Measuring Curvature

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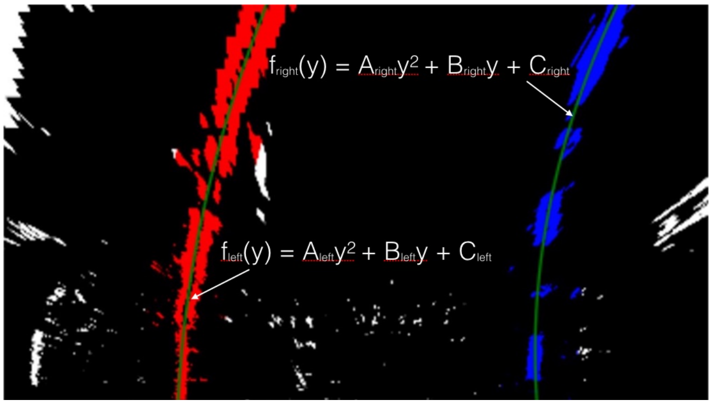
You're getting very close to a final result! You have a thresholded image, where you've estimated which pixels belong to the left and right lane lines (shown in red and blue, respectively, below), and you've fit a polynomial to those pixel positions. Next we'll compute the radius of curvature of the fit.



Here I have fit the left and right lines with a second order polynomial shown in green.

In the last exercise, you located the lane line pixels, used their x and y pixel positions to fit a second order polynomial curve:

$$f(y) = Ay^2 + By + C$$

You're fitting for $f(y)$, rather than $f(x)$, because the lane lines in the warped image are near vertical and may have the same x value for more than one y value.

Radius of Curvature

Measuring Curvature

is given as follows:

$$R_{curve} = \frac{[1+(\frac{dx}{dy})^2]^{3/2}}{|\frac{d^2x}{dy^2}|}$$

In the case of the second order polynomial above, the first and second derivatives are:

$$f'(y) = \frac{dx}{dy} = 2Ay + B$$

$$f''(y) = \frac{d^2x}{dy^2} = 2A$$

So, our equation for radius of curvature becomes:

$$R_{curve} = \frac{(1+(2Ay+B)^2)^{3/2}}{|2A|}$$

The y values of your image increase from top to bottom, so if, for example, you wanted to measure the radius of curvature closest to your vehicle, you could evaluate the formula above at the y value corresponding to the bottom of your image, or in Python, at `yvalue = image.shape[0]`.

- An insightful student has suggested an alternative approach which may scale more efficiently. That is, once the parabola coefficients are obtained, in pixels, convert them into meters. For example, if the parabola is `x= a*(y**2) +b*y+c`; and `mx` and `my` are the scale for the x and y axis, respectively (in meters/pixel); then the scaled parabola is `x= mx / (my ** 2) *a*(y**2)+`

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Sample Implementation

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Advanced Techniques for Lane Findi...

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Measuring Curvature

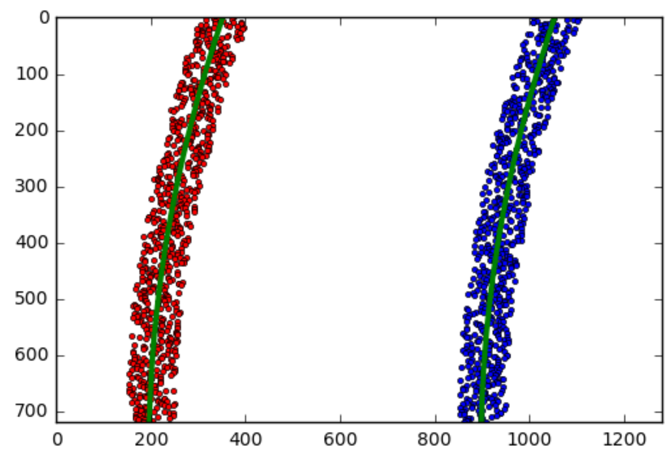
```
# Generate some fake data to represent
 lane-line pixels
ploty = np.linspace(0, 719, num=720)# t
o cover same y-range as image
quadratic_coeff = 3e-4 # arbitrary quad
ratic coefficient
# For each y position generate random x
 position within +/-50 pix
# of the line base position in each cas
e (x=200 for left, and x=900 for right)
leftx = np.array([200 + (y**2)*quadrati
c_coeff + np.random.randint(-50, high=5
1)
                              for y in
 ploty])
rightx = np.array([900 + (y**2)*quadrat
ic_coeff + np.random.randint(-50, high=
51)
                                for y i
n ploty])

leftx = leftx[::-1]  # Reverse to match
 top-to-bottom in y
rightx = rightx[::-1]  # Reverse to mat
ch top-to-bottom in y


# Fit a second order polynomial to pixe
l positions in each fake lane line
left_fit = np.polyfit(ploty, leftx, 2)
left_fitx = left_fit[0]*ploty**2 + left
_fit[1]*ploty + left_fit[2]
right_fit = np.polyfit(ploty, rightx, 2
)
right_fitx = right_fit[0]*ploty**2 + ri
ght_fit[1]*ploty + right_fit[2]

# Plot up the fake data
mark_size = 3
plt.plot(leftx, ploty, 'o', color='red'
, markersize=mark_size)
plt.plot(rightx, ploty, 'o', color='blu
e', markersize=mark_size)
plt.xlim(0, 1280)
plt.ylim(0, 720)
plt.plot(left_fitx, ploty, color='gree
n', linewidth=3)
plt.plot(right_fitx, ploty, color='gree
n', linewidth=3)
plt.gca().invert_yaxis() # to visualize
 as we do the images
```

Measuring Curvature



Now we have polynomial fits and we can calculate the radius of curvature as follows:

```
# Define y-value where we want radius o
f curvature
# I'll choose the maximum y-value, corr
esponding to the bottom of the image
y_eval = np.max(ploty)
left_curverad = ((1 + (2*left_fit[0]*y_
eval + left_fit[1])**2)**1.5) / np.abso
lute(2*left_fit[0])
right_curverad = ((1 + (2*right_fit[0]*
y_eval + right_fit[1])**2)**1.5) / np.a
bsolute(2*right_fit[0])
print(left_curverad, right_curverad)
# Example values: 1926.74 1908.48
```

But now we need to stop and think... We've calculated the radius of curvature based on pixel values, so the radius we are reporting is in pixel space, which is not the same as real world space. So we actually need to repeat this calculation after converting our x and y values to real world space.

Measuring Curvature

warped image. We could do this in detail by measuring out the physical lane in the field of view of the camera, but for this project, you can assume that if you're projecting a section of lane similar to the images above, the lane is about 30 meters long and 3.7 meters wide. Or, if you prefer to derive a conversion from pixel space to world space in your own images, compare your images with U.S. regulations that require a minimum lane width of 12 feet or 3.7 meters, and the dashed lane lines are 10 feet or 3 meters long each.

So here's a way to repeat the calculation of radius of curvature after correcting for scale in x and y:

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Measuring Curvature

```
ym_per_pix = 30/720 # meters per pixel
 in y dimension
xm_per_pix = 3.7/700 # meters per pixel
 in x dimension

# Fit new polynomials to x,y in world s
pace
left_fit_cr = np.polyfit(ploty*ym_per_p
ix, leftx*xm_per_pix, 2)
right_fit_cr = np.polyfit(ploty*ym_per_
pix, rightx*xm_per_pix, 2)
# Calculate the new radii of curvature
left_curverad = ((1 + (2*left_fit_cr[0]
*y_eval*ym_per_pix + left_fit_cr[1])**2
)**1.5) / np.absolute(2*left_fit_cr[0])
right_curverad = ((1 + (2*right_fit_cr[
0]*y_eval*ym_per_pix + right_fit_cr[1])
**2)**1.5) / np.absolute(2*right_fit_cr
[0])
# Now our radius of curvature is in met
ers
print(left_curverad, 'm', right_curvera
d, 'm')
# Example values: 632.1 m    626.2 m
```

Check out the U.S. government specifications for highway curvature to see how your numbers compare. There's no need to worry about absolute accuracy in this case, but your results should be "order of magnitude" correct.

NEXT