ALTERING THE PLANETARIUM IN THE ROTUNDA AND MUSEUM AT MCCORMICK OBSERVATORY

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Abstract

This project is an attempt to reconfigure the University of Virginia's planetarium in the Rotunda. Made in 2019, the original planetarium, while turned on every night automatically, is seldom used for community and public outreach and educational purposes. On top of this, some inaccuracies were noted in the original planetarium's designs, likely due to the use of Thomas Jefferson's original sketches for the final design and star locations (Bromley, 2019). Because of this, we made a decision to create a new planetarium using updated Raspberry Pi 4s and a more accurate sky using the planetarium software Stellarium. We intend to hire a Navajo artist to design and outline traditional Navajo constellations for our planetarium, and plan to host educational programs talking about these constellations and the cultural heritage surrounding them.

This project also involves updating the current displays at the McCormick Observatory Museum, by replacing the decades-old lightboxes with monitors connected to Raspberry Pi 4s in order to provide dynamic and multiple pictures. By swapping the lightboxes out, we are able to extend the lifetime of the displays, introduce modernized technology to the museum, and allow ourselves more mobility and options when deciding what to display in the museum.

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Introduction

1.1 Raspberry Pi 4 Background

The Raspberry Pi was first introduced in 2012, made by the Raspberry Pi Foundation in the United Kingdom. This small, Linux run computer was made in hopes of allowing for easier access to computer education. (Nuttall, n.d.) Today, many people use them for personal and professional projects, learning how to code, and automation. The fifth iteration of the Raspberry Pi (counting the Raspberry Pi Zero, but not the individual models), the Raspberry 4 is a standard sized Raspberry Pi with a more modernized and cleaner design. It comes in two models, the Raspberry Pi 4B and the Raspberry Pi 400, but the primary focus for this thesis will be the Raspberry Pi 4B.

1.2 Raspberry Pi in Educational Settings

Raspberry Pi's are often used for simple tasks and educational purposes, and are cheap enough to be able to be used in such a manner. In classrooms, Raspberry Pi's are used to teach programming, and are especially useful for learning programming languages such as Python and Java. Outside of classrooms, Raspberry Pi's are perfect for displaying information, or carrying out simple tasks.

1.3 Raspberry Pi in Planetariums and Museums

One example of a Raspberry Pi being used in a Planetarium is for the DeMoor Orrery planetarium. In this orrery, Raspberry Pi Zeros are used to move small cars connected to models of planets in order to move them (Hattersley, 2022). While this is an example of

Raspberry Pi being used for a planetarium, it takes a more physical approach than what we have decided to do.

1.4 Introduction to Ubuntu

Ubuntu is a Linux-based operating system run by a company called Canonical. This operating system is open source, meaning that its source code is open to the public, and anyone can modify it as they see fit. This allows for a more customizable experience that can be designed to fit individual needs. As of May, 2024, Ubuntu is still being supported and updated by its host company. Because of its free cost, easy accessibility, and customizability, Ubuntu is a popular operating system for many programmers. (King, 2022)

Hardware and Software Requirements

2.1 Necessary Components and Software Packages

For this project we have decided to use Raspberry Pi 4B's, and specifically ordered the CanaKit Raspberry Pi 4 Starter Kit. Pulling directly from their website, this kit comes with a "Raspberry Pi 4 Model B with 1.5 GHz 64-bit quad-core ARMv8 CPU and 8GB of RAM, a CanaKit 3.5A USB-C Power Supply with Noise Filter (UL Listed) specially designed for the Raspberry Pi 4 (5-foot cable), CanaKit Premium Black Case, Set of 3 Aluminum Heat Sinks, CanaKit Fan, Micro HDMI to HDMI Cable (6-foot cable), SanDisk 32GB Class 10 MicroSD Card, USB Card Reader Dongle, and CanaKit Quick-Start Guide" (CanaKit, n.d.).

Separately from the CanaKit supplies, you will need a keyboard, mouse, and monitor to effectively use the Raspberry Pi. To use Stellarium, you will need at least Linux/Unix, a 3D graphics card that supports OpenGL 2.1 and GLSL 1.3 or OpenGL ES 2.0, 512 MiB RAM, 600 MiB RAM on disk, a keyboard, and a mouse (Stellarium, n.d.) . While we recommend buying the CanaKit to set up your Raspberry Pi similar to ours, buying the required hardware separately is another viable option. The Raspberry Pi 4 Model B specifications are as follows: “Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.8GHz, 1GB, 2GB, 4GB or 8GB LPDDR4-3200 SDRAM (depending on model), 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE, Gigabit Ethernet, 2 USB 3.0 ports; 2 USB 2.0 ports, Raspberry Pi standard 40 pin GPIO header (fully backwards compatible with previous boards), 2 × micro-HDMI® ports (up to 4kp60 supported), 2-lane MIPI DSI display port, 2-lane MIPI CSI camera port 4-pole stereo audio and composite video port, H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode) OpenGL ES 3.1, Vulkan 1.0, Micro-SD card slot for loading operating system and data storage, 5V DC via USB-C connector (minimum 3A*), 5V DC via GPIO header (minimum 3A*), Power over Ethernet (PoE) enabled (requires separate PoE HAT) ,Operating temperature: 0 – 50 degrees C ambient”. These specifications are all pulled from the Raspberry Pi website for accuracy and convenience, and can be found in the link that follows (https://www.raspberrypi.com/products/raspberry-pi-4-model-b/specifications/) (Raspberry Pi, n.d.).

2.2 Reasoning for Choosing Raspberry Pi 4 and Ubuntu

When figuring out what to use for our planetarium and museum setup, we decided to use Raspberry Pi’s as our computing sources. When we observed the previous planetarium’s setup, we noticed that it used five Raspberry Pi 3’s for its projector setup, and found that the compactness and low maintenance of the Raspberry Pi was perfect for what we wanted to achieve. When we observed the museum's setup, we also noticed that some of the displays were operating on old Raspberry Pi's. While Raspberry Pi's can be low maintenance due to the ability to automate a lot of their processes, the default operating system, Raspbian (or Raspberry Pi OS), was noted to be prone to crashes in cases of long-time use. This was observed in the McCormick Observatory museum setup, and we found that the old Raspberry Pi was not stable for long-time use. As a result of the issues with the old Raspberry Pi, we were recommended to use Ubuntu, a Linux based operating system, for our new Raspberry Pi's, as it is a stable and reliable operating system for the Raspberry Pi to run on for long periods of time. Despite not being the default Raspberry Pi operating system, Ubuntu is easily set up through the Raspberry Pi imager, and its use is supported by Raspberry Pi users through a variety of help forums.

Methodology

3.1 Setting Up Ubuntu on Raspberry Pi 4

This section explains how to set up Ubuntu on a Raspberry Pi 4B through use of the CanaKit's equipment. Using the USB Card Reader Dongle, take the MicroSD card and insert it into the USB Card Reader. Then, insert the USB Card Reader into a laptop or PC. From the laptop or PC, install the Raspberry Pi Imager (https://www.raspberrypi.com/software/). After installing the Raspberry Pi Imager and launching it, it will display a screen that displays the following sections: "Raspberry Pi Device," "Operating System," and "Storage." Starting with "Raspberry Pi Device," you want to choose the Raspberry Pi device that you want to install this on, for this project, we used the Raspberry Pi 4 Model B. Next, under

"Operating System," scroll down to "Other general-purpose OS" and click on Ubuntu. Make sure to choose the latest version for Raspberry Pi 4. Finally, under "Storage," choose the microSD card that you inserted into the computer. Now, once you write the installation (it will take a while), you may safely remove the USB Card Reader and remove the microSD card from the USB Card Reader. Insert the microSD into the Raspberry Pi 4 and boot it up. When it boots up, you should reach a System Configuration process, asking for language, keyboard layout, and timezone settings. Once you fill this out, it will ask you to set up a password. You may choose whatever you like, but the usernames and passwords that are set up on the already configured Raspberry Pi's are:

Username: planetarium **OR** museum (depending on what the Pi has been set up for)

Password: ubuntu

Now, once you are able to log in, the setup for Ubuntu on the Raspberry Pi 4 is complete.

3.2 Putting Together Raspberry Pi 4

This section will cover how to put together the Raspberry Pi 4B through the use of the CanaKit, and may not be an accurate description for equipment used outside of the CanaKit. To start, open up your CanaKit. The first thing you want to do is locate your Raspberry Pi 4B and its casing. Before you do anything, put the Raspberry Pi 4 in its case to ensure proper protection throughout the setup process. Now locate the heatsinks in the plastic bag, and apply them to the appropriately sized chips located on the Raspberry Pi 4. The larger sized heatsink should go on the Broadcom CPU, the medium sized heatsink should go on the SDRAM chip, and the smaller sized heatsink should go on the USB 3.0 Controller. If you need help locating these, there is a user manual located in the CanaKit box that details these components. Now, install the cooling fan located inside of the box onto the Raspberry Pi, and connect the wires to the Raspberry Pi based on the figure in the instruction manual. Once you have done this, you will need to insert the microSD card that we set up in the previous step into the Raspberry Pi. Now, connect your ethernet cable (not in package) to your Raspberry Pi 4. Connecting to Wifi works, but may not provide the stability needed to run the Raspberry Pi for longtime use and is not recommended. Once all of this is done, you should connect your mouse and keyboard to the USB ports on your Raspberry Pi, and then connect the microHDMI plug into the main microHDMI port on the Raspberry Pi (labeled HDMI0). Connect this to an HDMI monitor, TV, or laptop, and ensure that the monitor is on and that the right input is selected. After you have completed all of these steps, connect the 3A USB-C power adapter to the Raspberry Pi 4 board. Now, your Raspberry Pi is ready to be used.

3.3 Installing Stellarium

To install Stellarium on the Raspberry Pi, you must first head to their website (https://stellarium.org/). From there, it should have download links at the top of the page. Our Raspberry Pi's are running Ubuntu, a Linux-based operating system, so we opted for the Linux based download. You can either download the source and build the application, or, Stellarium provides you with a package repository used by opening a terminal and typing "sudo add-apt-repository ppa:stellarium/stellarium-releases" then "sudo apt-get update" followed lastly by "sudo apt-get install stellarium" (https://stellarium.org/files/guide.pdf). This should be all you need to do, and you can run Stellarium by typing in "stellarium" in the terminal. Alternatively, they have a web option which is another viable option as long as you are connected to the internet. This option eliminates the need to download Stellarium, and works just as well as the downloaded version without the need to install updates.

Implementation

4.1 Physical Setup for the Rotunda Planetarium

The Rotunda Planetarium is located inside of the Rotunda dome on the top floor. Up there, there are five projectors each connected to a Raspberry Pi in order to project 5 images into one combined projection. There is a set of pull down stairs that you can use to get access to the five projectors and Raspberry Pi's set up to display the planetarium. In order to go up to the top floor of the Rotunda, you must talk to somebody at the front desk in order to get access to the top floor, as it is not available to the public. Once you are there, you should see five projectors spread out strategically around the base of the dome. These are not recommended to be moved, as they have been measured to provide a streamlined picture when combined. The Raspberry Pi's are located underneath the projector, and these can be swapped out with new Raspberry Pi's when needed. There is a laptop connected to all of the projectors that is required to enable all five to act together, that can be used to automate the process, and that is also located at the base of the Rotunda dome.

4.2 Physical Setup for the McCormick Observatory Museum

The McCormick Observatory museum is five rooms inside of the McCormick Observatory, with possible plans to add more. As a part of these expansions and improvements, we are updating the lightboxes which display pictures of stars and galaxies that are decades old.

These lightboxes are located on a large display shelf on the wall closest to the equatorial room of the observatory. We put monitors connected to the Raspberry Pi's in these display shelves, which measure out to be 24.25in horizontally, 15in vertically, and 28.25in diagonally. In this case, the shelves are quite deep, so the length/depth of the display shelves should not matter for this.

Results

5.1 Functionality and Usability of the Planetarium and Museum Displays

The usage of these Raspberry Pi's for the planetarium and museum displays was an important, yet rewarding decision. The mobility and simplicity of the Raspberry Pi 4B allows for easier maintenance and performance while still being able to connect to Stellarium and display images in the way that we set out to do. Being computers, the Raspberry Pi's are flexible and customizable, and are a new, modern way to approach museum displays. As the Raspberry Pi's are currently set up, they can quickly be configured in multiple ways based on user preferences to assist with future use and expansion. While the project has not been fully realized, this will allow for an easier transition between project members.

5.2 Problems Faced Along the Way

While carrying out this project, we encountered a few problems. At the Rotunda, we tested different methods of displaying the planetarium onto the inside dome of the Rotunda. Specifically, we attempted to use one large upwards projection system, but found that, no matter what, it produced too faint of a picture to be easily seen. This caused us to follow in the footsteps of the original planetarium design: putting five Raspberry Pi's, each connected to a separate projector, around the base of the dome in order to combine their pictures into one fully realized projection. At the museum, when observing the Raspberry Pi that was currently set up for display, we noticed that it often crashed and rebooted, and did so to the point that no display powered by the Raspberry Pi could reliably stay up. To combat this, we have set up the new Raspberry Pi 4B's with the Ubuntu OS to provide a more stable environment for the displays. We also encountered an issue with the display dimensions, and while we have figured out an appropriate size of monitor to fit in the displays, there is the problem of including a mount in order for the monitor to stay safely in place. This problem has not been solved yet, but should be noted for future endeavors.

Discussion

6.1 Analysis of the Effectiveness of Using Raspberry Pi

Within the last decade, the Raspberry Pi has emerged as a cost-effective, versatile alternative to laptops and PCs. While not able to output the same amount of power as a standard laptop or PC, the Raspberry Pi makes up for it with its simplicity, low maintenance, compact size, and extremely low cost. With these features, Raspberry Pi has picked up the attention of educational institutions, scientists, and at-home DIYers for implementing innovative projects and ideas.

As discussed in Section 2.2, we chose to use Raspberry Pi 4's set up with Ubuntu because of their compactness, simplicity, and low maintenance. By using the Raspberry Pi's, we aim to establish a more interactive planetarium and museum experience that can further enhance public education on astronomy and cultural heritage.

6.2 Comparison with Traditional Planetarium and Museum Setups

A traditional planetarium looks a lot different than the one in the Rotunda. While many planetariums in the present day are opting to use digital displays, traditional planetariums used optical-mechanical (OM) planetarium projectors. These projectors are complex, star-ball shaped machines capable of projecting both hemispheres in a single unit. While we certainly don't have the resources to be able to use one at the University of Virginia at this time, the Raspberry Pi system that we designed is more than capable of achieving what we set out to accomplish.

Museums often use a variety of ways to display their contents, and some of these ways employ the use of a Raspberry Pi. Because Raspberry Pi's are cheap and compact, they are a popular option for museums, as they can be used solely to display images that can either be still, changing, or even interactive. Raspberry Pi is also mostly open source, and there are packs created by users designed specifically for use in museum displays. This causes it to be a great option when considering use of a Raspberry Pi for a museum display.

Conclusions

7.1 Summary of Key Findings

The utilization of the Raspberry Pi 4B devices for setting up a planetarium in the Rotunda dome and for museum display at the McCormick Observatory Museum at the University of Virginia has demonstrated considerable promise and effectiveness at creating an educational experience that combines astronomy with cultural heritage. Through a comprehensive analysis of the project, several key findings have been found. The cost-effectiveness and overall accessibility of the Raspberry Pi 4 has allowed for the creation of new educational projects with limited budgets to be possible, and has proved to make educational endeavors in astronomy more attainable to educational institutions, smaller departments, and museums. Raspberry Pi's have shown satisfactory performance and stability in delivering proper functionality when being set up for the museum and planetarium. The flexibility of the Raspberry Pi systems allows for more diverse customization when setting up the planetarium and museum displays. This flexibility will be crucial to long term use of the system as it allows for implementation of further innovations and adaptivity to evolving technologies and educational needs. In light of these findings, it is clear that the Raspberry Pi is a viable and promising solution to implementing modern and innovative designs and systems at educational institutions and museums. However, it is important to notice the performance issues in the Raspberry Pi's when put under a heavy processing load, as a Raspberry Pi will not have the same processing power as a laptop or computer. This should not be a problem for projects such as this one, where Raspberry Pi's are being delegated to perform a single function.

7.2 Implications of the Project for Education and Outreach

The successful implementations of the Raspberry Pi-based planetarium and museum displays has the potential to significantly enhance the educational experience of students in not only astronomy, but history and cultural heritage as well. By providing this interactive environment for education, this project promotes an active engagement in the source material, and aims to inspire exploration and curiosity within the field of astronomy. This project also aims to make STEM education more accessible to the average student, and brings such educational endeavors to the most popular site on University of Virginia grounds, the Rotunda. The planetarium and museum displays serve as valuable resources to the community of UVA and Charlottesville, providing opportunities for the public to access education in astronomy in an easily accessible, engaging, and inclusive manner. By offering public events and outreach programs, the project has the possibility to expand its impact beyond the scope of the astronomy department to more diverse audiences. Not only this, but the project promotes collaboration between the astronomy department and different groups, and future endeavors may be built upon the baseline that is established by this project.

7.3 Last Notes

I, Zachary Wood, give permission for this project to be changed and expanded upon. As of right now, this project is a work in progress and is designed to be built even further. If you have any questions or need to reach me, I can be reached via email at zrw8jd@virgina.edu, or via text at (540)-359-1468.

References

Bromley, A. E. (2019, November 1). *Ph.D.. students transform rotunda into planetarium, realizing jefferson's vision*. UVA Today. https://news.virginia.edu/content/phd-students-transform-rotunda-planetarium-realizing-jeffersons-vision

CanaKit Raspberry Pi 4 starter kit. CanaKit. (n.d.). https://www.canakit.com/raspberry-pi-4-starter-kit.html

Hattersley, L. (2022, January 27). *Demoor Orrery Planetarium | the MAGPI #114 - raspberry pi*. Raspberry Pi. https://www.raspberrypi.com/news/demoor-orrery-planetarium-the-magpi-114/

How to install ubuntu desktop on raspberry pi 4 | ubuntu. Ubuntu. (n.d.). https://ubuntu.com/tutorials/how-to-install-ubuntu-desktop-on-raspberry-pi-4

King, B. (2022, February 23). *Introduction to ubuntu 20.04: A beginner's guide*. DigitalOcean. https://www.digitalocean.com/community/conceptual-articles/ubuntu-20-04-beginners-guide

Nuttall, B. (n.d.). *What is a Raspberry Pi?*. Opensource.com. https://opensource.com/resources/raspberry-pi#:~:text=Raspberry%20Pi%20is%20the%20name,and%20variations%20released%20since%20then

Raspberry pi 4 model B specifications – raspberry pi. Raspberry Pi. (n.d.). https://www.raspberrypi.com/products/raspberry-pi-4-model-b/specifications/

Stellarium Astronomy Software. (n.d.). https://stellarium.org/

Stellarium web online star map. Stellarium Web Online Star Map. (n.d.). https://stellarium-web.org/