the line of sight of the sensor.

Fig. 3-3: Milwaukee Fan Front View [12] **Fig. 3-4: Milwaukee Fan Back View [12]**

The team chose this option due to the complexity of the second option considered.

3.1.2. Design Option 2

The other solution the team considered is a Hall Effect sensor. The Hall Effect sensor works by exposing the sensor to a magnetic field, thus generating a voltage [2]. The plan to implement this sensor is similar to how the IR sensor is being used. The Milwaukee RO-T8 is oriented in front of the fan blades, but, unlike the IR sensor, this sensor requires a magnet to be attached to the fan blade. Each time the blade with the magnet passes by the sensor, it generates a voltage, and the frequency of this event can be used to calculate the RPM. This option was not pursued because the team was concerned with the effects the magnetic field could have on the motor of the fan, and the extra weight of the magnet could have on the performance of the fans.

3.2. System Overview

The Milwaukee RO-T8 ensures that the RPM of a fan falls within an acceptable range and determines pass-or-fail outcomes based on set criteria. It transmits the fan's RPM data and model number to a centralized database, promoting quality control and operational consistency across multiple units. Figure 3-5 offers a high-level overview of the Milwaukee RO-T8 system.

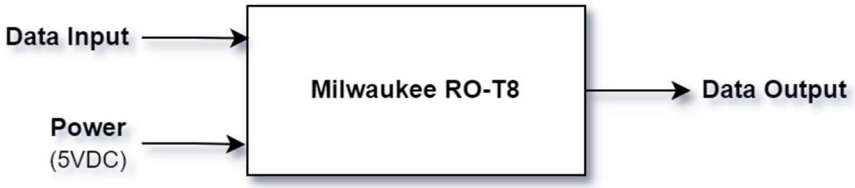

Fig. 3-5: Milwaukee RO-T8 System Overview (Level 0)

The Milwaukee RO-T8 not only gauges the speed at which the fan blades rotate but also evaluates whether the RPM falls within the acceptable range for a pass-or-fail outcome. Upon completion of the test, the RO-T8 automatically transmits the fan's RPM data along with its model number to a centralized database. This feature is particularly beneficial for maintaining quality control and operational consistency across multiple units. The database serves as a repository for tracking and analyzing performance over time, aiding in predictive maintenance, and ensuring that all fans meet their designated performance criteria. Figure 3-6 provides a more in-depth overview of the Milwaukee RO-T8 system.

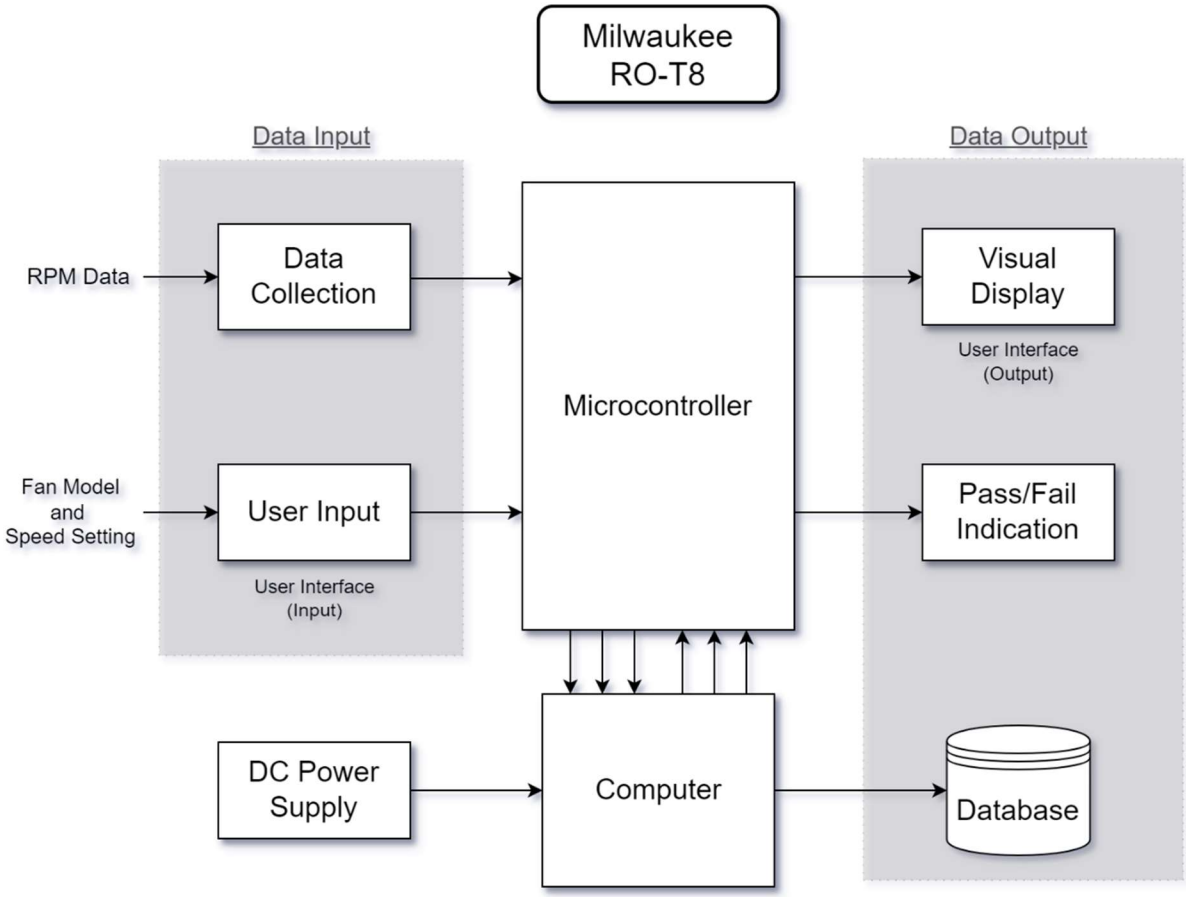

Fig. 3-6: Milwaukee RO-T8 Functionality (Level 1)

The Milwaukee RO-T8 features a USB connection with a dual function. It not only powers the device but also creates a communication channel with the service technician's computer. This link facilitates the transfer of data to a central database, which can then be used for analysis and troubleshooting purposes.

3.2.1. Microcontroller

The Milwaukee RO-T8 uses a microcontroller to collect, compute, and transmit data. The Arduino and Raspberry Pi brands of microcontrollers were considered by Magnolia Electric to meet the needs of the Milwaukee RO-T8. Table 3-1 compares the Arduino and Raspberry Pi.

Table 3-1: Microcontroller Brands

Brand	Programming Language	Ease of use	Applications
Requirements	C/C++	Easy to use	Good for complex projects
Arduino	C/C++, MicroPython [3]	Good for beginning users	Best for simple projects
Raspberry Pi	Python, C/C++, Java, JavaScript, Go, Ruby, Perl, PHP, Rust, Assembly, Scratch [3]	Good for experienced users	Best for complex projects

Arduino was chosen based on the simplicity of the Milwaukee RO-T8's design and the ease of programming. Arduino produces several models of microcontrollers with different features. The Arduino Nano, Uno, and Mega models were considered for the Milwaukee RO-T8. Table 3-2 compares the three models.

Table 3-2: Microcontroller Information

Model	Digital I/O Pins	Size (mm)	Memory	Price
Requirements	Min. 10	Max: 200 x 200	Min. 2 KB SRAM	Max. $100
Arduino Nano [13]	22	18 x 45	Flash - 32 KB (2 KB used by bootloader) SRAM – 2 KB EEPROM – 1 KB	$24.90
Arduino Uno [4]	14	53.4 x 68.6	Flash - 32 KB (0.5 KB used by bootloader) SRAM – 2 KB EEPROM – 1 KB	$27.00
Arduino Mega [5]	54	53.3 x 101.5	Flash - 256 KB (0.5 KB used by bootloader) SRAM – 8/ KB EEPROM – 4 KB	$49.00

The Arduino Uno model was chosen over the Arduino Mega model. The Arduino Uno has a smaller footprint which helps with portability yet provides enough I/O pins for the subsystems. The Arduino Uno also meets the Milwaukee RO-T8's engineering requirements of affordability.

3.3. Subsystems

The Milwaukee RO-T8 uses four subsystems. Subsystem 1 uses a Liquid Crystal Display (LCD) to help the user input a selection. Subsystem 2 is the user input used to interact with the microcontroller. Subsystem 3 is a CSV data entry used to record data measured and input by the user. Subsystem 4 is a data collection system used to record the RPM of the fan. Subsystem 5 is a pass/fail indicator, this tells the user if the RPM of the fan is within the passing range for the model.

3.3.1. Visual display

The visual display subsystem is an essential component that offers an interactive interface for the user. A Character LCD was selected for its cost-effectiveness, flexibility, and straightforward integration. The 1602 LCD I2C, with its Inter-Integrated Circuit (I2C) interface, reduces the number of required connections, streamlines the wiring, and conserves space on the circuit board, which is beneficial in space-constrained systems. Moreover, the 1602 LCD I2C's ability to display 16 characters over two lines ensures sufficient room for vital information while keeping a small footprint. Its built-in contrast adjustment and backlighting improve visibility under different lighting conditions, promoting user-friendliness. These attributes, along with its cost-efficiency and user-friendliness, render the 1602 LCD I2C a fitting choice for the Milwaukee RO-T8's visual display subsystem. Table 3-3 offers a comprehensive comparison of the available LCD modules.

Table 3-3: Display Options

Display Type	Interface Type	Resolution and Color	Dimensions (mm)	Refresh Rate	Ease of Programming	Cost
Requirements	I2C	Min. 16 x 2	Max. 80 x 36 x 12	Low	Easy	Max. $50
Graphic LCD [14]	Parallel, SPI, I2C	128 x 64, Monochrome	75 x 53 x 12	Low	Moderate	$25.95
1602 Character LCD [15]	Parallel, I2C	16 x 2, Monochrome	80 x 36 x 12	Low	Easy	$6.99
2.2" TFT LCD [16]	Parallel, SPI	176 x 220, Color	68 x 42 x 12	Moderate	Moderate	$14.49
0.96" OLED [17]	I2C, SPI	128 x 64, Color	27 x 19 x 2	High	Moderate	$11.99

The 1602 LCD I2C module stands out for its compatibility with numerous microcontrollers, adding to its adaptability. Its small footprint and low energy requirements also make it ideal for applications where space is at a premium and power efficiency is key. Figure 3-7 shows the LCD with I2C connectivity that the Milwaukee RO-T8 uses.

Figure 3-7: 1602 Character LCD with I2C [16].

The LCD serves as the output component of the user interface, displaying both the menu selection and the fan's RPM value. The following section outlines the input component of the user interface for the Milwaukee RO-T8.

3.3.2. User Input

User input provides the software with information to set the test parameters and record what model and speed are being tested. It was decided that of the three options: three push buttons, two potentiometers, and seven push buttons. Three push buttons were chosen; more information can be provided in Table 3-4.

Table 3-4: Input Options

Input Method	How it would work	Advantages	Disadvantages	Required Training
Requirements	Must be responsive, easy to use, and accessible.	The user input method chosen should be advantageous over the other methods	The user input method chosen should have minimal disadvantages.	The method chosen should require as little training as possible.
Three Push Button	The first button is used to move through a list of models, and then a list of speeds. The second button is used to select the model and speed. The third button is used to select the test.	This method appears easy to use and leaves little room for user error.	This method requires additional programming to set up the cycling list.	This method is the simplest to use and needs little training.
Two Potentiometers	One potentiometer is used to select the model. The other is to select speed.	This method appears easy to use and leaves little room for user error.	This method does not signal the system to start testing and requires extensive programming by the design team to correct this design method.	This method is simple to use and needs little training.
Seven Push Button	A push button is for each model and speed. One push button is used to cancel the selected test parameters.	This method is easy to program.	This method appears complex and cluttered.	This method requires more training time due to the complex design.

The three-push-button method was chosen because it requires less programming than the two-potentiometer method and is more visually appealing than the seven-push-button Method. The three-push-button method and two-potentiometer method both meet the design requirements to be user-friendly and require little training.

3.3.3. Database Entry

Milwaukee Tool requested that the design exports the results of tests to a database. To meet this goal, the prototype is designed to send test data to a .csv file for use in Microsoft Excel. The .csv file type was chosen as it is a commonly used file type throughout the industry and is what Milwaukee uses for its current databases. This data collection and transfer is facilitated by the Arduino microcontroller. The data sent to the file specifies the fan model, the fan's unique serial number, the fan RPM, and whether the fan

passed or failed the test. The .csv file is hosted on the testbench's computer, which then passes this data to a database for further use. A rough diagram of this process can be seen below in Figure 3-8.

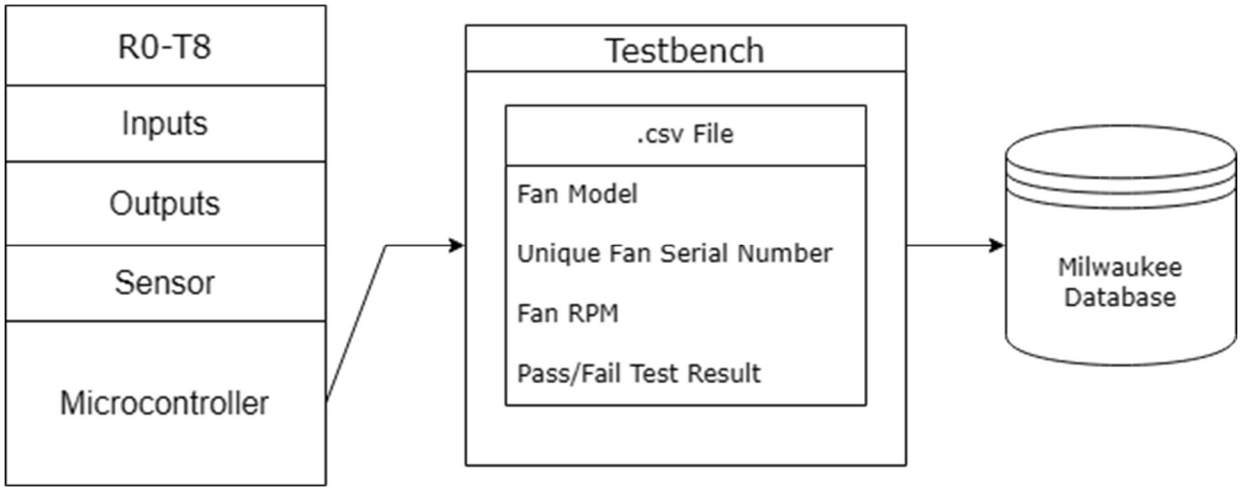

Fig. 3-8: Diagram of the Database

As shown above, the code of the Arduino has been written to the .csv file on the testbench and once this is checked by the user it is entered into the database.

3.3.4. Data Collection

The design collects data through an IR sensor. The IR sensor was chosen over other ways of RPM testing as it is easier for the end user. The Arduino IR module was chosen over other similar sensors due to the guaranteed compatibility with the Arduino microcontroller and it came with a purchased Arduino kit. Comparison data is listed in Table 3-5.

Table 3-5: Data Collection

Product	Operating Voltage (V)	Sensor Range (cm)	Dimensions (cm)	Price
Requirements	Max. 5	Min. 35	Max. 2 x 5	Max. $50.00
SparkFun Proximity Sensor Breakout [6]	1.7–3.6	20	0.515 x 0.298 x 0.053	$19.95
KY-032 Infrared Obstacle Avoidance Sensor Module [7]	3.3–5	40	1.6 x 4	$12.99
10PCs Arduino Obstacle Avoidance Sensor Module [8]	3.3–5	30	13.462 x 8.128 x 2.54	$8.79

As seen in Figure 3-9, the chosen sensor is the KY-032 Obstacle Avoidance Sensor. This sensor fits the range, price and dimension requirements as stated above.

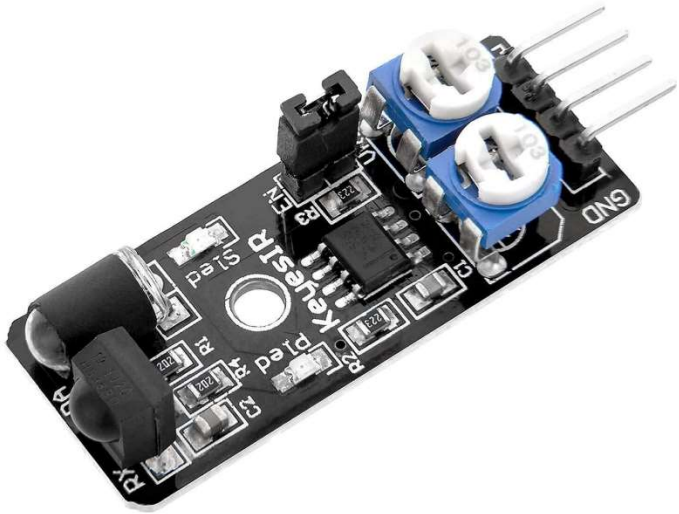

Fig 3-9: KY-032 Infrared Obstacle Avoidance Sensor Module [7]

The following section specifies how the design communicates the results of the pass/fail test.

3.3.5. Pass/Fail Indication

The pass/fail indicator serves to communicate to the user whether the fan type meets the RPM values required. The team considered three methods including two visual methods and an auditory method. The first visual method is to use two LEDs, one of which serves as a “pass” and the other serves as a “fail”. The second visual method is to use the LCD screen already used in the visual display subsystem. This would work by displaying a “pass” or “fail” message on the LCD. The auditory method would use a piezo buzzer and have two different frequencies to signify a “pass” or “fail”. The team chose the LED method to avoid having to listen for an auditory element in a noisy factory setting and to avoid cluttering the LCD display. Listed in Table 3-6 are the LED options considered.

Table 3-6: LED Options

Product	Operating Temp (°C)	Lens Size (mm)	Price
Requirements	**-**	<3	<$2
LED RGB Clear (WP154A4SUREQBFZGC) [9]	40-85	5	1.88
LED RED Clear (XLM2MR11W) [10]	40-85	3	0.73

LED RED Clear (SLR-56VC3F) [11]	25-85	5	0.51

The LED that was chosen was the LED RED Clear (XLM2MR11W) which is seen in figure 3-10. This LED met the size requirements needed for the housing unit that the mechanical engineering team designed, and it is cost efficient.

Fig 3-10: LED RED Clear (XLM2MR11W) [10]

The team was able to find the same model of LED in a different color to cover both the "pass" and "fail" options. In the following section, the team discusses the level 2 prototype design.

3.4. Level 2 Prototype Design

The Milwaukee RO-T8 prototype consists of a sensor that measures RPM, a database to store the data, and a user interface to alert the user if any deficiencies are detected. Currently, the system utilizes a comma separated value (.csv) format to store data. Later the team plans to consider using a Structured Query Language (.sql) database to manage the data. In addition to these primary tasks, the team plans to explore various options to improve the design, specifically a battery pack to power the device.

3.4.1 Level 2 Diagram

The final prototype for the Milwaukee RO-T8 is shown below in Figure 3-11. The Milwaukee RO-T8 is held inside of a case that protects the device, while also maintaining its usability.

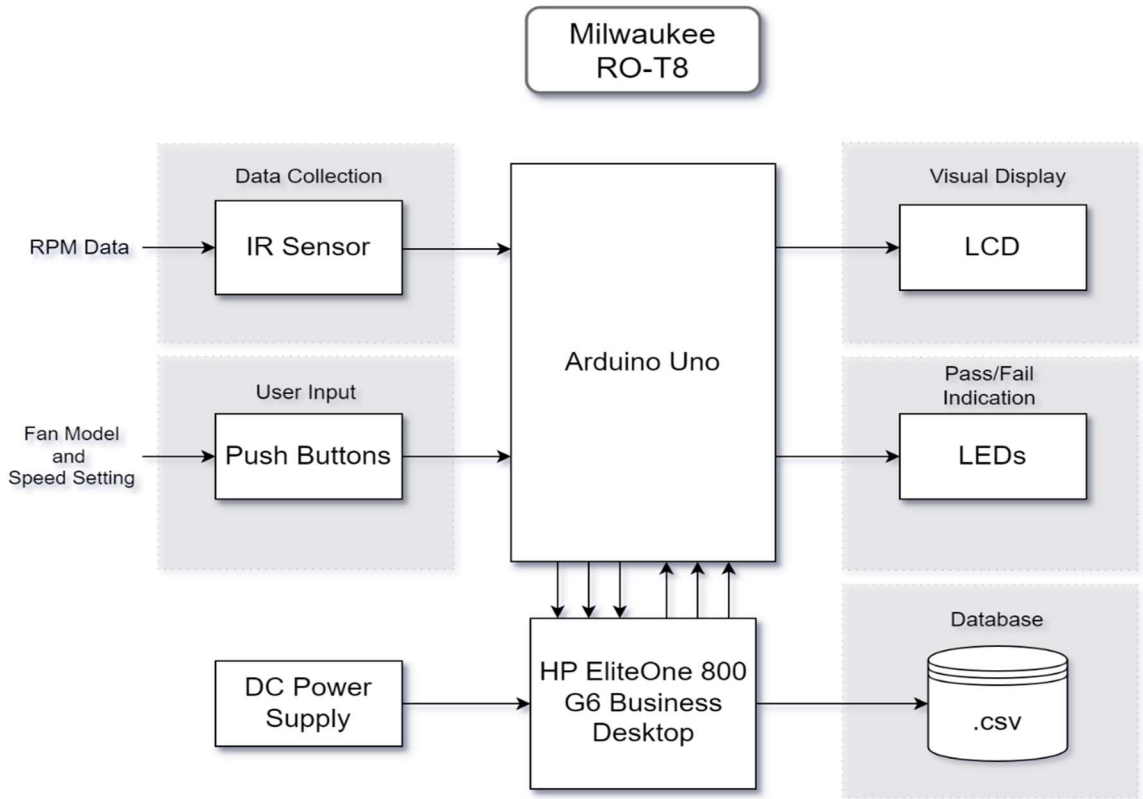

Fig. 3-11: Diagram for Milwaukee RO-T8 (Level 2)

The HP EliteOne 800 G6 Business desktop is the computer used by Milwaukee Tool on its testbenches, and as such Magnolia Electric included the desktop in the Level 2 diagram. A set of push buttons indicates the fan model and speed setting for the sensor. The Arduino Uno is the brain of the device, taking the data from the sensor and outputting it to the user with a message on the LCD screen and a light to indicate whether the test was a pass or fail. The Milwaukee RO-T8 performs on many different levels by sensing fan RPM, transferring the data, displaying the data, and saving the data in a database.

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