Miami University ECE 449 Senior Design Project Report

Power Measurement of Email Footers (Spring 2022)

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Hypothesis

Sending and receiving emails that contain images in the footer use significant amounts of power when compounded over the billions of emails sent in a year. These images can be headshots or company logos and are sent in the footer of an email. This excess power draw may be significant when considering the scale of the internet and the volume of email traffic that occurs.

I. Introduction

Electrical energy is used daily by nearly everyone in the world, which costs money and requires precious resources to produce. Many computing processes run in the backgrounds of our devices that we don't pay any mind to, or we run these processes inefficiently without realizing. Do we really need to have notifications turned on for Tik Tok or Facebook twenty-four seven? These operations not only use power to light up our screen, but they also have services constantly running to check for new notifications. Is this really necessary if you are going to check those apps at some point anyway? And do you really need to send every text with ten heart emojis at the end? These operations all consume energy , and there is a finite amount of energy on your phone, and on the planet. According to a study conducted in 2020, global data center electricity use in 2018 was estimated to be 205 TWh which represents approximately 1% of total global energy use (How, 2020). It would be wise to lower energy consumption in any reasonable way possible to spend less and so we use less energy and resources.

During fall semester we developed a method to measure and record energy consumption for computing operations that were executed on a Raspberry Pi. This system allowed us to calculate the energy consumption of finite computing operations on a Raspberry Pi. This semester, we focused on determining the energy consumption of sending images over the network to get an accurate representation of how much energy is consumed sending images in email footers.

We ran tests to determine the energy consumption of sending images of various resolutions, file formats, amounts of color, and from different storage locations. We also determine the energy consumption for sending text files of different file sizes. In Section II, we discuss the background behind our approach. In Section III, we determine what instruments to use. Our measurement system is shown Section IV. In Section V, we go over our experiment in detail and analyze the data we have obtained. Future goals for this project are brought up in section VI, and we conclude in Section VII. Finally, we ponder the ethical duties of engineers in Section VIII.

II. Project Background

Last semester we created a method and validated our ability to accurately measure the power consumption of small-scale computing operations (i.e. printing to console, writing to disk, arithmetic, etc.). This semester, we circle back to our original goal of measuring the power consumption of images sent in an email footer. We set up several different experiments with different variables so that we were able to get a greater understanding of what factors affected power consumption for sending an image. Below are the variables that we came up with to test in our experiments.

- Original, half, double resolution
- Redhawk logo (4-color), Miami "M" logo (2-color), headshot (full color)
- BMP vs. PNG
- Local vs. Remote script execution

We also measured power consumption for a 22 MB text file and a 44 MB text file to get a greater understanding of the correlation between file size and power consumption. Our experiments were run on a Raspberry Pi which requires only a 5V power supply. Although most email traffic is likely sent from systems running full-fledged Operating Systems, our reasoning is that using a Raspberry Pi would at least give us relatively realistic data on power consumption that we could scale up to a "global context". We know that there are approximately 300B emails sent per day, so we used this figure along with our data to approximate the annual global energy energy consumption in the context of our experiments.

III. Project Research

We needed to research the power draw characteristics for our system which was a Raspberry Pi 3B+. The Raspberry Pi is a single-board computer that runs on Raspberry Pi OS. Raspberry Pi OS is a Debian-based Linux operating system optimized for use on ARM-based hardware like the Raspberry Pi. For the ease of later webpage tests, our test Pi has a full desktop version of the operating system. The Pi is interfaced over the network via SSH (Secure Shell Access) so the only connection to the Pi other than the power supply is an ethernet cable. No external monitors/mice/keyboards were plugged into the system. To determine the power draw characteristics with the Pi, we simply needed to measure the power draw of the system at idle as well as while one of our test scripts was running. The difference between these two values would give us the power increase the system experienced during script execution.

A Fluke 87V multimeter was set to its current measuring function and connected in series with the 5V lab bench power supply to the Raspberry Pi's power input as shown in Figure 1. Once the Pi had a steady-state current measurement after boot, the Fluke measured a current draw of approximately 470mA. According to the Pi's online user guide, this falls within the expected value for idle current draw. We ran one of our basic arithmetic scripts and measured a maximum current draw of approximately 700mA. These findings did surprise us as we weren't expecting such a significant increase in power draw during the execution of the script. This made our job easier since we knew that our current measuring sensor wouldn't have to have as high of granularity as we would have thought. We did need to find a current sensor, however, to have a method to record data using a computer.

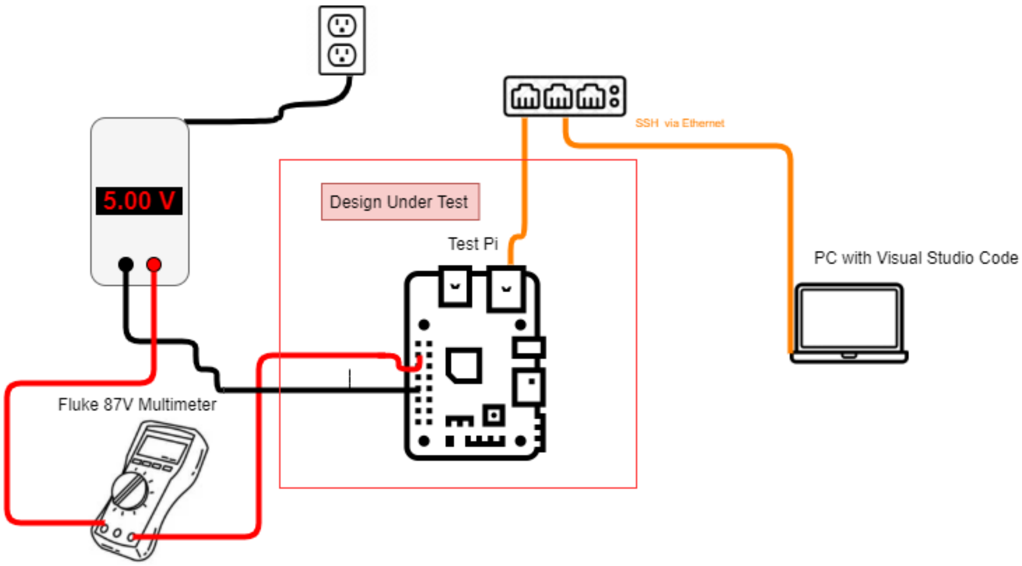

Figure 1: Original test computing system with Fluke 87V multimeter

To do this, we used a Texas Instruments INA219 current and power monitoring IC (integrated circuit). The IC's datasheet defines a maximum current measurement rating of 3.2A and a maximum voltage of 26V. This falls well within our test environment characteristics which we saw draw up to 700mA at 5V. The datasheet reports a current measuring resolution of 0.8mA which should be plenty accurate when we saw our system current spike from ~470mA to ~700mA of. The INA219 operates with a 3 to 5.5V power supply and communicates over I^2C. I^2C is a common serial communication protocol used by microcontrollers. These are all ideal characteristics for our test environment.

Figure 2 below showcases a data sample that we collected during a file write to disk test. You can see the idle power draw is measured at approximately 2.5 W before and after the script is executed. The script execution is represented by the middle section of the graph where the energy consumption fluctuates between 2.8 to 3.5 W. To determine the energy use for the script, we take the energy consumption data that we measured and multiplied by the duration of the test.

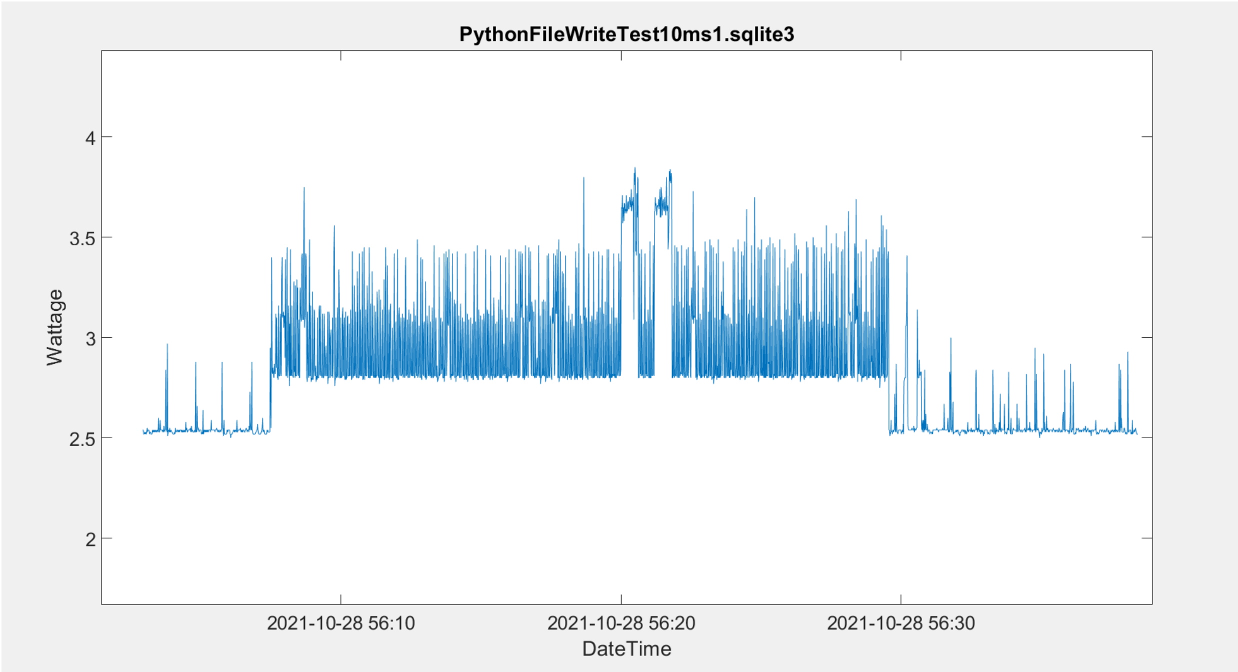

Figure 2: Sample data plot from a file write experiment

This particular experiment was calculated to use about 7.28E-8 W/s per operation as seen below in *Figure 3*.

File:	AvgWattage Operation	AvgStandby Wattage	Difference:	Average Time:	Trials:	Time/Operation:	AvgPwr/Operation (W/s):	AvgPwr/Operation (kwh):	Cost: ($)
CFileWriteTest1	3.31275	3.117095044	0.195654956	37.189921	100000000	3.72E-07	7.28E-08	2.02E-14	6.36E-16

Figure 3: Calculations from file write experiment

IV. Solution Implementation

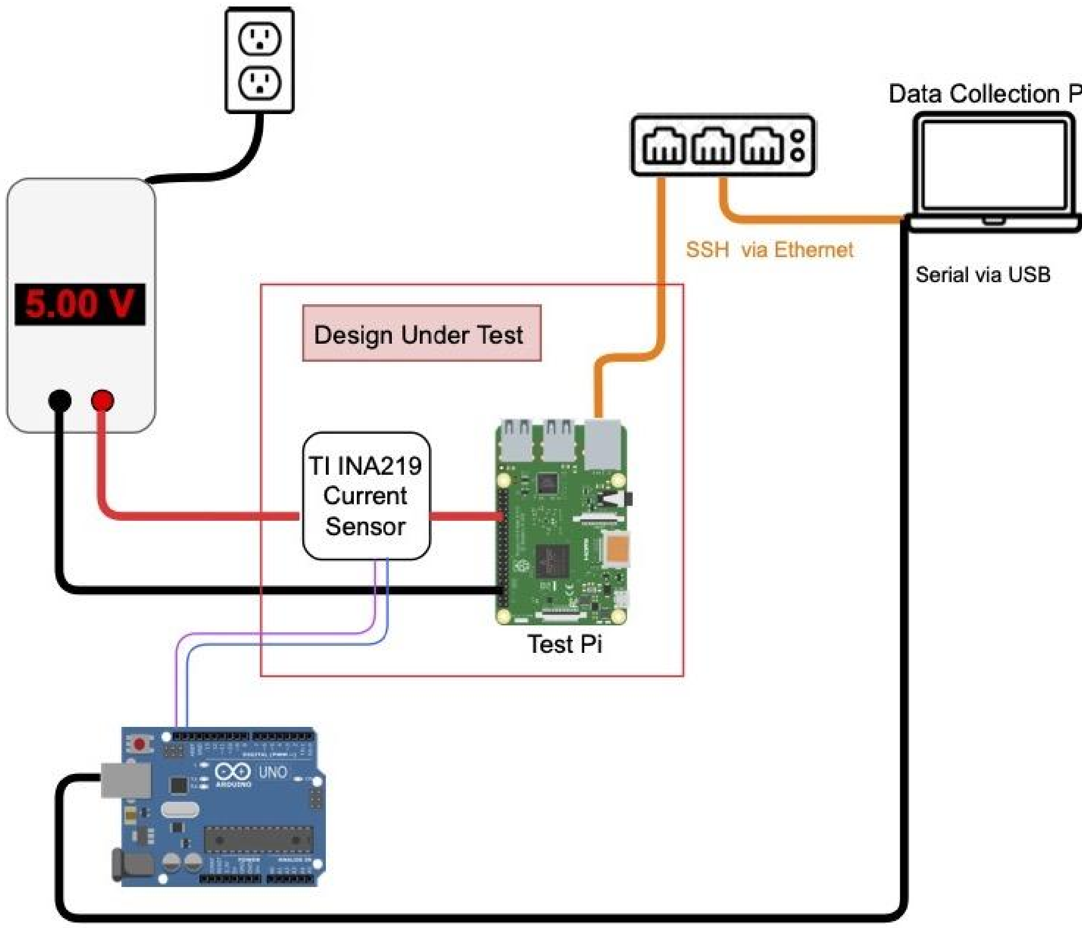

Figure 4: Test system with TI INA219 current and power measurement IC

Specifically, we measure the power consumption of the Raspberry Pi with a Texas Instruments INA219 voltage and current measurement IC connected to an Arduino via I^2C. An Arduino communicates the power measurement data to a PC over USB Serial and a Python script that records the data to a SQLite file with timestamps. We then analyze the data to determine when operations were taking place and when they were not by looking at when the power increase occurs. The sections of power increases were taken and sorted through to be averaged by using the database file format SQLite. The time periods in which the power increases are used to create a query that SQLite could take and find the correct data to compile. *Figure 4* shows a diagram of the test system.

To conduct our experiments with emails, we used three images: the Miami "M" logo, a headshot of Dr. Jamieson, and the Miami Redhawk logo shown in *Figure 5*. These three selections were selected because we thought they are an accurate representation of authentic footer images that may be used by people in an educational or professional setting.

Figure 5: The three images sent and received using a Python script

Our three test images were subjected to a variety of tests. First we compared the power consumption of sending each as a BMP and PNG. A BMP image is uncompressed and lossless, whereas PNG images are compressed and lossless. This means that a BMP image will be larger while retaining as much of the image detail as possible, while a PNG image will be smaller and retain as much image detail as possible. We also compared the energy consumption of each image when sent at the original resolution, half-original resolution, and double-original resolution. The file size differences between BMP and PNG are featured in *Table 1* and *Table 2* below. We also compared the energy consumption when the transfer script was executed on the local Pi vs the remote PC, as well as when the image was stored on the local and remote device that was executing the script.

	Original resolution BMP (kB)	Half resolution BMP (kB)	Double resolution BMP (kB)
Miami “M”	38	15	607
Headshot	6329	1583	25313
Miami Redhawk	2945	755	11777

Table 1: File sizes for BMP images

	Original resolution PNG (kB)	Half resolution PNG (kB)	Double resolution PNG (kB)
Miami “M”	13	4	62
Headshot	2632	866	8680
Miami Redhawk	164	74	1387

Table 2: File sizes for PNG images

	Half resolution Δ ratio	Double resolution Δ ratio
Miami “M”	0.25	4.0
Headshot	0.25	4.0
Miami Redhawk	0.25	4.0

Table 3: Ratio of difference in number of pixels in each image from original

V. Data Findings & Interpretation

We ran each experiment by collecting the power changes from sending and receiving the image twenty times, and executing it five times. Our tests show that sending an image with more details (headshot) consumes about five times more energy than images with fewer details ("M" and Redhawk) as shown in *Figure 6.* BMP images generally consume more energy than PNG images. This is expected since BMP images are uncompressed and larger in file size than PNG images which are compressed and smaller in size.

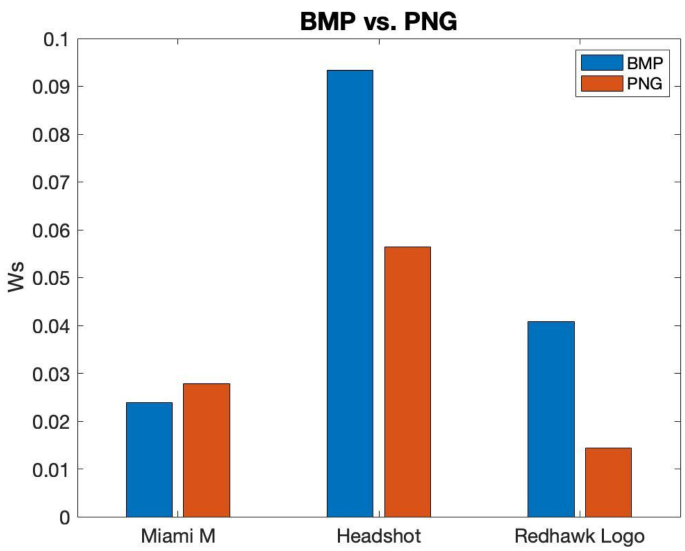

Figure 6: The comparison of the three images alongside their BMP and PNG formats

Figure 7 shows the results of testing original, half, and double image resolution. The data says that power consumption does not have a linear relationship to image resolution. For the Miami "M", power consumption was roughly the same for the original and double resolution while the half resolution consumed about one-third less power than the original. We see more of a discrepancy between power consumption for the headshot photo. The double resolution uses about 40% more power than the original and the half resolution uses roughly 40% less power than the original.

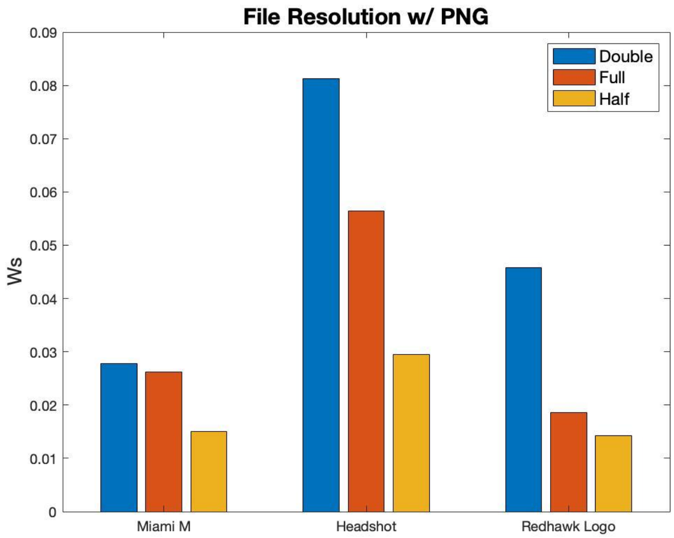

Figure 7: Power consumption for various image resolution sizes for PNG

Figure 8 shows data for our experiment testing power consumption when the transfer script was executed on the Pi compared to when it was executed on the PC. We can see that in red, the PC script execution consumed about four times as much power for the Miami "M" and Redhawk logo. We see the same correlation for the headshot, however, with a less significant difference in power consumption compared to the Pi. Since PCs running "full" OSes (i.e. Windows) have a lot more background process overhead, they will generally consume more energy than when the same operation is completed on a Raspberry Pi. That being said, these test results are as expected.

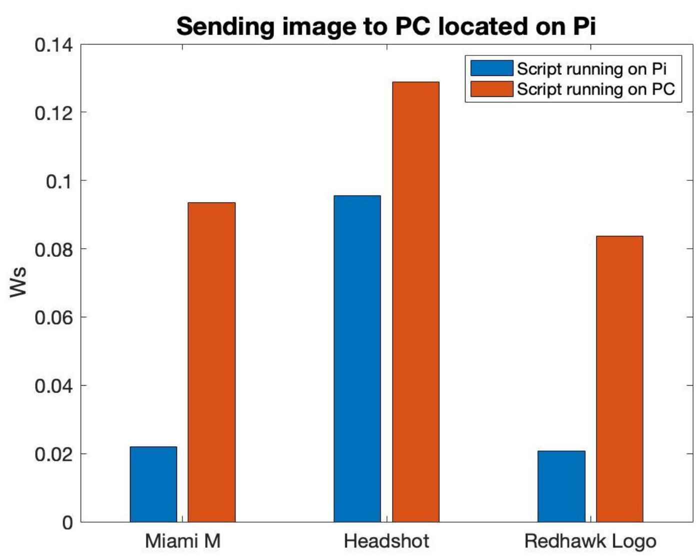

Figure 8: The comparison of all three images being sent with the script running via Pi vs PC

We also tested to see the relationship between energy consumption and file size. We ran a test transferring a 22 MB and a 44 MB test file. In *Figure 9*, we can see that the 44 MB text file consumed approximately double the power that was required for the 22 MB text file. This experiment shows that for text files, there seems to be a linear relationship between file size and power consumption.

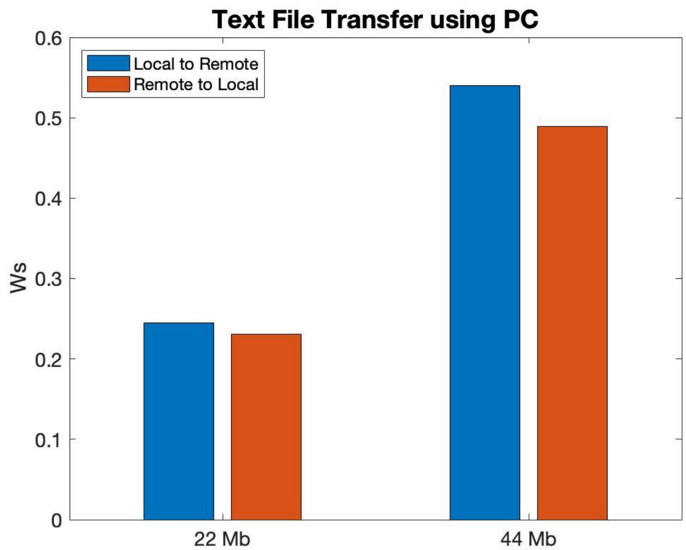

Figure 9: The comparison of the two text file sizes and where they were being sent from

Our results for energy consumption of transferring images are as we expected. A headshot with more detail consumes more energy than images with fewer colors. Additionally, we would expect that BMP images use more energy than PNG images due to the fact that the former are uncompressed and thus have a larger file size than a PNG image which is compressed. It's also not a surprise to us that executing the transfer scripts on the Pi consumes less power than on the PC since the Pi has significantly less computer power than a full desktop PC and therefore a much smaller maximum power draw.

One interesting point that we see in our data was that power consumption did not scale linearly as we change the image resolution. When we double the original image resolution, we generally only see a small increase in energy consumption. When we halve the original image resolution, the energy consumption barely changes at all. In fact, in our test with the Redhawk logo, the energy consumption is slightly higher for the half resolution than the original resolution. We did, however, see a linear relationship between text file size and power consumption.

Extrapolating the energy use required to send our 600x900 headshot photo, one kWh would be consumed every 60M headshots. It is estimated that 300B emails are sent daily. If all of these emails were to include a headshot and they consumed energy at the rate we measured from our experiment, this would use roughly the energy equivalent required to power the average home for four hours.

To better apply to Miami University in general, we can apply the same data to average daily email data for the University's google mail system. On average about 60 thousand are sent and 1M emails received through Miami's domain daily. If all of the sent emails through the domain contained a footer image, over the course of a year approximately 0.179 kwh would be consumed. This is less energy required then to light two 100W lightbulbs for an hour. If all of the received emails contained a footer image, just under 3kwh of energy would be consumed to receive the footer images.

VI. Future Project Goals

If we were able to spend more time on this project, then we would acquire an Atomic Pi. An Atomic Pi is x64 and runs on an Intel Atom processor, which are more commonly used in desktop applications than the ARM processors that Raspberry Pis use. Atomic Pis are also much faster than Raspberry Pis, so we would be interested to see how our scripts run and how the data changes based on the system we test them on. We would also like to do testing with email servers where we test the power consumption differences between sending and receiving emails with and without files, with and without images, and different quantities of text. Should we have more time after all of that, we would run tests over WiFi instead of Ethernet.

After gathering data from the email servers, we would be looking into the Google Search Bar. Or, more specifically, the auto-fill feature of the search bar. This is a process that gives the user options to fill in what they've already typed. For instance, if the user typed "how to" into the search bar, Google might suggest that the query they're searching for is "how to commit murder", or "how to hide a body", or "how to remove the evidence". Our goal in this instance is to determine how much power having that auto-fill feature on at all times will take over not having it on at all. To do this, we intend to use a Raspberry Pi to isolate the Google search engine as much as possible, then collect data with the auto-fill feature turned on and with it turned off. Then, we may test if there's a difference between if you're using the search bar and if it's sitting idle.

VII. Conclusion

Sending emails requires the use of energy, sending emails with images attached would need even more energy. Let's consider how much energy generation would be required to complete sending 300B 600x900 headshots per year. The average solar panel in the US can be expected to produce about 2kWh per day. That means that two solar panels would produce enough power for all email footers. One pound of coal produces approximately 0.88 kwh of electrical energy per pound. This means that all of the email footers globally, if powered by coal, would use about 2.2lbs of coal per day, or 805 pounds of coal annually. This annual consumption of coal would provide enough energy to an original steam locomotive for about 16 miles.

VIII. Ethical Implications

It is our responsibility as engineers to ensure that the systems we create are energy efficient and not completing unnecessary operations. Using power costs money and unnecessary processes across a connected world with millions or even billions of devices likely consume an extreme amount of energy. We would like to determine how much energy these unnecessary operations use, so others can decide if the power use is worth it. Is it worth the energy it takes to send images in an email signature line? Is it worth it to have an always-on virtual voice assistant? Is it worth it to have autocomplete always completing our searches for us? It is not right to design systems this way, to intentionally make it so it consumes more energy than is necessary. Our goal as engineers is to design systems that a customer can rely on and doesn't cause them a net loss overall. We want to shed some light on what some commonly disregarded features cost.

It is also our responsibility as engineers to engage in life-long learning. To keep up with ever-changing technology, we need to constantly be learning about it. There is every possibility that new technology will introduce very energy inefficient processes or features that may be able to be turned off, or updated to be more efficient. If we keep ourselves up to date with technology and its nuances, we would be able to identify which process is causing such a high power draw through thorough testing and suggest ways to alter it to cost less.

Having a broad education is something an engineer needs to thrive. A broad education is key to understanding the wide range of people who might benefit from knowing how much energy the processes that run on their devices use, and how much that may cost. We live in a highly connected world and nearly everyone uses technology and consumes power on a near-daily basis, so having an understanding of how people use their devices will serve to help them understand how to cut down on energy consumption.

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