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In the last decade, the use of 3D printing in university settings has greatly increased, but studies have found that nearly 41% of prints in this environment result in failure (Song &

print very fine edges (Dwamena, n.d.-b). Ultimately, the human side of 3D printing is a crucial part, and inexperienced users could be more prone to mistakes.

Humidity is a factor that affects the filament used in 3D printing. The most common filament used in 3D printing is PLA, which is a hygroscopic material; this means that it absorbs moisture from the air, becoming saturated (Faegnell, 2017; Frunzaverde, et al., 2022; Hanon, et al., 2021). Once the filament becomes saturated, it is referred to as wet filament, and wet filament has distinctly different characteristics than dry filament (Toor, 2022; Dwamena, n.d.-a). For example, wet filament has a larger diameter as well as a weaker structure than dry filament, and both of these characteristics can lead to print failure (Faegnell, 2017; “Humidity: The Great Enemy,” 2018). Specifically, the larger diameter has been shown to increase the flow rate of filament when printing (Faegnell, 2017) which leads to over-extrusion and inaccurate or even completely faipriŏlʼtkŏun weakefilameen humdruificaf, tThe2018).

Raspberry Pi with a DHT11 is an effective way to measure the ambient temperature and humidity in an area (Campbell, 2015; Khan, et al., 2021). A Python script along with the Adafruit library can be used to get humidity readings from the DHT11 (***Dht Humidity Sensing on Raspberry Pi***, 2023).

By understanding factors that can lead to a failed 3D print, this study can more effectively target and measure those factors in a makerspace. Literature indicates that humidity and human error are common factors for failed 3D prints (“Humidity: The Great Enemy,” 2018; Dwamena, n.d.-b; Team Xometry, 2022b). Additionally, each of these factors can be identified as the potential cause of failed 3D prints; for example, humidity can be identified if the print has significant warping, and human error is likely the problem if the print does not have supports where it should (Ultimaker, 2021; Team Xometry, 2022b). By isolating the prints caused by human error from the prints caused by humidity, this study can more effectively measure the true impact of humidity on 3D printing failure rates.

Understanding a trusted method of collecting humidity data means this study can more productively create a humidity data collection device.

[redacted]

- This study is limited to data collected in single makerspace.
- This study is limited to data collection over a period of fourteen non-consecutive days.
- This study did not consider factors such as printer calibration, filament color, shape

Makerspace	A collaborative workspace where university students have access to a variety of tools, including 3D printing (Halbinger, 2020).

The focus of this

collection for this study, they were not taken into account. In addition to the humidity data, the date and time of each data point were also collected using the datetime library. The file module was used to open a CSV and export each data point into it, with the humidity in one column, the date in another, and time in the final column.

An app was made using Google Cloud for the purposes of connecting the Python script to the Google Application Programming Interface (API) (de Langen, n.d.); this allowed the use of Gmail from the Python script. The smtplib library was then used in the script to open a Gmail port, log in to a Gmail account, and create and send emails with the CSV attached.

The device was tested and improved upon over the course of five iterations, with each iteration attempting to complete more of the criteria. For each iteration, the device was tested for a minimum of two days to see which of the criteria it met.

To assess the applied sub problem, 3D print failure rates needed to be collected. This was done by lab assistants in the makerspace who tracked 3D print failures using a physical log. The log asked assistants to record the date !

This section explains the results obtained for each of this study’s sub-problems. The success of the design of the autonomous humidity collecting device is discussed first, followed by the results of the correlation analysis between humidity and 3D printer failure rate.

Literature indicates that humidity may play a role in the failure rate of 3D prints (Faegnell, 2017; Frunzaverde, et al., 2022; Hanon, et al., 2021), so the first goal of this study was to create a device that could autonomously and remotely collect and send data. For this, a checklist was created to determine if the device was viable for data collection; namely, it had to successfully complete four functions: collect the data at specified intervals, export every piece of data to a running CSV, email the complete CSV at specified intervals, and work autonomously (Khan, et al., 2021; ***Sending Emails with Csv***, n.d.; Baranovsky, 2023). The functions were tested in five iterations for at least two days to determine if the checklist criteria were met.

For the first iteration, the Adafruit library was used to get readings from the pin to which the DHT11 was connected, and these readings were refreshed continuously using a while True loop and printed to the console at specific intervals using the time library (i.e. the time.sleep() function). In addition, the date and time were printed for each reading using the datetime library. The first iteration was successful in being able to collect while True loop to keep the function running as well as control when the data was collected and exported.

The third iteration was made specifically to email the CSV. Using a Google Cloud app, the Python script was able to connect to the Google API and use Google services, specifically Gmail. Specifically, the smtplib library was used to create a port for Gmail, login to an account, create an email, add the CSV to the email, and send the email. It did not use a loop, nor have the code to collect data, it only emailed the CSV. It was done this way to make sure the code worked before inserting it into the main script.

In the fourth iteration, the email script was successfully added to the main script. The setup of the port, login, and CSV was put outside of any loops

CSV

“email” CSV and the “saved” CSV diverged, with the code sending the same outdated version of the CSV during the same run of code, despite the actual CSV that was saved to the computer being confirmed to be updating live. Once the code was stopped again, however, the updated CSV was sent. Because of this issue, the device was unable to email the completely updated CSV at the specifi ¥ eczCSV

(Table 2). The average humidity over the time span of fourteen non-consecutive days was 35.674%, with a minimum of 19.931% and a maximum of 46.918%. The total number of prints was 113, with 69 being successes, 32 being printing fails, and 11 being non-printing fails. The average daily printing failure rate was 21%, with a minimum of 0% and a maximum of 56%. There was an average daily non-printing failure rate of 8.967%, with a minimum of 0% and a maximum of 33.333%. Then, to better understand if there is a relationship between

Literature indicates that humidity can affect 3D printing in different ways, but research has not indicated whether humidity correlates with failure rate (Faegnell, 2017; Frunzaverde, et al., 2022; Hanon, et al., 2021). So, this study set out to fill this research gap by exploring whether such a correlation exists in data collected from a makerspace. The first step in the research process was the creation of a device to autonomously collect and send humidity data. Literature indicates that a DHT11 is a practical way of measuring humidity and that emailing a CSV is an effective method to transport data (Khan, et al., 2021; ***Sending Emails with Csv***, n.d.). The device created in this study used a Raspberry Pi with a DHT11 with a Python script to email CSVs. The measures of success for the device were that it had to collect humidity data at specified intervals, export data to a CSV, email CSV at specified intervals, and work autonomously. The device was successful in meeting all the requirements of the checklist, except being able to autonomously email the complete CSV. Having this device enabled continuous humidity readings to be collected at set intervals without the presence of a lab assistant, reducing human error in the data gathering as well as the need to staff the makerspace throughout the day. Future studies that involve the collection of humidity readings may benefit from the use of this device.

Failure data were collected from the makerspace alongside the humidity data and a linear regression test was conducted to determine the correlation coefficient (***r***). Results showed that ***r*** ≈ -0.111, meaning that there was a weak correlation between humidity and 3D printing failure rate. Therefore, the hypothesis that there would be a strong correlation was rejected. In other words, while humidity may have effects on some aspects of 3D printing, this study’s results indicate that it does not affect 3D printing failure rate.

This study provided tools for the makerspace to effectively measure humidity, which can also be used by other makerspaces. Having this device enabled collection of continuous humidity readings at set intervals without the presence of a lab assistant, reducing the need for human intervention when collecting humidity data in the makerspace.

Overall, this

understand 3D printing failure rates. While this study attempted to account for influencing factors such as human error, it did not account for factors such as printer calibration, filament color, and shape of print. This study serves as a springboard for future research on the effects of humidity on 3D printing, in addition to providing a framework

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