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Photography and Computer Vision with the Raspberry Pi Camera

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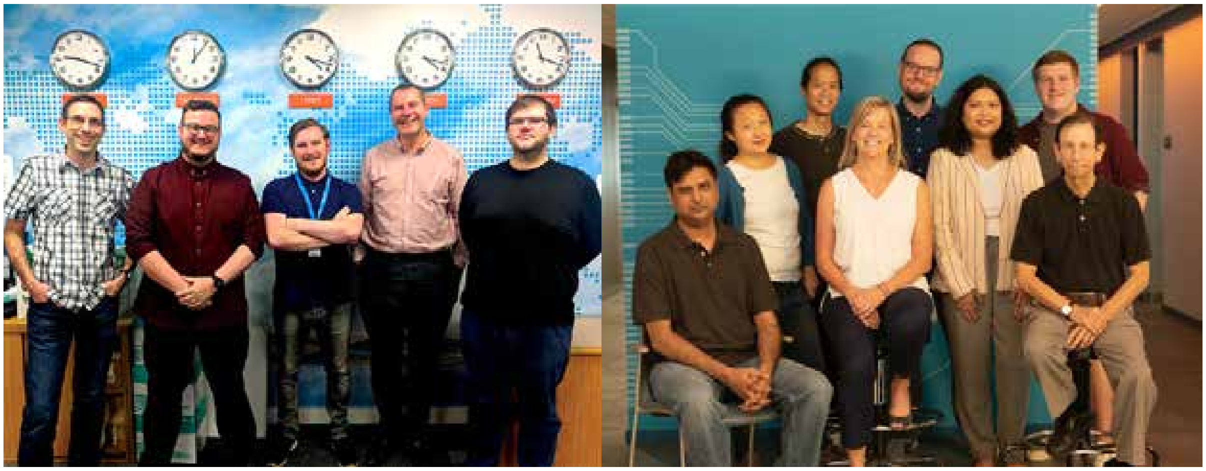
element14 is a Community of over 800,000 makers, professional engineers, electronics enthusiasts, and everyone in between. Since our beginnings in 2009, we have provided a place to discuss electronics, get help with your designs and projects, show off your skills by building a new prototype, and much more. We also offer online learning courses such as our Essentials series, video tutorials from element14 Presents, and electronics competitions with our Design Challenges.

Digital photography has improved by leaps and bounds since its introduction, with camera specifications matching or exceeded film and even the human eye. These advancements bring new opportunities, such as image analysis, object detection, automation, and AI. This eBook discusses photography and videography with the Raspberry Pi, including tutorials, example applications, and more.

element14 Community Team



CHAPTER - 1 Introduction

The Raspberry Pi was launched ten years ago as an educational platform designed to get kids interested in the STEM fields. It has since become one of the most popular development boards on the market. The Raspberry Pi Foundation's latest flagship board, the Raspberry Pi 4 Model B, comes equipped with a 1.5 GHz 64-bit quad-core ARM Cortex-A72 processor, onboard 802.11ac Wi-Fi, Bluetooth 5 and full gigabit Ethernet. It also features a pair of USB 2.0 ports, two USB 3.0 ports, up to 8 GB of RAM, and dual-monitor support via two micro-HDMI (HDMI Type D) ports that can output a 4K resolution.

The board packs more than enough hardware to drive just about any project, including photography and machine vision applications. In fact, the Foundation has released several camera modules and add-on devices to help facilitate those imaging-based projects. In 2013, the Foundation and the distributors' RS Components & Premier Farnell/element14 launched the Raspberry Pi camera module alongside a firmware update, allowing it to run on the Pi. Before the camera module, it was possible to access a camera feed on the Raspberry Pi using a suitable webcam.

That said, camera functionality had already worked its way into a variety of projects, from live weather monitoring to robotics. However, the clever folks at the Raspberry Pi Foundation were aware that if the highly enthusiastic Raspberry Pi community were willing to repurpose their existing webcams, an add-on camera module would indeed offer a chance of success.

CHAPTER - 2 Comparison of Raspberry Pi Cameras

Raspberry Pi Camera V2

Figure 2: The Raspberry Pi 8-megapixel Camera Module 2 provides a wide variety of video and still image resolutions using the Sony IMX219 sensor.

The Foundation currently has three camera modules in its toolbox, each with different specifications and feature sets. The original camera is no longer available and was retired in 2016. That model was replaced with the Camera Module 2, which features a Sony IMX219 8-megapixel sensor and is capable of producing 1080p (30 fps), 720p (60 fps) and 480p (90 fps) video, in addition to 3280 x 2464p still images. The image sensor used on this model offers a 10-bit A/D converter (on chip), back-illuminated CMOS, PLL on-chip, 2-wire serial communication, CSI-2 serial data output (selection of 4lane/2lane) and provides 30 frames/s in all-pixel scan mode.

The camera has a wider angle of view over the original, as the lens has a lower focal length of just 3.04 mm. This means users can get more in the frame, and the images have a reduced grain effect prevalent in the original due to the lower resolutions. The Camera Module 2 can be used with all Raspberry Pi development boards (1, 2, 3 and 4) using the same CSI port. It can also function on the Pi Zero line; however, doing so requires the Pi Zero cable, as the standard ribbon cable is not compatible. The Foundation added another camera under the same moniker as the Camera Module 2, known as the Camera Module

2 NoIR, and while it features the same technology, it omits the IR filter, meaning it can "see" in the dark (hence the No Infrared) with IR lighting.

In 2020, the Foundation launched its Raspberry Pi High Quality Camera outfitted with Sony's 12.3-megapixel IMX477 sensor, with a 7.9mm diagonal image size, back-illuminated sensor architecture, with an adjustable back focus and support for C- and CS-mount lenses. The camera provides an alternative to the Camera Module V2 for industrial and consumer applications, including security cameras, which require a high level of visual fidelity and/or integration with aftermarket optics. These include CGL 6 mm CS-mount and 16 mm C-mount lenses.

The camera is also much larger than previous models, measuring 38mm square, versus 24mm by 23mm for the V2. This is due to the interchangeable aluminum C mount where compatible lenses can be screwed into place. The High Quality camera also offers a RAW12/10/8, COMP8 output, an adjustable back focus from 12.5 mm to 22.4 mm and an integrated cut IR filter. Photographers will appreciate the integrated tripod mount on the bottom of the C mount, which is ideal for stable imaging, astrophotography, tracking, CCTV and more.

While any off-the-shelf C- and CS-mount lenses will work with the new sensor, Raspberry Pi has partnered with retail partners to carry a pair of lenses: a 6mm CS-mount lens and a 16mm C-mount lens. Of course, there's always the option of 3D printing and purchasing third-party adapters to create unique combinations for any number of projects. As with the other Pi cameras,

RPI-6MM LENS

Figure 3: The RPI 6mm lens is designed for the Pi High Quality Pi Camera module and features an F 1.2 aperture and a ½ inch image format.

the HQ platform is compatible with most Raspberry Pi boards but does need the Zero cable to function with the Zero line of development boards.

Official hardware isn't the only platform that works with the Raspberry Pi for taking images and video; off-the-shelf webcams can also be utilized without spending much money. As long as the camera features a CSI connection or an aftermarket adapter, it should function within the camera's specified parameters. Most webcams will use a USB port to offload video and still images for processing, but the Raspberry Pi should also be able to handle those loads. This also means users don't have to utilize the CSI port found on nearly every Raspberry Pi, although the tradeoff comes with higher latencies and performance.

CHAPTER - 3 Taking Photos and Videos

After choosing a Raspberry Pi development board and procuring the best camera platform, it's time to get the system together and set up to get the best images and video. Most of the boards in the Raspberry Pi lineup and the official Pi cameras will connect using the included CSI ribbon cable. Consult the corresponding manual for connecting a webcam, but most will connect via USB, and others can also take advantage of the CSI port.

Once the hardware is connected, it's time to start up the Raspberry Pi and configure the camera. The Raspbian

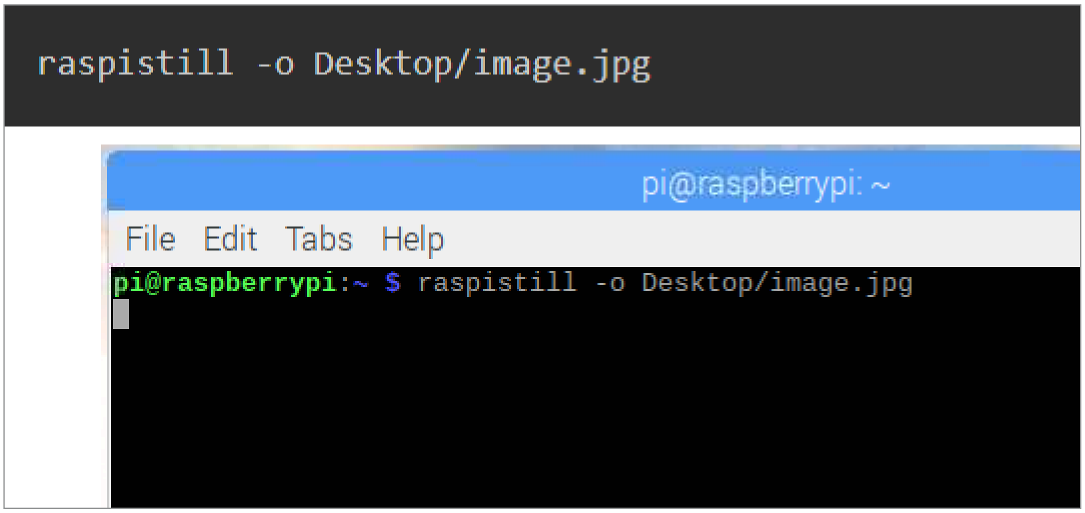


Figure 4: Opening the terminal and entering command lines allows users to test and operate connected cameras using text-based inputs. Image source: raspberrypi.org

OS (Operating System) is the preferred software for the Pi, but any Linux-based system will also work. Once the OS loads, go to the main menu and select Preferences, then Raspberry Pi Configuration. Select Configuration and make sure the camera is enabled, then Reboot the Pi. The camera should be connected, and the software enabled, meaning the user can now enter some simple command lines and take a few test images and videos.

First, open a terminal by clicking on the black monitor icon in the taskbar, then type the following command line to take a still image and save it to the desktop: raspistill -o Desktop/image.jpg. Then press 'enter' to run the command. This will open an image preview for 5 seconds before a still image is taken. Now look for the picture file icon on the desktop, and double-click the file to open the image.

Adding different options allows users to set the size and look of the image the raspistill command takes. For example, adding an -h and -w will change the height and width of the image: raspistill -o Desktop/image-small.jpg -w 640 -h 480. The same can be done for video by substituting raspivid for raspistill, then entering the command line: raspivid -o Desktop/video.h264. To play the video file, double-click the video.h264 file on the desktop, which will then open the VLC Media Player for playback.

Users can also control the camera using the Python programming language, which is open-source and uses the same command line entry system. What's more, the Foundation has an extensive Python library for controlling anything connected to the Pi. Several Python-based apps can be utilized to control cameras, but for simplicity, we'll use the Thonny Python IDE. Once the editor is open, open a new file and save it as: camera.py

Now enter the following code:

```
from picamera import PiCamera
from time import sleep

camera = PiCamera()

camera.start_preview()
sleep(5)
camera.stop_preview()
```

Save and run the program, and it should produce a five second preview, then close again. At this point, the preview will only show if the Raspberry Pi is connected to a monitor. If the preview is upside down, it can be reoriented by 180° using the following command:

```
camera = PiCamera()
camera.rotation = 180
```

Users can also rotate the image by 90°, 180° and 270° by resetting the image: set rotation to 0°. What's more, the preview can be made opaque (or slightly see-through) by setting an alpha level: camera.start_preview(alpha=200) The alpha value can be any number between 0 and 255. Users can amend the code using camera.capture() and take some still images using the command line:

```
camera.start_preview()
sleep(5)
camera.capture('/home/pi/Desktop/image.jpg')
camera.stop_preview()
```

Users should see the camera preview open for about five seconds, and a still image should be produced and saved to the desktop. Users can also create a loop that allows them to take five images in a row:

```
camera.start_preview()
for i in range(5):
    sleep(5)
    camera.capture('/home/pi/Desktop/image%s.jpg' % i)
camera.stop_preview()
```

The variable *i* in the fourth line is used to count how many times the loops have run, in this case, 0 to 4, which is denoted as image0.jpg and image1.jpg, and so forth. Recording video is done in the same fashion as images, only remove the line capture() and add start_recording(). The code should now look like this:

```
camera.start_preview()
camera.start_recording('/home/pi/Desktop/video.h264')
sleep(5)
camera.stop_recording()
camera.stop_preview()
```

The Python programming language also incorporates many effects and configurations to adjust images and how they appear. It's important to note that some settings only affect the image preview, while some only affect the captured image. Other settings affect both. That said, one of the great features of altering images is resizing them. The default resolution is 2592×1944 for still images (min is 64x64) and 1920×1080 for video recording. Users can adjust the image for the max resolution using the following code:

```
camera.resolution = (2592, 1944)
camera.framerate = 15
camera.start_preview()
sleep(5)
camera.capture('/home/pi/Desktop/max.jpg')
camera.stop_preview()
```

Adding text is pretty simple as well; just add the command annotate_text. Try entering these command lines to add text:

```
camera.start_preview()
camera.annotate_text = "Hello world!"
sleep(5)
camera.capture('/home/pi/Desktop/text.jpg')
camera.stop_preview()
```

Users can also adjust the text size by adding camera.annotate_text_size = 50. The size can range from 6 to 160, but has a default setting of 32. It's also possible to change the color, brightness, and contrast, and add effects such as emboss, watercolor, cartoon and more. Exposure modes and white balance can also be utilized using the Python IDE.

CHAPTER - 4 Raspberry Pi Camera Projects

There are a limitless number of projects that can be created with a Pi and a camera. This section features several interesting creations and how they were made, ranging from sky trackers to remote pet monitoring.

ALL SKY METEORITE CAMERA BUILD

Raspberry Pi enthusiast jippo12 created an automated celestial event tracker using a pair of Raspberry Pi boards and a High Quality camera. The rig operates using a Raspberry Pi 4 and a 13.2-megapixel HD camera with 180° lens. His goal was to build a fully automated night sky meteorite camera within a weather-proof enclosure with temperature control to keep the setup working in adverse weather.

After several days of testing using a single Pi 4 outfitted with Meteotux PI, a program to continuously record nighttime images, jippo12 added a second Raspberry Pi (Pi 3+) and a V2 color camera with relay controller HAT and temperature sensor. "Both Raspberry PI's run with Raspberry PI OS lite. They are automated to run Meteotux

Figure 5: The fully automated All Sky camera uses a pair of Raspberry Pi boards and an HQ camera to capture night sky events. Image source: [jippo12]

PI when sunset and stop when sunrise," states jippo12 on his project blog. "This is done with basic Python script that uses the Python3 runtime library. Images are saved to ~/meteotuxpi/images/, and after images are ready in the morning, they are moved to NAS storage with wlan+sftp."

It's important to note that Meteotux Pi doesn't take video, but creates stacked images without losing any frames from the camera. For example, users can set the camera to take one image every 10 minutes, but that single image contains every frame from 0 seconds to 10 minutes. These are then stacked together in one image.

REMOTE BIRDING WITH TENSORFLOW LITE AND RASPBERRY PI

Rob Lauer wanted to find a way to watch birds taking advantage of his bird feeder, but found himself sitting in front of a display most of the time instead of gazing at nature. Rob decided to build a remote bird-watching platform using the Raspberry Pi, Pi camera and TensorFlow to identify the birds that visit the feeder. He also incorporated cellular connectivity because the feeder was outside his Wi-Fi range. To power the unit, he added solar panels.

For his remote birdwatching platform, Rob went with the Raspberry Pi 4 and the Pi camera V2 for image and video capturing and processing. Both are compatible out-of-the-box. For cellular capability, he tasked Blue's Wireless Notecard, a cellular and GPS-enabled device-to-cloud data pump outfitted with a Cortex-M4-based SoC (System on a Chip) and 500 MB of storage. Blue's Wireless also set him up inexpensively with ten years of cellular service.

The Raspberry Pi and Notecard are connected via a Notecarrier-Pi HAT with passthrough headers, making for a streamlined build, even with the camera connected. Moreover, the Notecard comes preconfigured to securely communicate with Blue's Notehub.io wireless service, which provides a secure device-to-cloud data transfer. All the hardware was secured into an Awclub ABS junction box that offers a level of protection in outdoor environments and is powered by a 30000mAh battery.

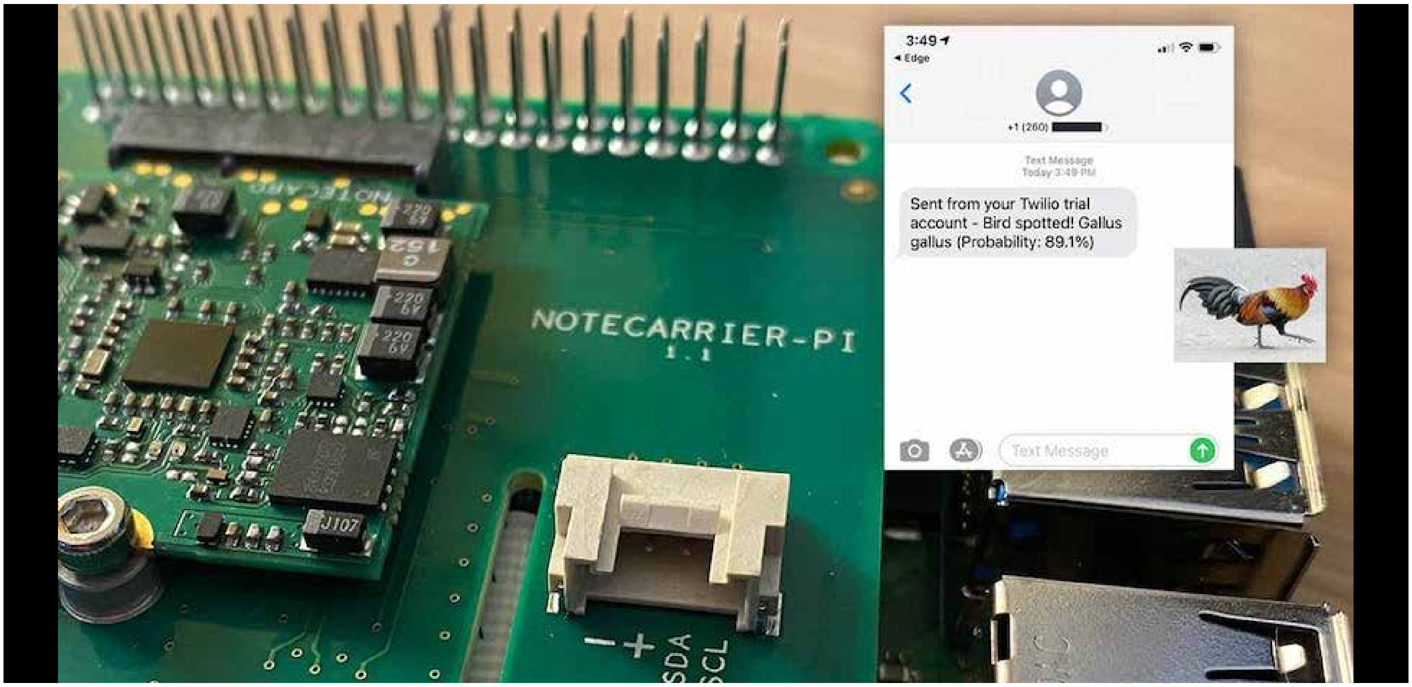


Figure 6: The bird-watching platform uses a Raspberry Pi and machine learning to identify birds in remote areas using a cellular connection. Image source: [Rob Lauer]

RASPBERRY PI SECURITY CAM NETWORK

One of the most popular projects for which to employ the Pi camera is a security system, which can be simple or highly complex depending on the requirements. Angus Young created a simple security system with his Raspberry Pi Security Cam Network, an affordable option and is an excellent introduction to camera networking.

The build is pretty straightforward and uses a Raspberry Pi 4 Model B development board, a Pi Camera Module V2, a Pi case, an Ethernet cable (or Wi-Fi), a power supply and a micro-SD card. The camera connects to the Pi via the CSI port, and the electronics are housed in an acrylic case, which is all the technical know-how users will need for this setup.

The MotionEye OS drives the security system and allows for imaging, video and even stop-motion if needed. Users will find setting up the system easy as well and includes grabbing the hostname of the network being used, logging in as an administrator, then accessing the camera stream. Adding additional cameras is also easy and requires setting adjustments within the OS after connecting additional cameras to the Pi, or setting up multiple units with their own development boards and cameras, then connecting them to the MotionEye network.

Figure 7: The Raspberry Pi Security Camera Network is an easy security solution that's motion activated and can be viewed over a network. Image source: [Angus Young]

PROJECT GOLDIE (REMOTE FISH TANK CONTROLS)

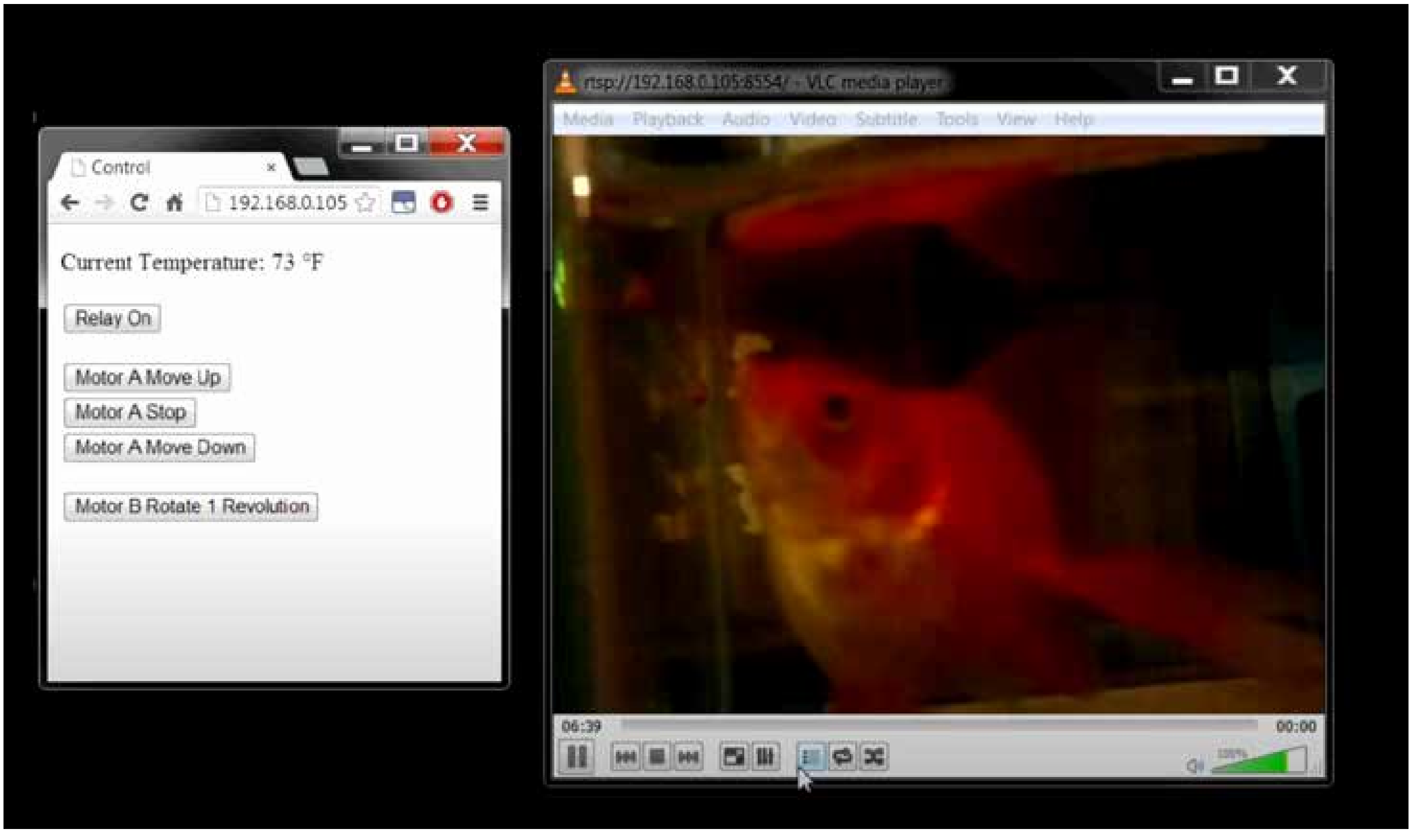


Figure 8: Project Goldie is a remote fish viewing platform with environmental data gathering and an automated feeder. Image source: element14.com

The Raspberry Pi Remote Fish Tank Controls (AKA Project Goldie) is a remote monitoring and feeding system for fish and other aquatic animals. The platform allows users to monitor water conditions and the surrounding environment (temperature) to maintain optimal conditions and features an automatic feeder and camera system that allows users to see and feed pets remotely. While that may sound like an easy build, it does take a certain level of skill and coding knowledge to put it together.

The Pi Remote Fish Tank Controls uses the Raspberry Pi Model B, an Arduino Uno, a Pi Camera module and waterproof digital temperature sensors to monitor water. It also features a fish tank feeding wheel, stepper motor, relays, linear slide actuator, switching power supply and various electronic components. As with any project, the build is still evolving, but a list of materials and schematics have been uploaded (linked above) for anyone who would like to recreate the build.

RASPBERRY PI INSTANT CAMERA

The Raspberry Pi camera was designed to take pictures, and Phillip Burgess used that notion to build his Polaroid-like Instant Camera. Instead of producing photos using chemical-based film, his camera utilizes thermal printer paper in the same fashion as Nintendo's Game Boy Camera and Printer. For his project, Phillip states that any Raspberry Pi board will work, so he went with the Model A+ because of its size and efficiency. The same for the Pi camera, although the Instant Camera build doesn't require HD capabilities.

Phillip also took advantage of the Nano TLL thermal receipt printer due to its compact size and paired it with a particular nano roll of thermal paper that works specifically with the printer; however any other printer and paper can be utilized. He also used a Perma Proto Hat to connect buttons and power to the Raspberry Pi GPIO, which uses a pair of momentary push-buttons and a 4xAA battery holder.

The Raspberry Pi Instant Camera project does require soldering skills and knowledge of the Pi, such as the information listed in this article, which isn't difficult to follow. Phillip has also uploaded a complete build walkthrough, including a list of materials needed and how to set up the Pi for taking photographs.

Figure 9: The build acts similar to an instant camera and was designed around the Raspberry Pi, Pi camera and a thermal paper nano printer. Image source: [Phillip Burgess]

POSTURE DETECTION WITH THE RASPBERRY PI CAMERA

Due to the pandemic, more employees are working from home. Sitting for long periods can negatively affect our posture, and while some workers take advantage of ergonomic chairs, the rest should keep tabs on their sitting habits. To that end, Dixon Selvan designed a novel Posture Detector that can alert users when their posture is less than optimal, per medical health guidelines.

Dixon designed his Posture Detector using the Raspberry Pi HQ kit, which packs a Raspberry Pi 4 Model B, the Pi HQ camera (12.3 MP) and the 16 mm 10 MP telephoto lens. The build is straightforward, with the Pi and Pi camera connected via the CSI port, with each housed in a separate case: one to keep the Pi board cool with an integrated fan, and the camera and telephoto lens secured in its own box enclosure.

Dixon then utilized the OpenCV computer vision platform as the brains to analyze photos and video the camera kit has captured in order to identify the optimal sitting position. Dixon's system also makes use of OpenPose, which the CV uses to detect key positions of the body that help identify a person's ideal posture. The detector will then alert the user if their posture is less than ideal for preventing any long-term adverse health effects.

Figure 10: The Posture Detector uses the Raspberry Pi HQ kit and computer vision to monitor posture while sitting based on medical health guidelines. Image source: element14

CHAPTER - 5 Computer Vision

Computer vision (CV) is a field of artificial intelligence (AI) that allows computers and other systems to derive pertinent information from digital images. In essence, it learns by "seeing" images based on a particular subject or project task, which can include methods for acquiring, processing, analyzing and understanding digital images and extraction of high-dimensional data from the real world to produce numerical or symbolic information in the form of decisions.

AI in all its forms is resource intensive, meaning computers need a high level of hardware power to process information. Companies such as Nvidia and AMD have developed GPUs with integrated AI cores to handle large data loads, but even the latest Raspberry Pi 4 Model B can now be used to take advantage of computer vision for any number of projects. Open-source software such as TensorFlow, OpenCV, Acumos AI, ClearML and more can be used with the Raspberry Pi with very little prep or modifications. Programs such as SimpleCV provide a Python shell wrapped around OpenCV, making it easy to install and get up and running with minimal input.

Users can load SimpleCV onto the Raspberry Pi using the following command lines. These will install the packages needed to allow SimpleCV to run.

```
$ sudo apt-get update
$ sudo apt-get install ipython python-opencv python-scipy
$ sudo apt-get install python-numpy python-setuptools python-pip
$ sudo pip install svgwrite
```

After entering several lines of code, it's time to load SimpleCV itself:

```
$ sudo pip install https://github.com/sightmachine/SimpleCV/zipball/master
```

After installation is completed, its time to test the software, which is done by executing the following commands:

```
$ simplecv
+-----------------------------------------------------------+
 SimpleCV 1.3.0 [interactive shell] - http://simplecv.org
+-----------------------------------------------------------+
Commands:
    "exit()" or press "Ctrl+ D" to exit the shell
    "clear()" to clear the shell screen
    "tutorial()" to begin the SimpleCV interactive tutorial
    "example()" gives a list of examples you can run
    "forums()" will launch a web browser for the help forums
    "walkthrough()" will launch a web browser with a walkthrough
```

As mentioned earlier, AI software is hardware intensive, so although users can get some AI platforms to work with the Raspberry Pi 1 and 2 using some modified solutions, it's best to utilize the Pi 3 and Pi 4 for AI-related projects. Users are also not limited to using the Pi camera here as well, as most webcams can handle the task remarkably well.

Computer vision can do more than identify objects, people or posture in home projects using the Raspberry Pi. It's utilized in semi-smart and autonomous vehicles, medical imaging, and industrial and manufacturing environments. With imaging data gathered from cameras and other sensors placed around rooms, buildings and even cities, computer vision technology can learn about visual data and turn it into beneficial information for decision-making. These can be used for all sorts of tasks, including fire detection, security, traffic and more.

Computer vision is already a part of our daily lives, as it can be found in smartphones with facial recognition capabilities, modern cars with embedded cameras that alert drivers to obstacles and in manufacturing plants for safety and maintenance. Moreover, an AI system in Japan was recently designed to identify croissants from bear claws but found better use as a cancer detector known as Cyto-Aiscan. The system is capable of identifying cancerous cells viewed under a microscope with 98% accuracy, which it does by measuring the nuclei of cells and picking out visual cues.

The future of computer vision won't be limited to one industry or several. It will continue to evolve in areas such as cloud computing, data storage, application servers, networks, and other computer system infrastructure to individuals or businesses over the internet. It will also be used for AutoML and other automation applications, including feature engineering and model selection. Computer vision will also push mobile devices into areas such as Edge computing with on-device inference capabilities with increased pattern recognition and low latencies. There's also increased development in augmented and VR applications, enabling computer vision developers to extend their skills into new areas, such as developing intuitive and efficient methods of replicating and interacting with objects in a 3D space. Moving forward, computer vision applications will continue to change and influence the future.

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