Callisto-Pi: Callisto Spectrograms from Raspberry Pi

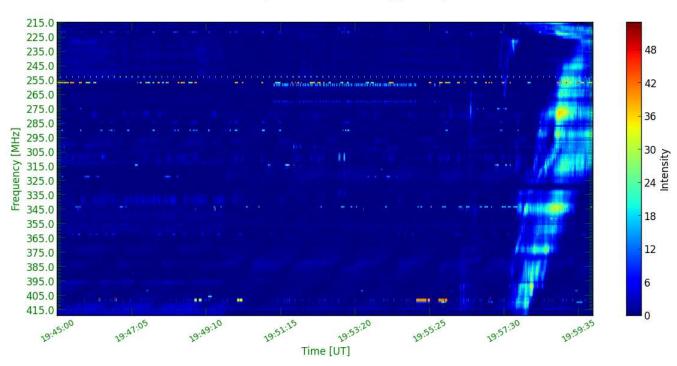Whitham D. Reeve

1. Introduction

This paper describes how to use the inexpensive Raspberry Pi computer to automatically produce spectrogram images in near real-time from Callisto FITS data files (figure 1). In this article the hardware is called RPi and the hardware together with software is called Callisto-Pi. The RPi is used rather than a Windows desktop PC because the installation and operation on a Windows PC of the many Python libraries and dependencies needed for Callisto-Pi would require huge effort and time and have a low probability of success. All libraries were originally written for the Linux operating system and run naturally on the RPi whose operating system is based on Linux.

My involvement in developing this application was merely as project manager. Others did all the hard work (see **Acknowledgements** at the end). As a service to Callisto users I have made available an RPi hardware platform with a preprogrammed 8 or 16 GB memory card setup to run Callisto-Pi (see **Contact Information** at the end). Real-time spectrograms produced by Callisto-Pi may be viewed at {Reeve} and {Nelson}.The Callisto-Pi project is a follow-up to my LWA TV Raspberry Pi project described at [RvLWATV].

Note: Internet links in braces { } and references in brackets [ ] are provided in **section 7**.

Figure 1 ~ Image of the first Callisto spectrogram produced by Callisto-Pi from a FITS file over a 15 minute interval starting at 1945. It shows a Type II radio burst on 16 April 2014 at 1957; the horizontal bands are radio frequency interference, mostly from TV broadcast stations. The vertical axis is frequency and horizontal axis is time. Color indicates intensity relative to the background noise level. See text for additional details. (Image © 2014 W. Reeve)

The standard file format for data produced by the e-Callisto solar radio spectrometer network is the NASA-designed Flexible Image Transport System {FITS}. Archived and current data and spectrogram images for all Callistos that participate in the network are available online at {CallistoData}. These data and images generally are accessible within 30 to 120 min after the FITS files are produced at a given Callisto station. However, there often is a need to prepare spectrograms in near real-time for local viewing or for posting on a user's website. Callisto-Pi meets this need at low complexity and cost.

A Callisto spectrogram simultaneously shows three pieces of related information – frequency, time and received intensity. Frequency is shown on the vertical axis in MHz with the low frequency limit at the top. Callisto-Pi automatically scales the spectrogram frequency scale between 10 and 870 MHz according to the frequency data in the FITS file. Time is shown in Coordinated Universal Time (UTC) on the horizontal axis in HH:mm:ss, progressing left to right. Most Callisto spectrograms cover a 15 min interval starting at HH:00:00, HH:15:00, HH:30:00 and HH:45:00 throughout local daylight hours. Intensity is a relative scale indicated by colors. Darker colors (blue) indicate lower intensities and lighter colors (green, yellow, orange, through red) indicate progressively higher intensities. The scale is logarithmic (nonlinear in absolute power) so the color indicates the relative power in dB of each frequency-time pixel.

2. Raspberry Pi and Callisto-Pi

Hardware: The Raspberry Pi is a low-cost, small computer platform designed for educational purposes by the Raspberry Pi Foundation {RPi}. The RPi can be plugged into an ordinary computer monitor or TV and can use a wired Ethernet connection or WiFi wireless access device for LAN and internet access and a wired USB or Bluetooth wireless keyboard and mouse. However, the RPi used in Callisto-Pi is operated "headless" in which no monitor, keyboard or mouse is required for setup or operation. Callisto-Pi requires an internet connection if spectrogram images are to be sent to and viewed on an internet website.

Figure 2 ~ Raspberry Pi model B and B+ hardware. The model B+ is shown in an aluminum enclosure with USB WLAN and BlueTooth dongles (left) and with no enclosure (middle). The model B (right) also is in an aluminum enclosure. The interfaces vary slightly between the model B and B+ but Callisto-Pi works on both models. Enclosure dimensions are approximately 100 x 65 x 25 mm. (Image © 2014 W. Reeve)

The RPi hardware has become available in four versions – original model A (not generally available in North America), model B, model B+ and model 2. Callisto-Pi has been tested only with the model B, B+ and 2 (figure 2), and there is no advantage of one over the other. The RPi uses an SD memory card (B) or micro-SD memory card (B+) for program storage. Refer to [Reeve] or online search for a more detailed hardware description.

Software: Callisto-Pi uses a software image on the memory card that includes the operating system and Python software applications, libraries and support files. The operating system is based on a Raspbian distribution. Callisto-Pi uses relatively simple scripts to call Python libraries and routines. The bulk of the work is done by three libraries: SunPy {SunPy}, which processes the FITS files; MatPlotLib {MatPlotLib}, which plots the spectrograms as PNG image files; and Optipng {Optipng}, which optimizes (reduces) the size of the image file for web use.

3. Basic Operation

The system block diagram shows how the various components work together (figure 3). An ordinary Windows PC controls the CALLISTO instrument. It typically produces a FITS file at 900 s (15 min) intervals as determined by the Callisto configuration file.
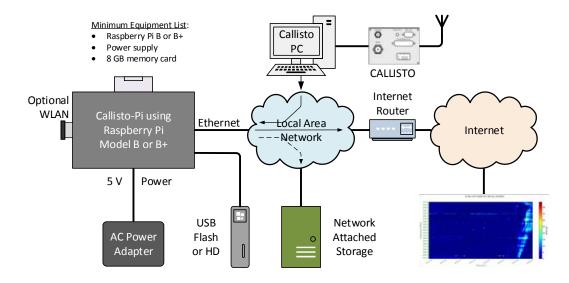

Figure 3 ~ System block diagram. Callisto-Pi collects FITS files from the Callisto PC, processes them and then sends the spectrogram images to a website and archive storage. (Image © 2014 W. Reeve)

The Callisto PC is configured to send each new FITS file to Callisto-Pi, which acts as an adjunct spectrogram processor to produce an image file. After producing the image file, Callisto-Pi sends it to a website (or any FTP server) for viewing. These images are produced as picture.png files and are disposable; that is, each new image overwrites the previous image. Callisto-Pi also produces and sends a date- and time-stamped copy of the image (based on the original FITS date and time) to local Network Attached Storage (NAS) or, alternately, to a USB flash or hard drive connected to the RPi.

For the RPi model B and B+, the production time for a spectrogram image is about 1 minute after Callisto-Pi receives a new FITS file. Optimization requires another 4 minutes. Therefore, Callisto-Pi requires approximately

5 minutes from the time it receives a new FITS file to the time it sends the PNG file to a web server. Archiving usually requires less than 1 minute. The RPi model 2 has higher performance than the model B or B+ and reduces the total processing time by a couple minutes.

Two program functions embedded in the Raspbian distribution called *crontab* and *launcher.sh* control Callisto-Pi actions. Crontab loads and runs when Callisto-Pi is powered up and whenever it is rebooted. Crontab then loads launcher, a shell (command line interpreter) with a list of actions and routines that produce and send the images. Underlying these activities on the RPi are FTP server and client functions that load automatically and operate in the background.

4. Spectrogram Production

The scripts used to run Callisto-Pi are relatively simple because the SunPy and MatPlotLib libraries do all the complicated work "under the hood". The user needs to tell the Callisto PC where to send the FITS files and to tell Callisto-Pi where to send the processed images (figure 4). A *CallistoSpectrogram* function in the SunPy library is called to calculate the background noise level for each new FITS file and then to subtract that level before the spectrogram is produced. Thus, the displayed intensities are relative to the calculated background. The displayed intensities follow a standard color map for solar imaging originally developed for the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) spacecraft mission.
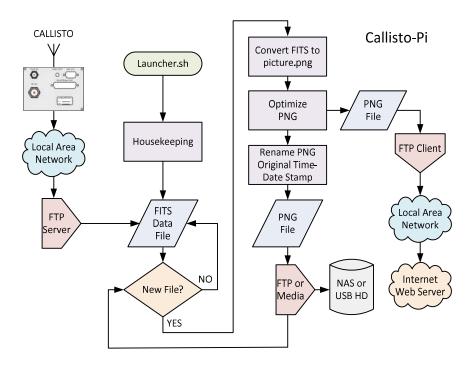

Figure 4 ~ Callisto-Pi flowchart. A launcher script collects data and controls production of the spectrogram images and then sends the images to a web server and archive storage. (Image © 2014 W. Reeve)

When there is considerable radio frequency interference in the data, the background calculation can limit the displayed intensity range and weak solar radio bursts or other natural phenomena in the data may be masked by

the noise. However, each file is calculated separately. Therefore, the background calculation has no memory beyond the current spectrogram and there are no lingering effects beyond the 15 min data interval.

5. Installation and Operation

Callisto-Pi uses stock RPi hardware with no modifications. The software image is contained on an 8 or 16 GB memory card. As mentioned earlier, a display, keyboard and mouse are not required. All setup can be performed from a Windows PC running a Secure Shell (SSH) terminal program such as PuTTY or Tera Term. Complete step-by-step instructions are included with the Callisto-Pi Package.

Before use, the launcher shell script in Callisto-Pi needs to be setup for the user's specific environment. This is done with a built-in editor in Callisto-Pi. Also, external devices need to be setup to send files to and receive files from Callisto-Pi. In summary, it is necessary to
- Setup the Windows PC running Callisto software to send FITS files to Callisto-Pi
- Edit the launcher for the user's specific Callisto-Pi environment including LAN and WAN addresses and login details.
- Setup the external webserver to receive and display Portable Network Graphics (PNG) images from Callisto-Pi (this typically is an internet or intranet web server)
- Setup a local NAS or USB-drive for archive storage of PNG files

6. Conclusions

Callisto-Pi is a small, inexpensive, maintenance-free platform that produces near real-time spectrogram images from Callisto FITS files. It has applications with any CALLISTO instrument where a user wishes to produce their own images for posting and display on a website. No programming is required. A built-in editor is used to configure the Callisto-Pi for the user's specific environment, including LAN and web server addresses and archive storage.

7. References and Web Links

[RvLWATV]   Reeve, W., *LWA TV on the Raspberry Pi*, Society of Amateur Radio Astronomers, Radio Astronomy, September-October 2014

{CallistoData}   http://soleil.i4ds.ch/solarradio/callistoQuicklooks/
{FITS}   http://fits.gsfc.nasa.gov/fits_home.html
{MatPlotLib}   http://matplotlib.org/
{Optipng}   http://optipng.sourceforge.net/
{Python}   https://www.python.org/
{Reeve}   http://www.reeve.com/e-CALLISTO/Callisto_Spectrogram/CallistoSpectro_simple.html
{Nelson}   http://www.roswellmeteor.com/e-Callisto2/picture.png
{RPi}   http://www.raspberrypi.org/

{SunPy}   http://sunpy.org/

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Ordering Callisto-Pi: A Calllisto-Pi Package may be ordered by sending an email inquiry to the address right; be sure to put something meaningful in the email Subject line or else the email will be automatically deleted by the server.

OrderInfo@reeve.com

The Callisto-Pi Package includes the RPi model B+ in an aluminum enclosure, preprogrammed 8 or 16 GB memory card and 10 W power supply with interchangeable worldwide ac input plugs. The preprogrammed memory card also is available without the RPi hardware. The memory card is supplied as a micro-SD memory card in a full-size SD card carrier (adapter), so it will work in either the model B, B+ or 2. Instructions for the necessary user setup are provided with the Callisto-Pi Package.

Prices:

Callisto-Pi Package: 143 USD plus postage

Callisto-Pi memory card: 20 USD plus postage.

Document information

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Revision: 0.0 (Original draft started, 22 Nov 2014)

             0.1 (Revisions to simplify discussion, 04 Jan 2015)

             0.2 (Updated text, 06 Jan 2015)

             0.3 (Completed 1st draft, 12 Jan 2015)

             0.4 (Minor revisions, 16 Jan 2015)

             0.5 (Final revisions to 1st draft, 17 Jan 2015)

             0.6 (Added frequency scale, 22 Jan 2015)

             1.0 (Distribution, 25 Jan 2015)

             1.1 (Minor edits, 06 Feb 2015)

             1.2 (Added RPi 2, 25 Jul 2015)