Image processing using

OpenCV + Python + mjpg-streamer

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NE FIRST University Day

Agenda

- Why OpenCV + Python?
- Image filtering demo
- pynetworktables

Image processing

- FRC Teams do it a lot of ways
  - NIVision (LabVIEW)
  - GRIP (Uses OpenCV as engine)
  - OpenCV (various custom stuff)
- We're going to talk about OpenCV

Why OpenCV?

- Originally developed by Intel
- It has thousands of image processing related algorithms and functions available
  - Highly optimized and reliable
  - Has building blocks that fit together
- Lets you do complex image processing without needing to understand the math
  - If you understand the math, it helps!

Why OpenCV?

- Bindings for multiple languages
  - C/C++
  - Java
  - Python
- Multiple platforms supported
  - Windows
  - Linux
  - OSX
  - Android
- Oh, and it’s **FREE**!

What OpenCV Provides

- Image I/O:
  - Read/Write images from disk
  - Use native OS functionality to interface with cameras
- Image Segmentation
  - Edge finding
  - Contour detection
  - Thresholding

What OpenCV Provides

- Face detection
- Motion tracking
- Stereo vision support
- Support for GPU acceleration
- Machine learning operations
  - Classifiers
  - Neural networks

What OpenCV Provides

- Distributed with lots of useful samples that you can use to figure out how OpenCV works
  - Face detection
  - Edge finding
  - Histograms
  - Square finder

Lots and lots and lots of stuff...

Why Python + OpenCV?

- Python is really easy to learn and use
  - Simple syntax
  - Rapid prototyping
- Most of the compute intensive work is implemented in C/C++
  - Python is just glue, realtime operation **is** possible
- NumPy is awesome
  - Manipulating image data is trivial compared to other OpenCV bindings (Java, C++)

Time to CODE!

Go to http://goo.gl/nB0NCG

About this environment

http://goo.gl/nB0NCG

- It's a Jupyter Notebook (formerly IPython Notebook)
  - This slideshow uses Jupyter too!
- It allows you to mix text and executable code in a webpage
- You execute each cell using SHIFT-ENTER

Hello World!

- Click the cell with the following text, and press SHIFT-ENTER

In [2]:
```
print("Hello class")
```

```
Hello class
```

Next Steps

- Execute the helper code

- The next cell tells you about the images available in your environment

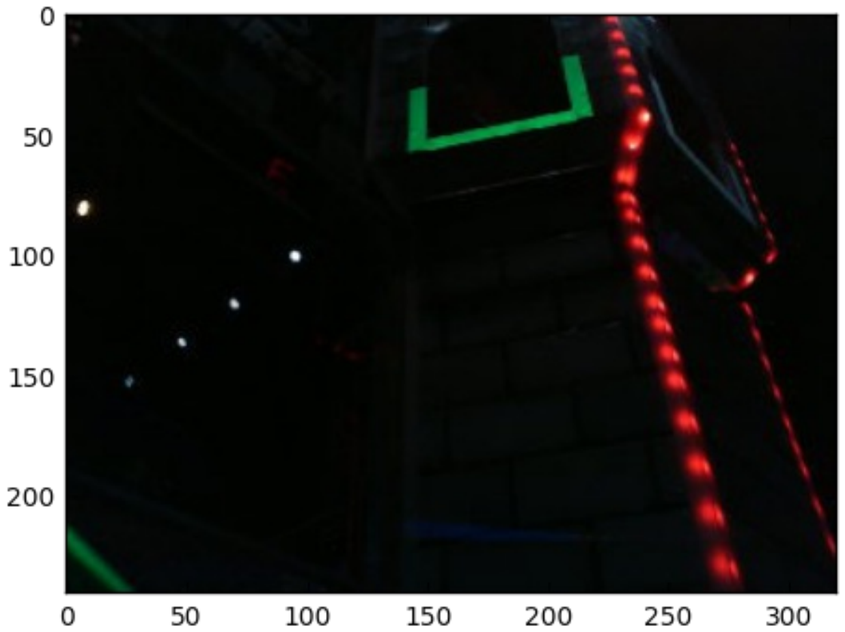
In [3]:
```
%ls images
```

```
2013-f0.png     2016-cmp-0.jpg  2016-cmp-5.jpg  2016-p0.jpg
2013-p0.png     2016-cmp-1.jpg  2016-dcmp1.jpg  2016-p1.jpg
2013-p1.png     2016-cmp-3.jpg  2016-dcmp2.jpg  2016-p2.jpg
2014-f0.png     2016-cmp-4.jpg  2016-dcmp3.jpg  2016-p3.jpg
```

Hello image!

- Let's load an image and show it

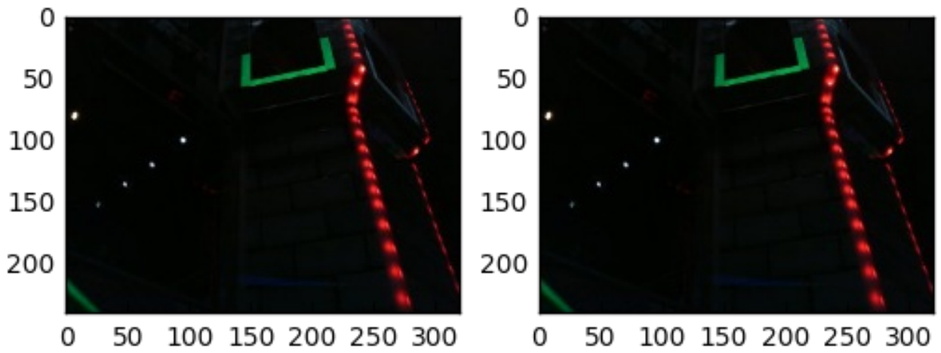
In [4]:
```
# Change this to load different images
img = cv2.imread('images/2016-cmp-5.jpg')
imshow(img)
```



Hello image!

- You can show multiple images next to each other

In [5]:
```
imshow(img, img)
```



OpenCV Image Basics

- Images are stored as multidimensional arrays
  - Color images have 3 dimensions: height, width, channel
- Each pixel is a number stored in the array
- Numpy array notation allows you to do operations on individual pixels or ranges of pixels

In [6]:
```
img[50, 150, :]           # Access a single pixel,
```

Out[6]:
```
array([ 8, 19,  0], dtype=uint8)
```

In [7]:
```
x = img[24:42, 42:100, :]    # Access a range of pixels
```

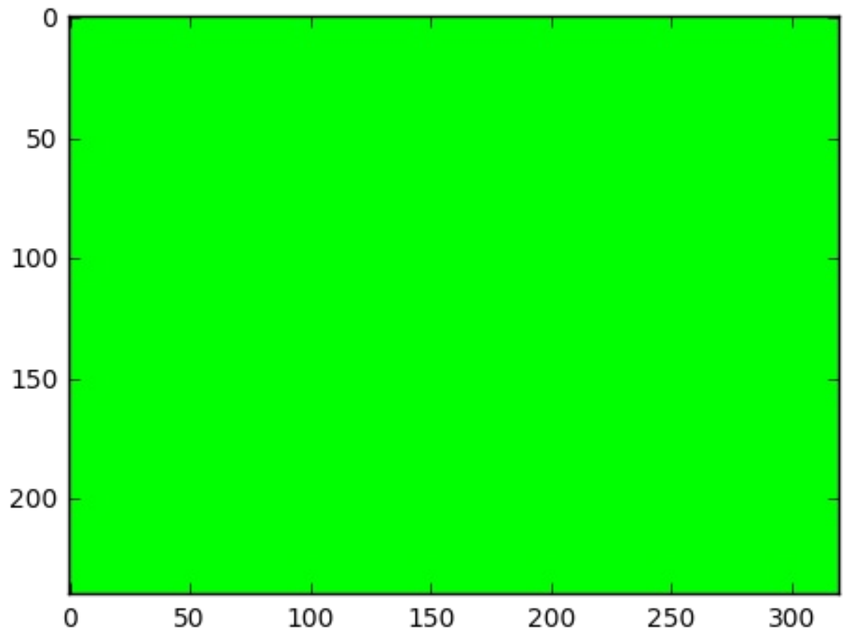
OpenCV Image Basics

- Color is represented by storing combinations of Red, Blue, and Green pixels in separate channels
  - OpenCV uses BGR representation, not RGB
- The amount of each individual color is represented in the individual channel
  - ‘dark’ is zero, ‘bright’ is 255
- Combine the channels to represent a color
  - Green = RGB(0, 255, 0)
  - Deep Pink = RGB(255, 20, 147)

OpenCV Image Basics

- Using numpy we can easily fill an image with a single color

In [8]:
```
# define image with height=240, width=320, 3 channels
shape = (240, 320, 3)
pink_img = np.empty(shape, dtype=np.uint8)

# Fill every pixel with a single color
pink_img[:] = (0, 255, 0)

imshow(pink_img)
```



Practical Example

- 2016 FIRST Stronghold: find targets that are surrounded by retroreflective tape, and shoot boulders into them

Practical Example

- Finding gray tape at a distance isn’t particularly easy
  - Key part of image processing is removing as much non-essential information from image
- We can do better!

Retroreflective Tape

- It has a useful property -- it reflects light directly back at the source
- What can we do with this property?

- Shine bright LEDs at the target and the tape reflects that color back to the camera
  - Many teams have found that green light works best
- Reduce exposure of camera so only bright light sources are seen

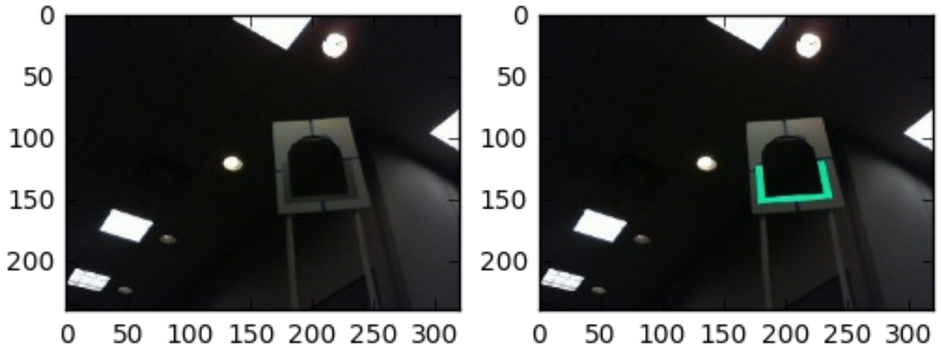
A note about exposure

- Webcams support setting the exposure manually (yay)
- Some cameras only allow particular exposure settings
  - The lifecam is one of them
- OpenCV has bugs, it doesn't set the exposure properly
- Here's a workaround that works on linux:

```
v4l2-ctl -d /dev/video0 -c exposure_auto=1 -c exposure_absolute=10
```

Retroreflective Tape

In [9]:
```
img1 = cv2.imread('images/2016-p0.jpg')
img2 = cv2.imread('images/2016-p1.jpg')
imshow(img1, img2)
```



Practical Example

Processing steps to find targets:

- Isolate the green portions of the image
- Analyze the green portions to determine targets

Note: There are a lot of ways to go about this, I'm just showing you one way

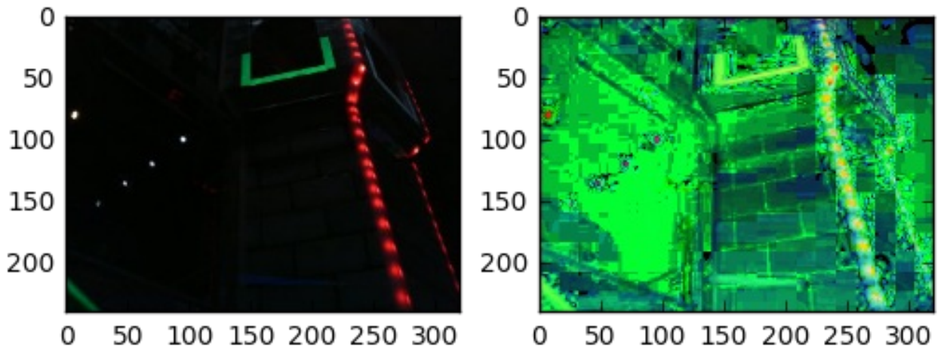
Identify the green

- What is “green” anyways?
  - This is green. This is also green.
- To a computer, green is really a range of colors
- An object’s color changes depending on lighting conditions
- We can transform the image to identify colors independent of lighting conditions

Identify the green

- Convert the image from RGB to HSV
  - Hue: the color
  - Saturation: Colorfulness
  - Value: Brightness

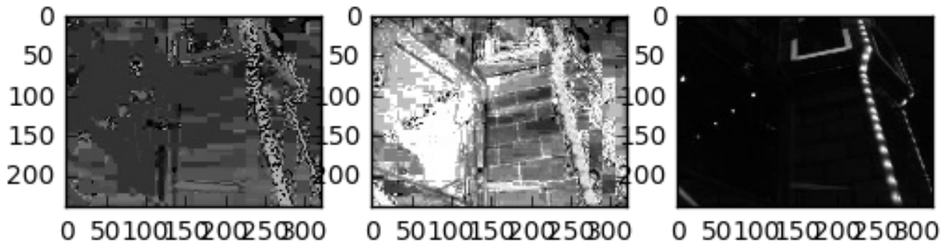
In [10]:
```
hsv = cv2.cvtColor(img, cv2.COLOR_BGR2HSV)
imshow(img, hsv)
```



Identify the green

That doesn't show why HSV is useful. Let's look at the individual channels instead.

In [11]:
```
h, s, v = cv2.split(hsv)
imshow(h, s, v)
```



Identify the green

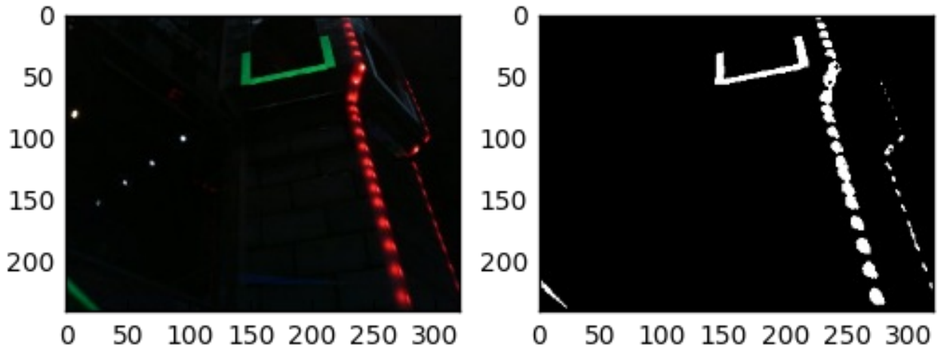
- Green is a range of values present in the image
- ‘Threshold’ the image to get rid of the colors that we don’t care about
- Lots of ways to do this
  - Manually specify values
  - Automated methods

Identify the green

`cv2.inRange` can threshold an image given two ranges of pixels.

- Wanted values are converted to 255
- Unwanted values are now 0

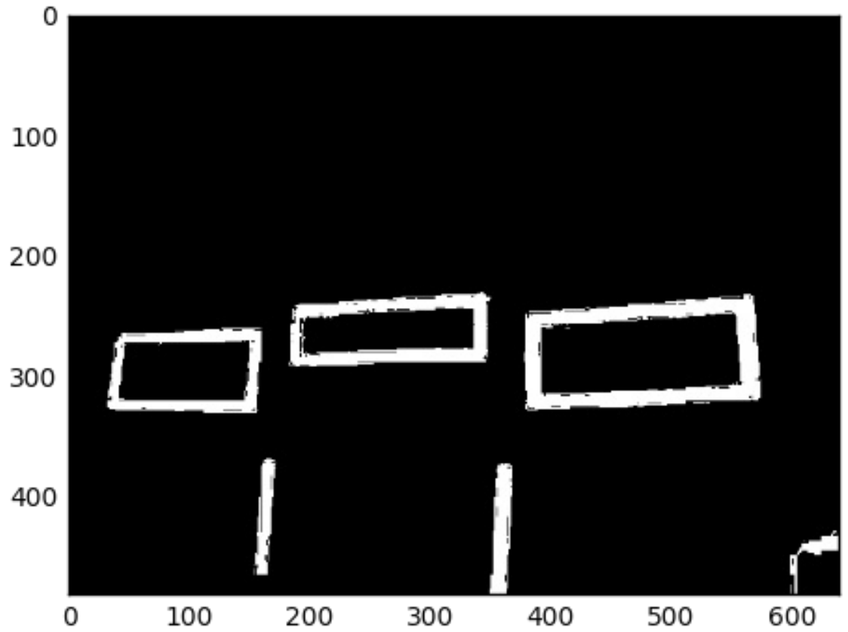
In [12]:
```
lower = np.array([0, 145, 80])
upper = np.array([255, 255, 255])

filtered = cv2.inRange(hsv, lower, upper)
imshow(img, filtered)
```



Identify the green

Sometimes, you end up with holes in your output

In [13]:
```
img3 = cv2.imread('images/2013-f0.png')
hsv3 = cv2.cvtColor(img3, cv2.COLOR_BGR2HSV)

# Thresholds are different because different camera/lighting
lower3 = np.array([30, 188, 16])
upper3 = np.array([75, 255, 255])
filtered3 = cv2.inRange(hsv3, lower3, upper3)
imshow(filtered3)
```

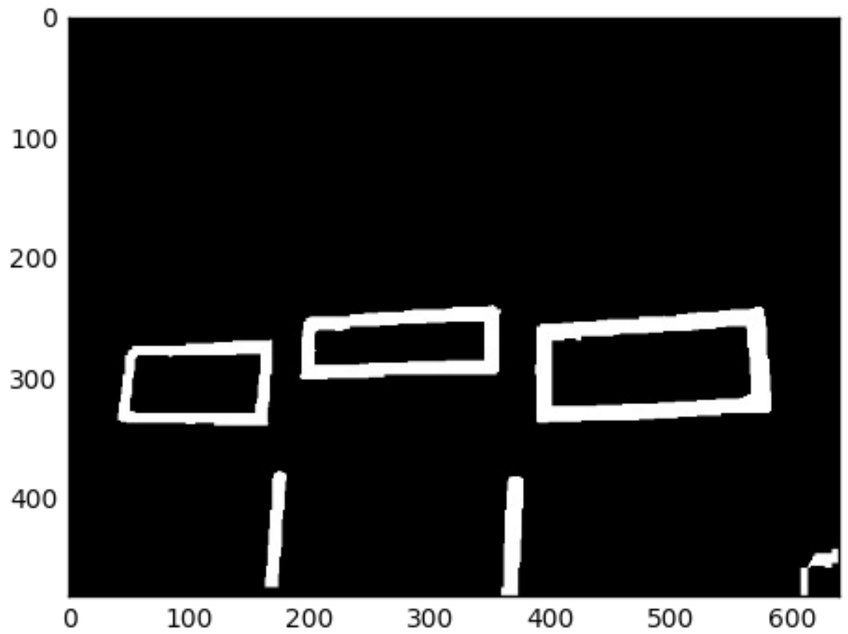


Identify the green

- We can use a morphological operation to fill in the holes
  - Various types of morphology operations available
- They modify a pixel based on the values of its neighboring pixels
  - The one we use to fill in holes is a “closing” operation

In [14]:

```
kernel = cv2.getStructuringElement(cv2.MORPH_RECT, (2,2), anchor=(1,1))
output = cv2.morphologyEx(filtered3, cv2.MORPH_CLOSE, kernel,
                          iterations=9)
imshow(output)
```



Identifying Targets

Use `findContours()` to find regions of interest

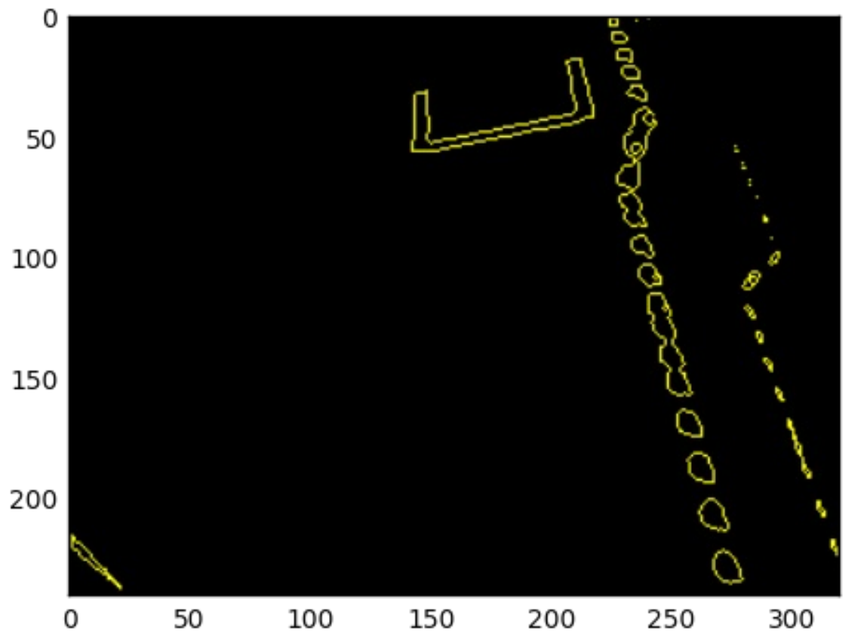
- Returns a list of points bounding each separate blob in the image (called a contour)
- Also returns a hierarchy so you can determine whether a contour is entirely inside another contour

In [15]:
```
image, contours, hierarchy = cv2.findContours(filtered,
                                              cv2.RETR_LIST,
                                              cv2.CHAIN_APPROX_SIMPLE)
```

Identifying Targets

If you want to see what it found, you can draw the found contours.

In [16]:
```
dst = np.zeros(shape=img.shape, dtype=img.dtype)
cv2.drawContours(dst, contours, -1, (0, 255, 255), 1)
imshow(dst)
#print(contours[0])
```



Identifying Targets

- As you can see, contours aren't the whole story

Identifying Targets

- Contour analysis
  - Discard non-convex contours
  - Convert to polygon approximation (approxPolyDP)
  - Discard polygons that aren’t rectangles
  - Discard polygons that aren't the right size

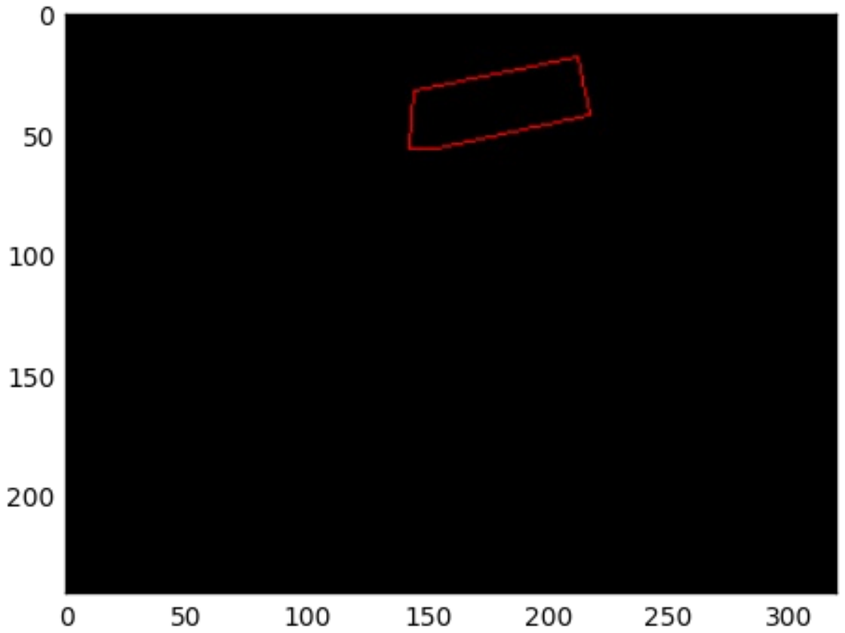
Magic?

In [17]:

```
min_width = 20 # in pixels
results = []

# Iterate over each contour
for c in contours:

    # Contours are jagged lines -- smooth it out using an approximation
    a1 = cv2.approxPolyDP(c, 0.01*cv2.arcLength(c, True), True)

    # This fills in the contour so that it's a rectangle
    hull = cv2.convexHull(c)

    # Approximate the points again, smoothing out the hull
    a2 = cv2.approxPolyDP(hull, 0.01*cv2.arcLength(hull, True), True)

    # We only care about objects that are wider than they are tall, and things w
ider
    # than a particular width. Only keep things that meet that criteria.
    _, _, w, h = cv2.boundingRect(a2)
    if w > h and w > min_width and len(a2) in (4,5):
        results.append(a2)
```

Magic?

In [18]:
```
# Finally, draw out our results
dst = np.zeros(shape=img.shape, dtype=img.dtype)
cv2.drawContours(dst, results, -1, (0, 0, 255), 1)
imshow(dst)
#print(results[0])
```



Identifying Targets

- Sometimes you need to do more work
  - Use ratios to determine which target you're looking at
  - Remove duplicates (inner rectangles)
  - Other types of validation

Now what?

We have targets... probably should do something with them?

Calculate angle/distance to target

- I'm not a math guy, but this sorta works
  - Angle works, distance is a bit iffy
- Get the minimum bounding rectangle
- Figure out the horizontal and vertical field of view for your camera
  - Look it up online
- Do math to it

In [19]:

```
# Just do the first one for now
result = results[0]

# Get the height/width
h = float(img.shape[0])
w = float(img.shape[1])

# Define HFOV and VFOV
VFOV = 45.6 # degrees
HFOV = 61.0 # degrees
```

In [20]:

```
((cx, cy), (rw, rh), rotation) = cv2.minAreaRect(result)

# These work fairly well
angle = VFOV * cy / h - (VFOV/2.0)
height = HFOV * cx / w - (HFOV/2.0)

print(angle, height)
```

```
-15.564704704284669 3.2886390209198026
```

In [21]:

```
# This is magic, but it doesn't really work
target_height = 7.66 # 7' 8"
camera_height = 1.08 # 13"
camera_pitch = 40.0  # What angle is the camera at?
t = (target_height - camera_height)
distance = t/math.tan(math.radians(-angle + camera_pitch))

print(distance)
```

```
4.5113763224432235
```

Now What?

- Send data via NetworkTables
- ... I forgot to write this slide. It's easy, I promise.

Where to run the image processing

- RoboRIO
  - RoboRIO is relatively slow, OpenCV eats a lot of CPU
    - Hint: Make the images small (320x240)
  - Less hardware to deal with
  - FIRST intends to install OpenCV by default in 2017

Where to run the image processing

- Driver Station
  - Streaming images to OpenCV is possible
    - Various latency bugs
  - Latency is an issue here
  - mDNS problems (hopefully will be resolved in 2017)

Where to run the image processing

- Coprocessor (Jetson, Raspberry PI, Nexus 5)
  - Lots of teams do this
  - More hardware to deal with
  - Potentially higher fidelity processing

mjpg-streamer

- Open Source application for streaming Webcam over HTTP
- Allows accessing camera stream from a webpage
- Very little CPU usage if no image processing happening

mjpg-streamer

- I created an OpenCV plugin for it
- You can provide python processing code:

```
class MyFilter:
    def process(self, img):
        pass

def init_filter():

    f = MyFilter()
    return f.process
```

mjpg-streamer

- I would show you a demo here, but my RoboRIO's USB is toasted

mjpg-streamer

- Peter Johnson is working on a better FRC-specific version of this
- Expect to see it in 2017

Want code?

- Working OpenCV code integrated with mjpg-streamer
  - https://github.com/frc2423/2016/tree/master/OpenCV
  - Includes code for storing images onto USB drive during matches
  - Don't let our robot's performance fool you... :(
- The stuff we did here will be available sometime tonight
  - https://github.com/virtuald/frc-imageprocessing-workshop-2016

If you want more

- Team 254 gave an excellent presentation at CMP in 2016
  - https://goo.gl/mppi4E
  - Video/audio: http://www.chiefdelphi.com/forums/showthread.php?t=147568&page=3
  - Latency compensation is an excellent technique presented here

Resources

- Python 3.5.x
  - https://www.python.org/downloads/
- Learn Python
  - http://www.codecademy.com/tracks/python
- OpenCV 3.1.0
  - http://opencv.org
- NumPy
  - Official site: http://www.numpy.org

Resources

- roborio-packages
  - https://github.com/robotpy/roborio-packages
- OpenCV for RoboRIO
  - https://github.com/robotpy/roborio-opencv
- mjpg-streamer for RoboRIO
  - https://github.com/robotpy/mjpg-streamer

Resources

- pynetworktables
  - source code + examples @ https://github.com/robotpy/pynetworktables
- Edit & debug python code using Eclipse
  - Pydev: http://pydev.org/

One more thing...

FIRSTwiki: https://firstwiki.github.io

- Publicly editable repository of information related to FIRST Robotics
  - Technical topics
  - Non-technical
  - Team pages
- Add content to your team’s page!

Questions?