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Localization

ECSE 211: Design Principles and Methods

Overview

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- Introduction
- Assumptions
- Ultrasonic Localization
- Light Sensor Localization
- Summary

Introduction

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- When placing the robot on the field, human error plays a role in the accuracy of the odometer
  - A case in point: An error in the orientation of the robot of one (1) degree when placed on the field will result in up to 7.5 cm of error in the odometer across the field.
- It is desirable to standardize (and, preferably, reduce) this error by having the robot orient itself automatically, given reasonable assumptions about its initial position
- This process of autonomous orientation is called *localization*

Assumptions

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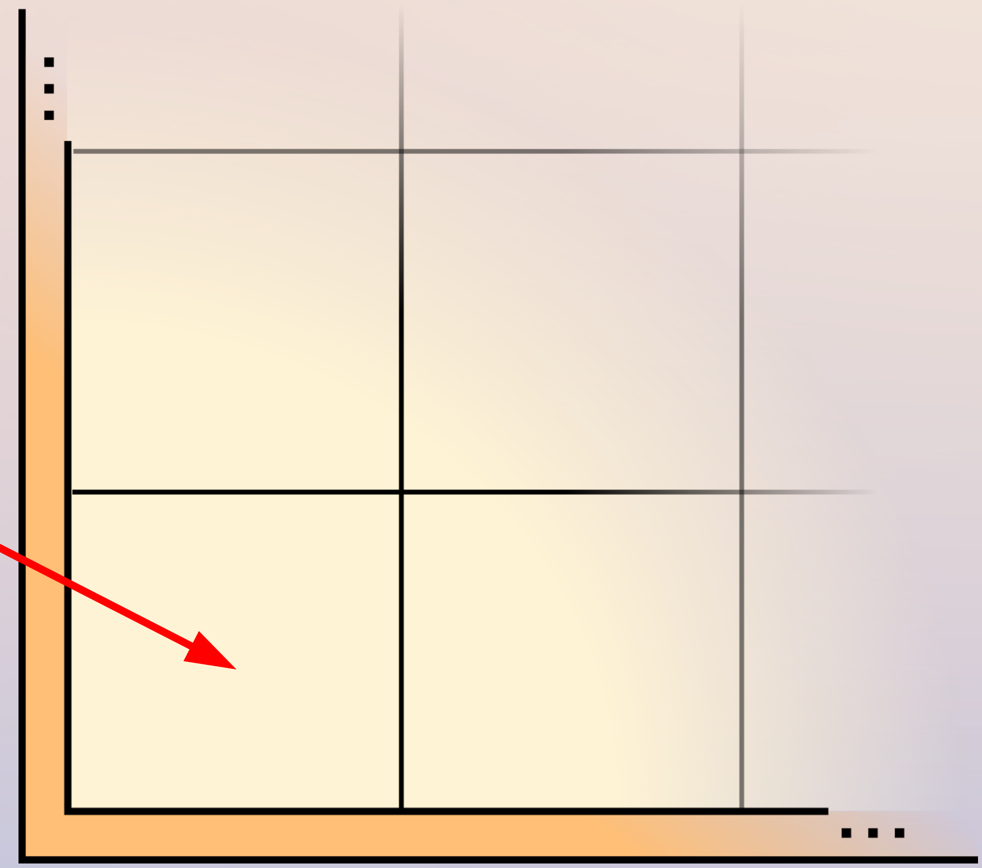
- To perform localization, the key assumption is that the robot will start with its center of rotation located in the back-left tile of the field
- Its initial orientation (heading) is assumed to be unknown



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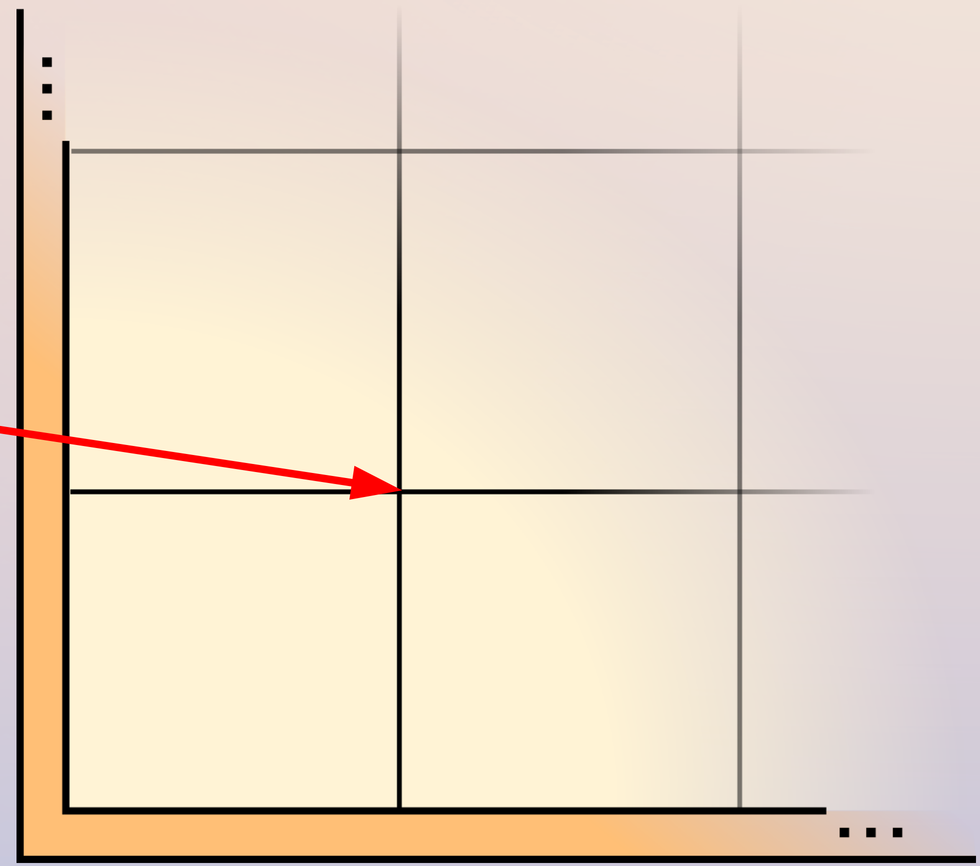
Assumptions

- Additionally, we will use the convention that the origin, (0, 0), is located here



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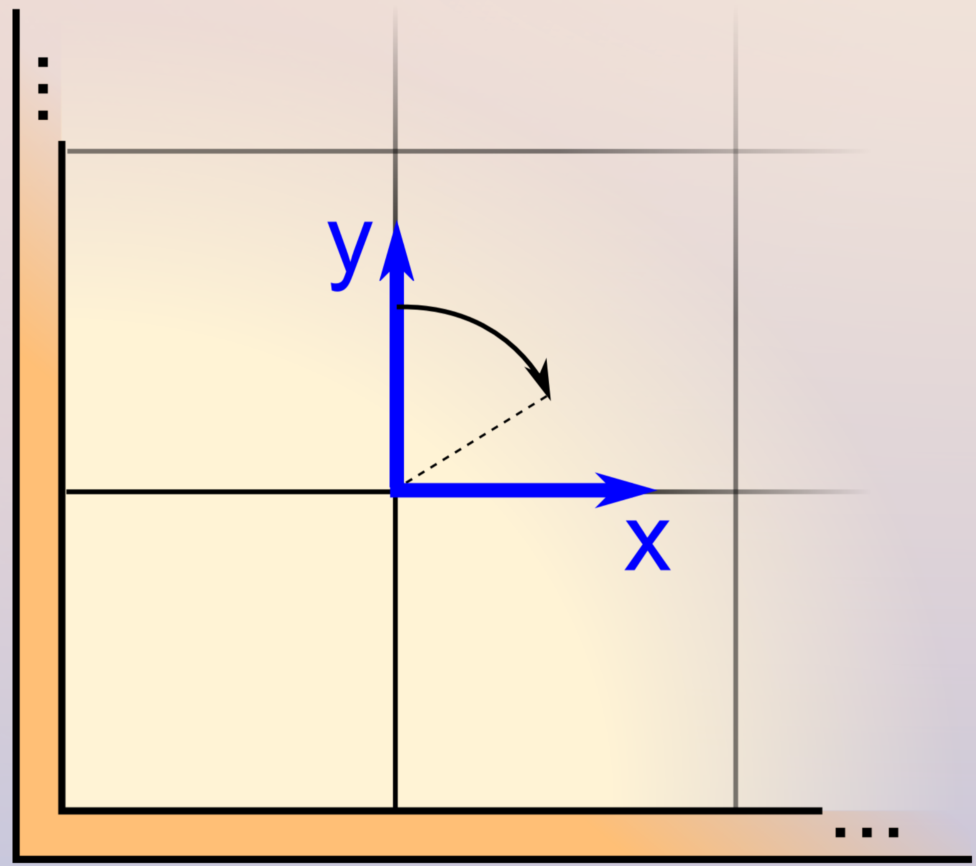
Assumptions

- Finally, angles will be measured clockwise from the positive *y*-axis, as seen on the right



Ultrasonic Localization

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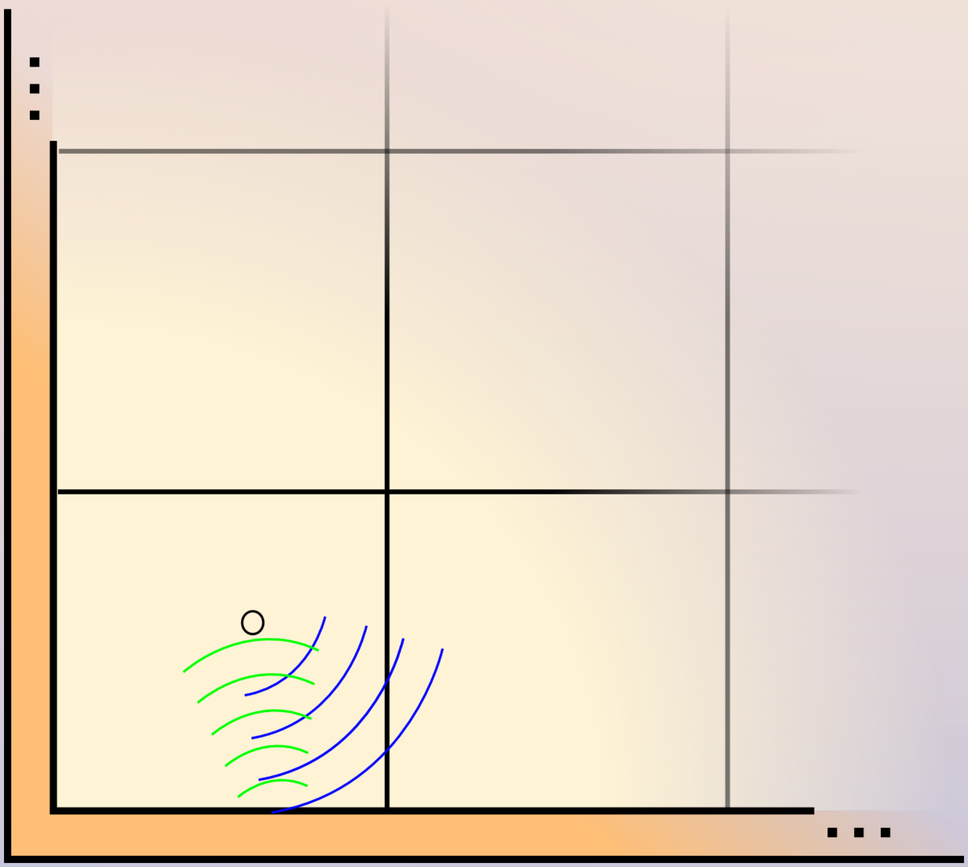
- The first step to accurately localizing is to determine the initial orientation of the robot
- To do this, we will use the ultrasonic sensor to measure the distance to the two walls nearest the robot



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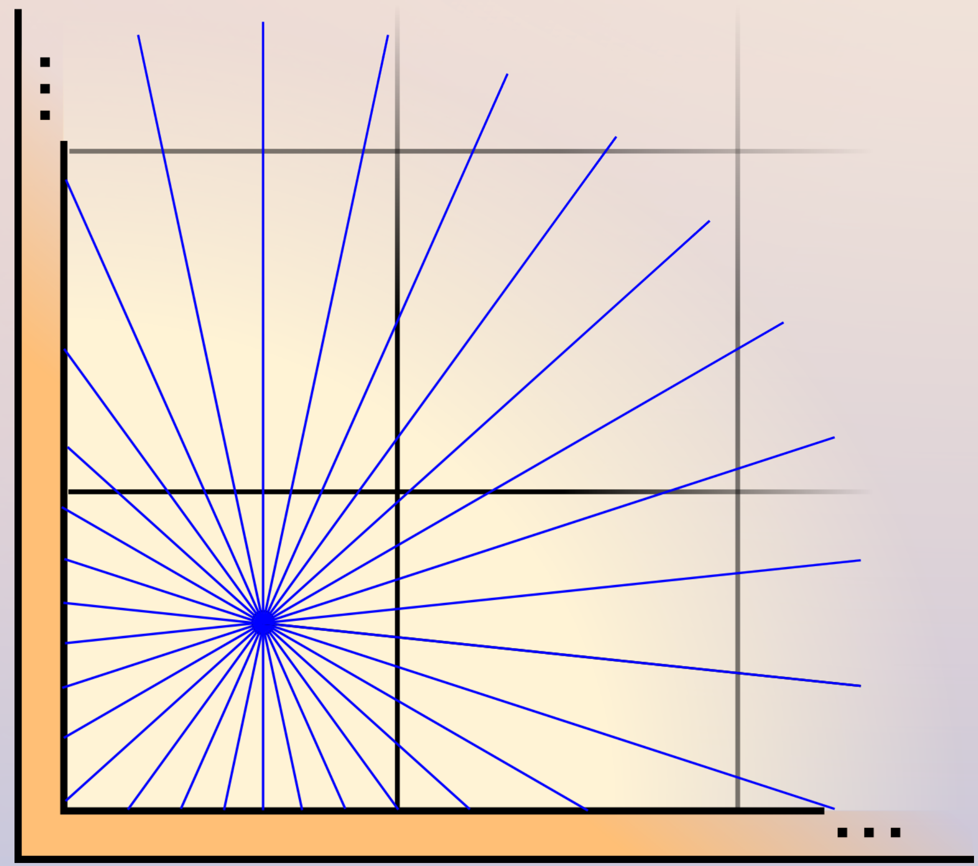
- Assume the robot has an ideal ultrasonic sensor (it measures only the distance along the straight line extending forward from the robot)
- Rotating the robot 360º could result in the distances illustrated on the right being measured



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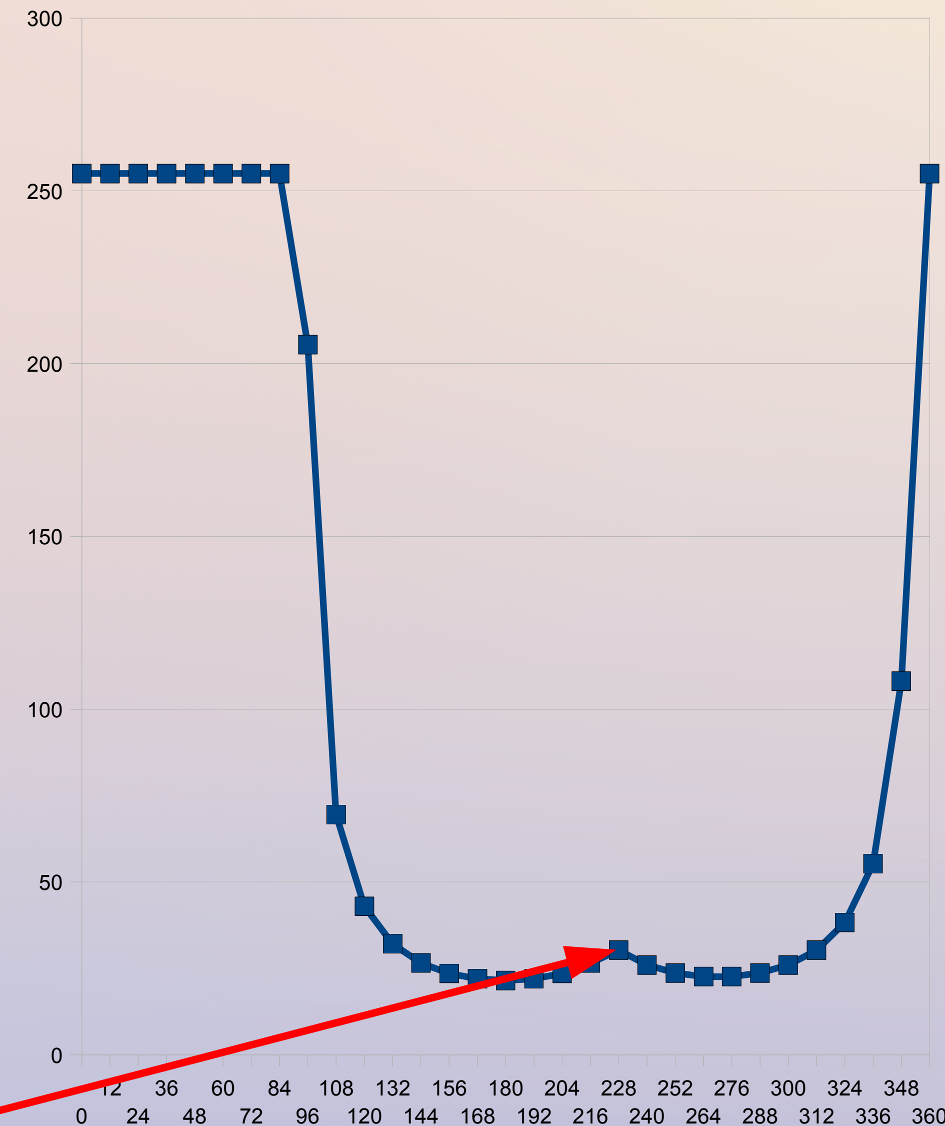
- We can plot these distances as a function of the orientation of the robot, θ
- If the robot is placed near the diagonal of the field (the invisible line connecting the back left and front right corners), the local maximum seen on the right is roughly at a heading of 225 degrees



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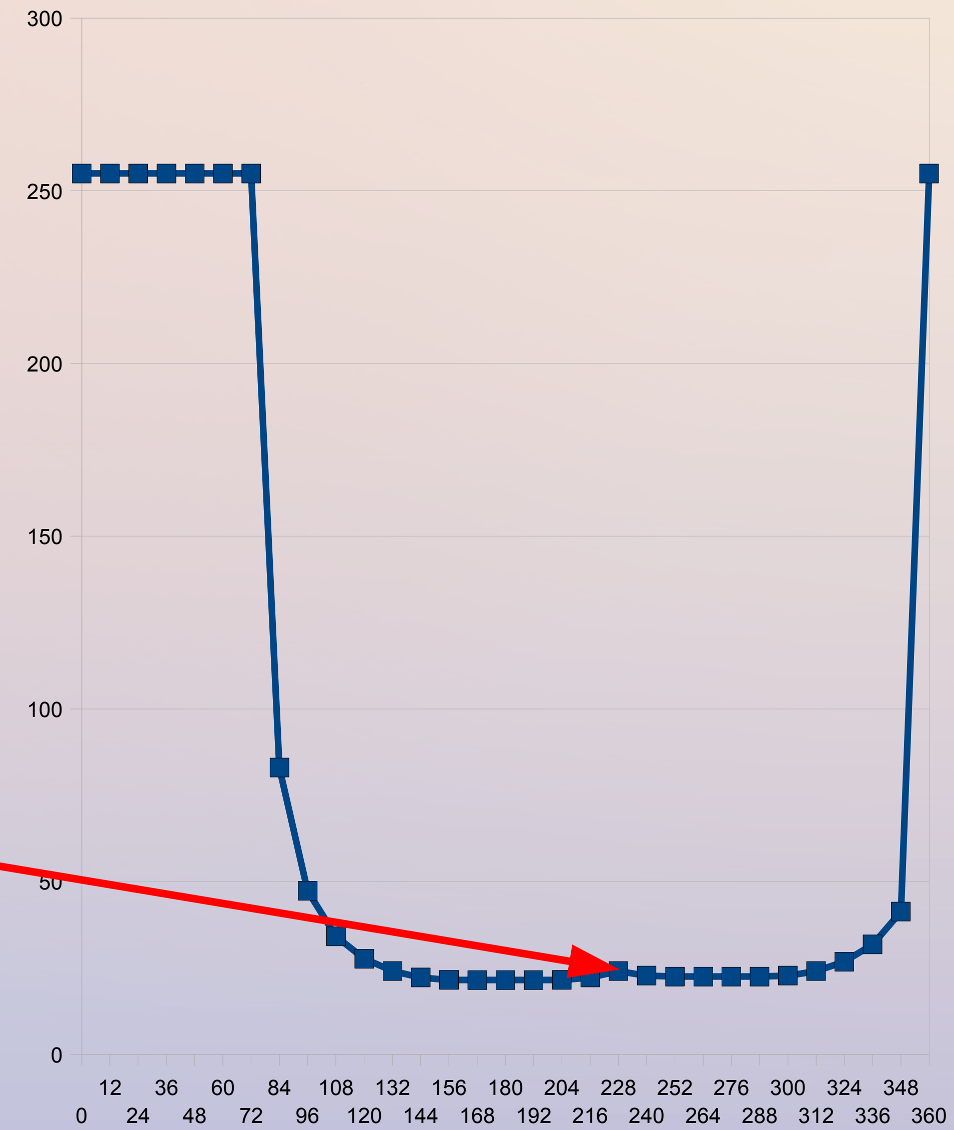
- Unfortunately, the ultrasonic sensor is not ideal: it detects the *minimum* of a wide range of distances
- As can be seen on the right, when this is taken into consideration, detecting this local maximum becomes difficult



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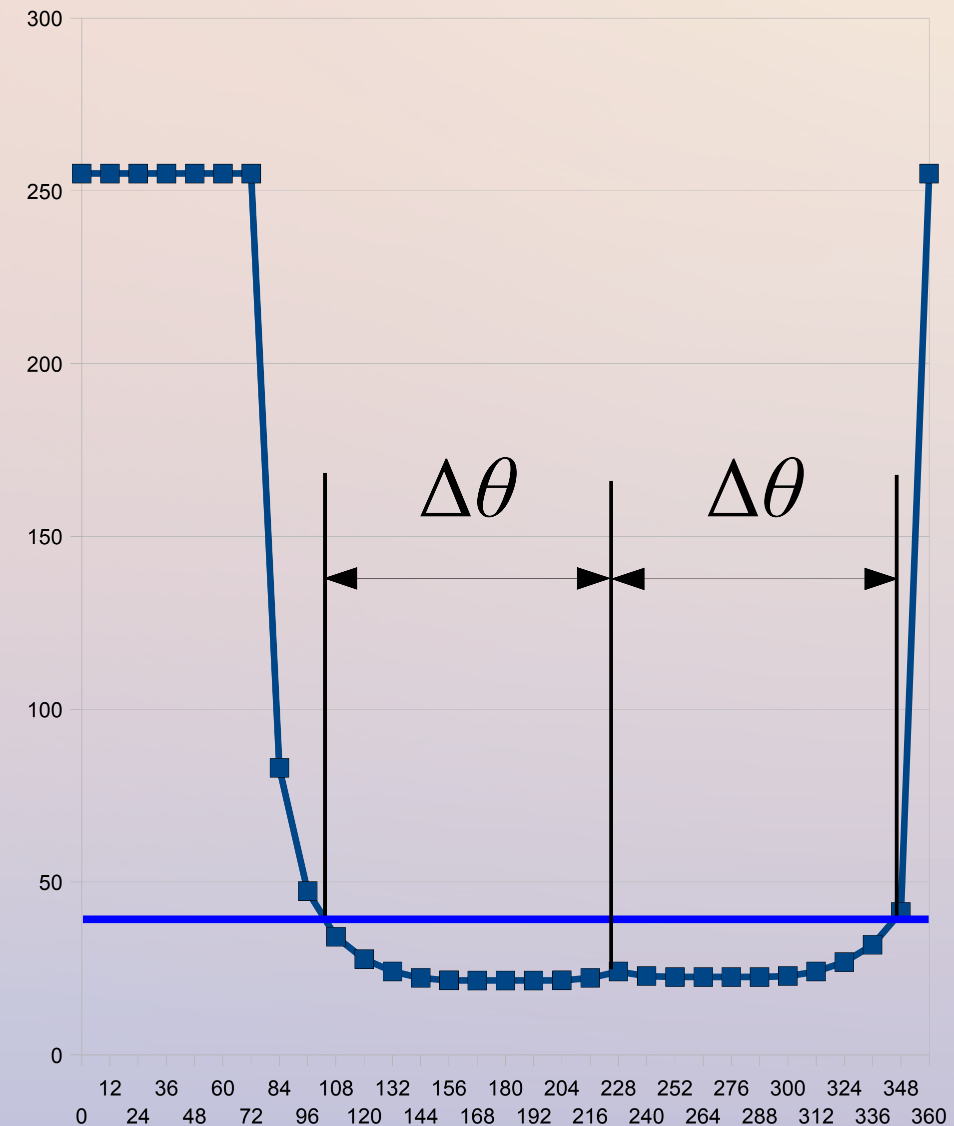
- Instead, it is noted that this maximum exists half way between the intersection of this curve and the line $y = d$, where d is an arbitrary constant (that does *not* mean you can pick it at random!)
- On the right, $d = 40$



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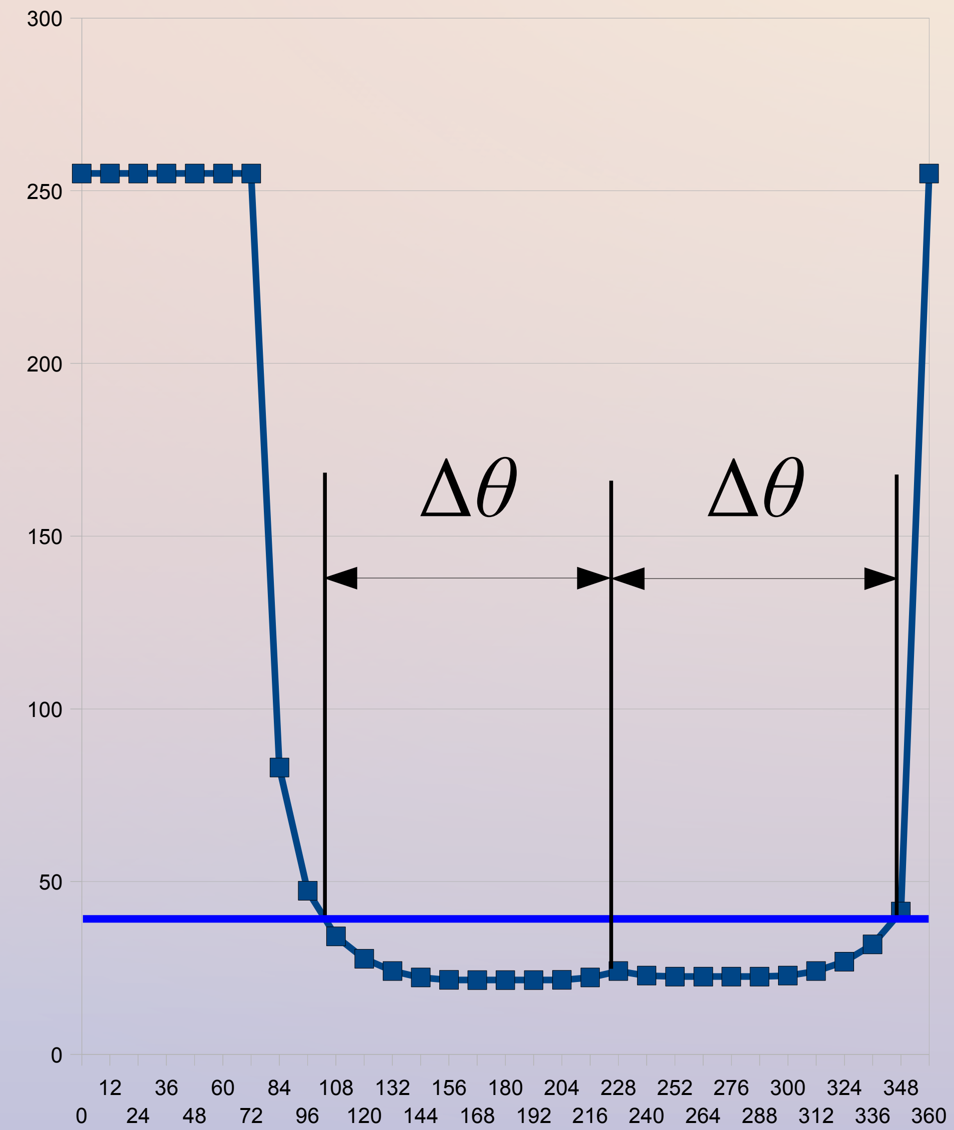
- Knowing the heading of the robot when the distance it measures drops below *d*, and the heading of the robot when the distance it measures rises above *d* appears to provide sufficient information to orient the robot
- This is not *quite* true, because of noise



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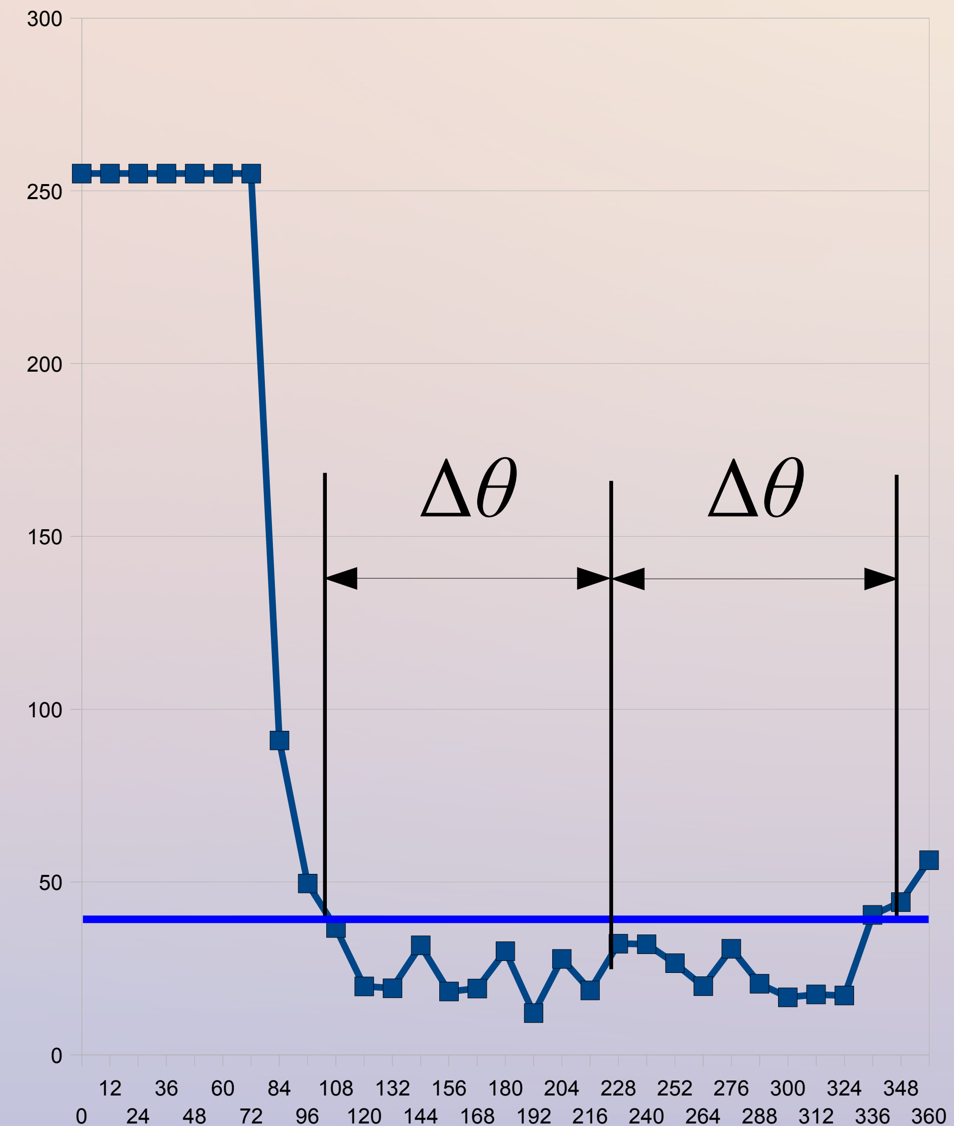
- On the right is a more realistic plot of the values measured using an ultrasonic sensor
- It is noted that at a macroscopic level (as is displayed here), the method still looks viable



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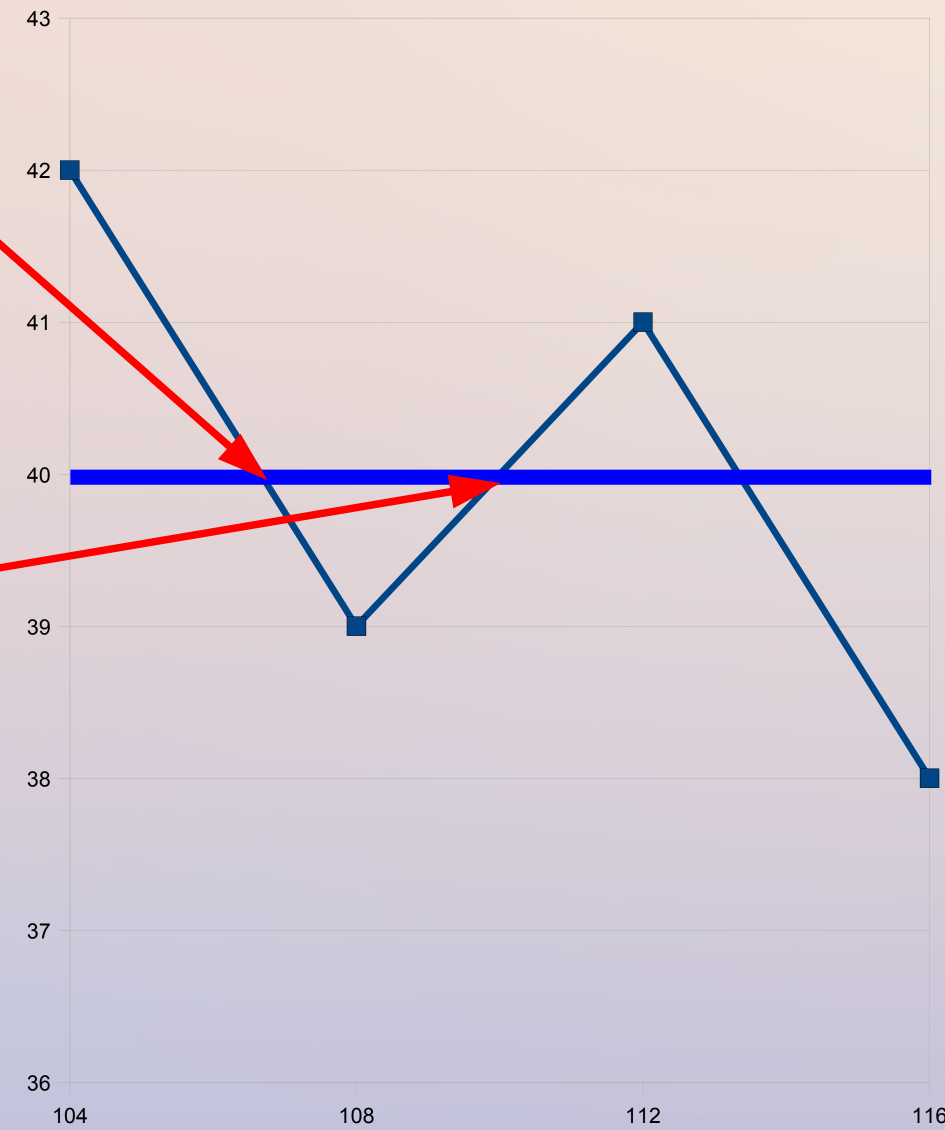
- However, *locally*, noise may cause the *falling edge* (the point at which the measured distance *falls* below *d*) and the *rising edge* (the point at which the measured distance *rises* above *d*) to be right next to each other



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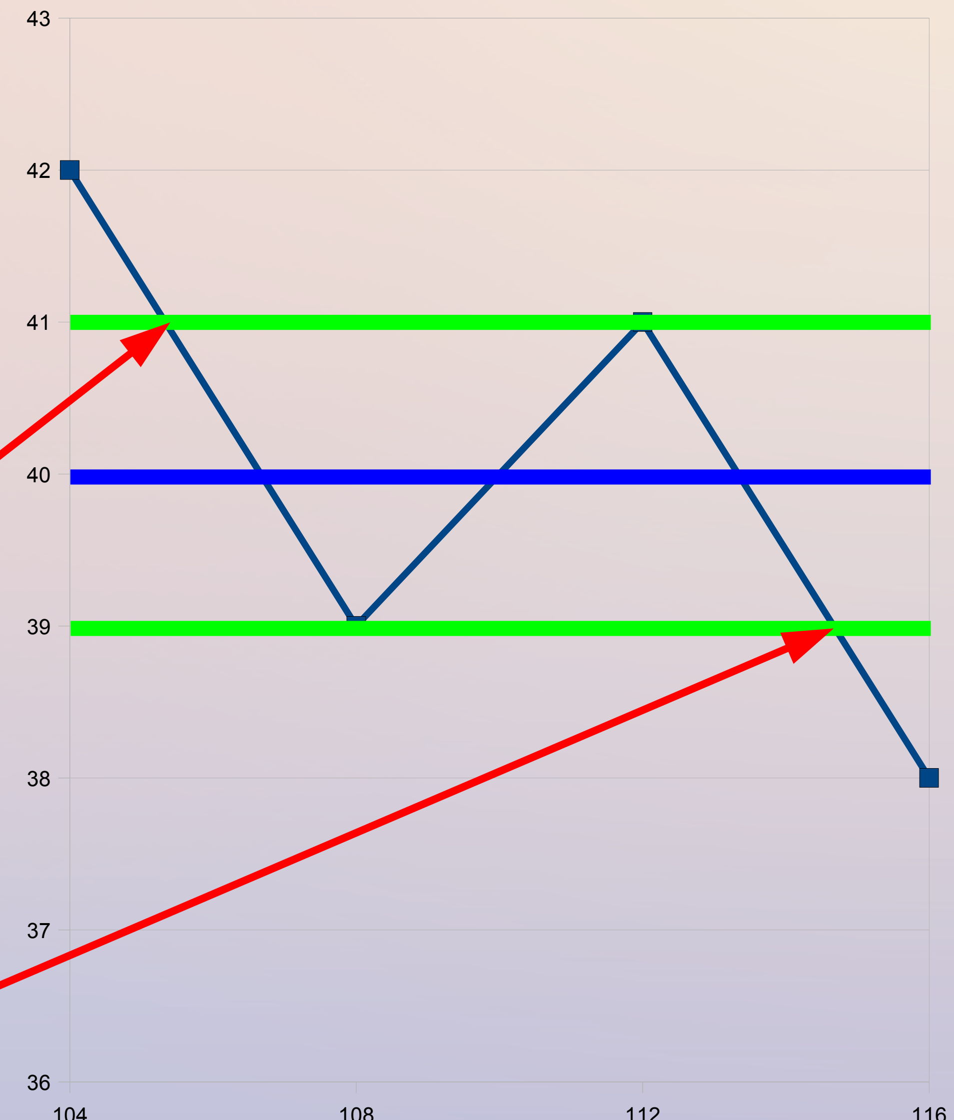
- The solution is to introduce a *noise margin*
- Here, when the measured distance falls below a value $d + k$, it is said to have entered the noise margin
- However, only when the measured distance falls below the value $d - k$ is the falling edge said to be detected



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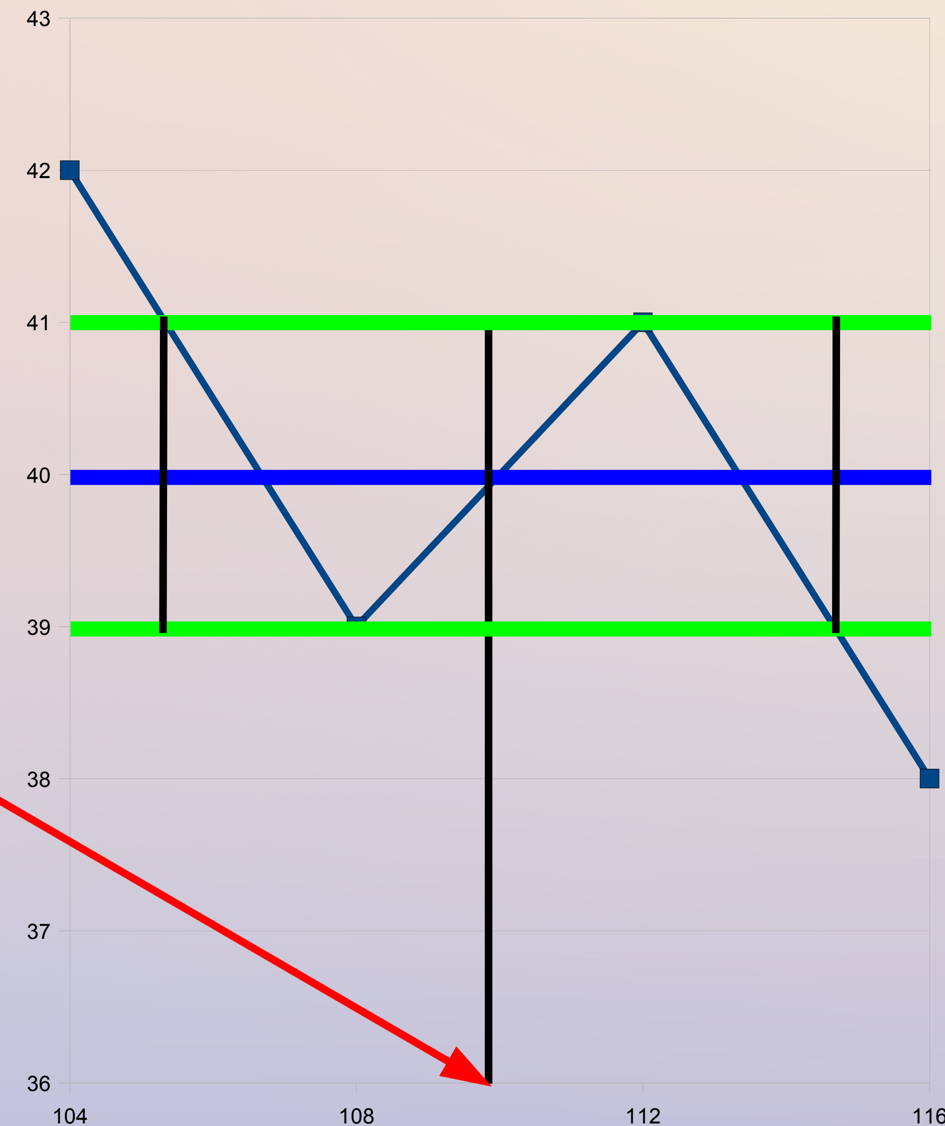
- The angle at which the falling edge is detected can then be taken to be the average of these two points
- In this example, this is roughly $\theta = 110°$
- Note that, although in this example, $k = 1$, the correct values of d and k should be determined experimentally



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- If the robot starts facing away from the walls, it can:
  - Detect a falling edge, switch directions, then detect another falling edge
  - Detect a falling edge, continue in the same direction, then detect a rising edge
- If the robot starts facing a wall, it can:
  - Detect a rising edge, switch directions, then detect another rising edge
  - Detect a rising edge, continue in the same direction, then detect a falling edge

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- When computing the average of the two headings, make sure that the wraparound from 359° to 0° is taken into consideration
- If α and β are the angles at which the back and left walls are detected respectively, then

$$\Delta\theta = \begin{cases} 45 - \dfrac{\alpha+\beta}{2} & \alpha < \beta \\ 225 - \dfrac{\alpha+\beta}{2} & \alpha > \beta \end{cases}$$

where $\Delta\theta$ is the angle to be added to the heading reported by the odometer to orient the robot correctly

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- Note that in the previous slide's equations, the values 45 and 225 are derived from an idealized model of the ultrasonic sensor, and may need to be adjusted
- The actual values can only be determined by experimentation
- Once ultrasonic localization is complete, the orientation of the robot should be known with sufficient accuracy to perform light sensor localization
- This will enable determination of the position and orientation of the robot with greater accuracy than that the ultrasonic sensor can provide

Light Sensor Localization

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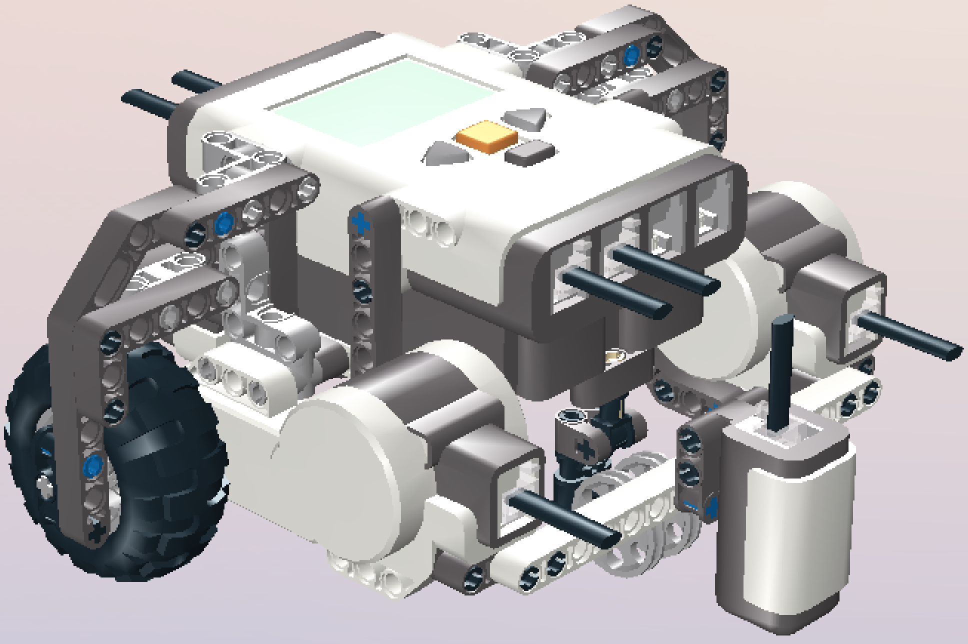
- For this part, the light sensor should be located away from the center of rotation of the robot, as seen on the right
- It will be used to detect grid lines' positions relative to the robot



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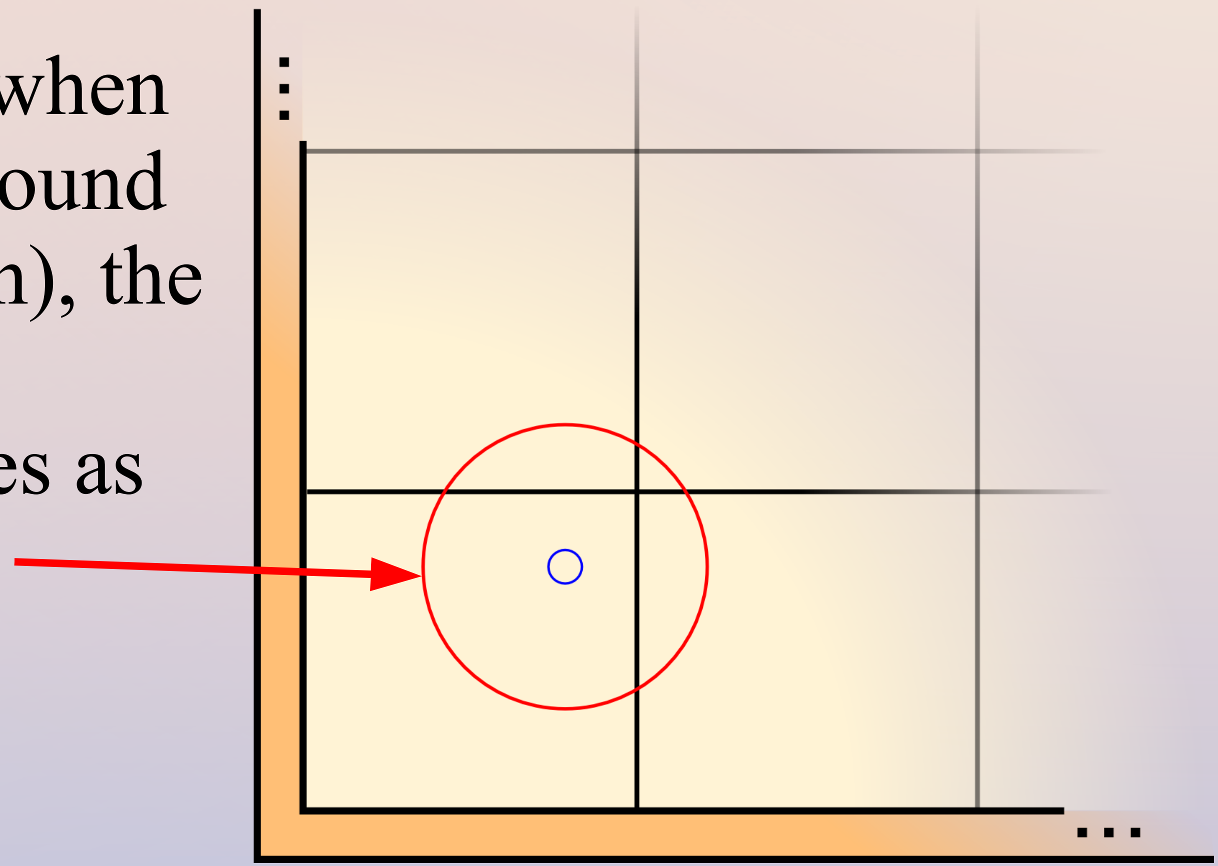
- It is left to the reader to get the robot to a position such that, when rotated on point (around its center of rotation), the light sensor's path crosses the grid lines as shown on the right



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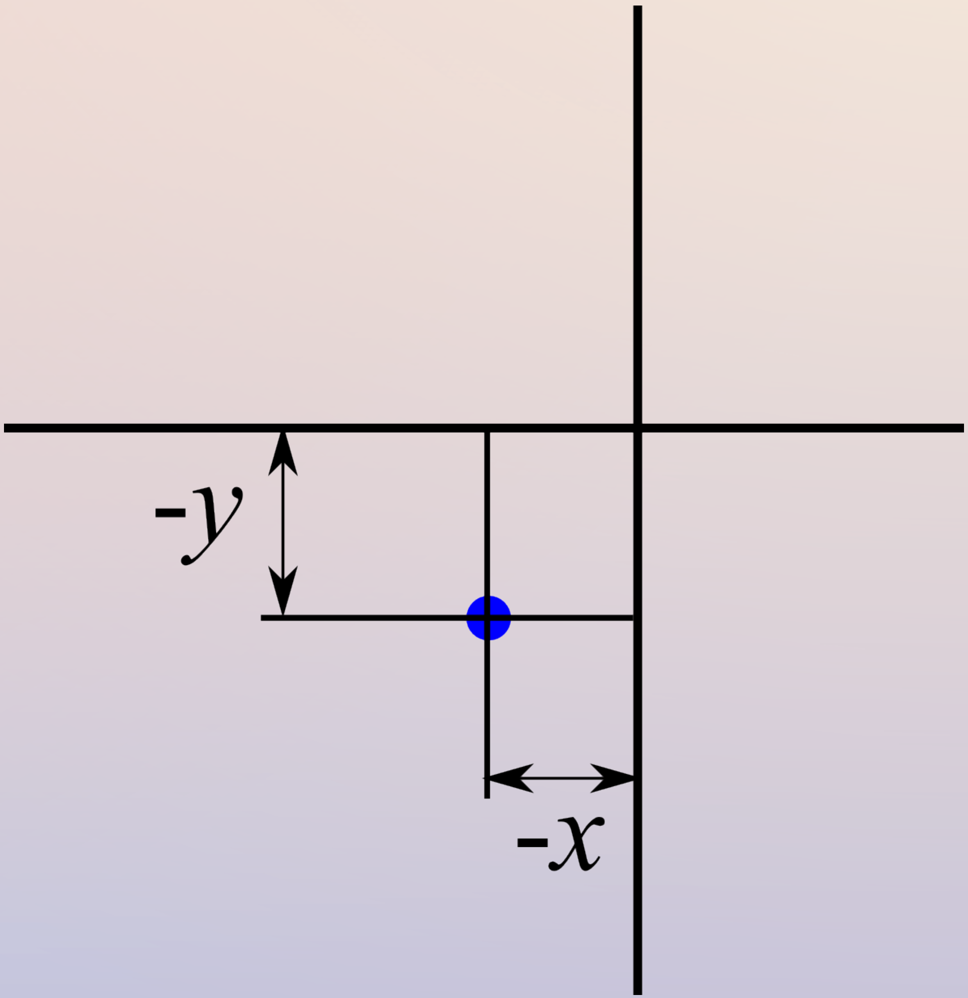
- For this derivation, it will be assumed that the robot (or, more precisely, its center of rotation) exists at a position ($-x$, $-y$)



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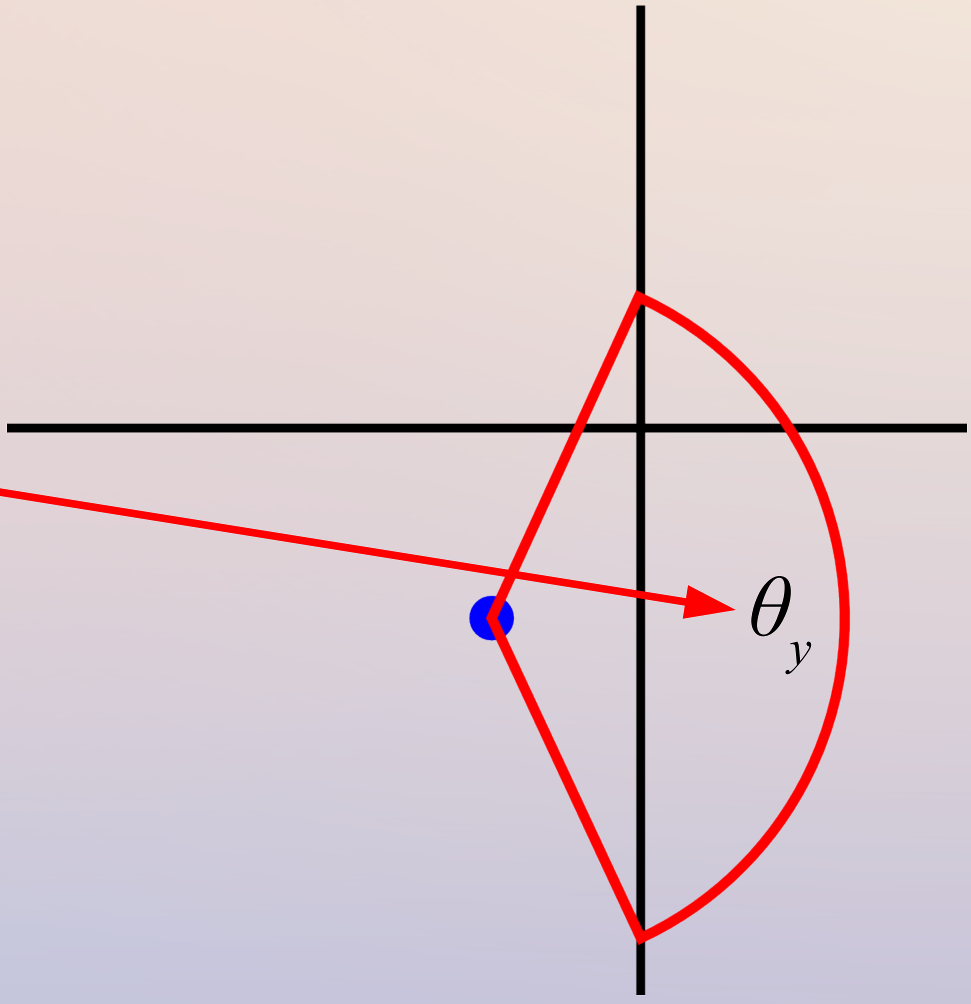
- The angle that subtends the arc connecting the intersections of the light sensor's path with the *y*-axis will be called θ_y



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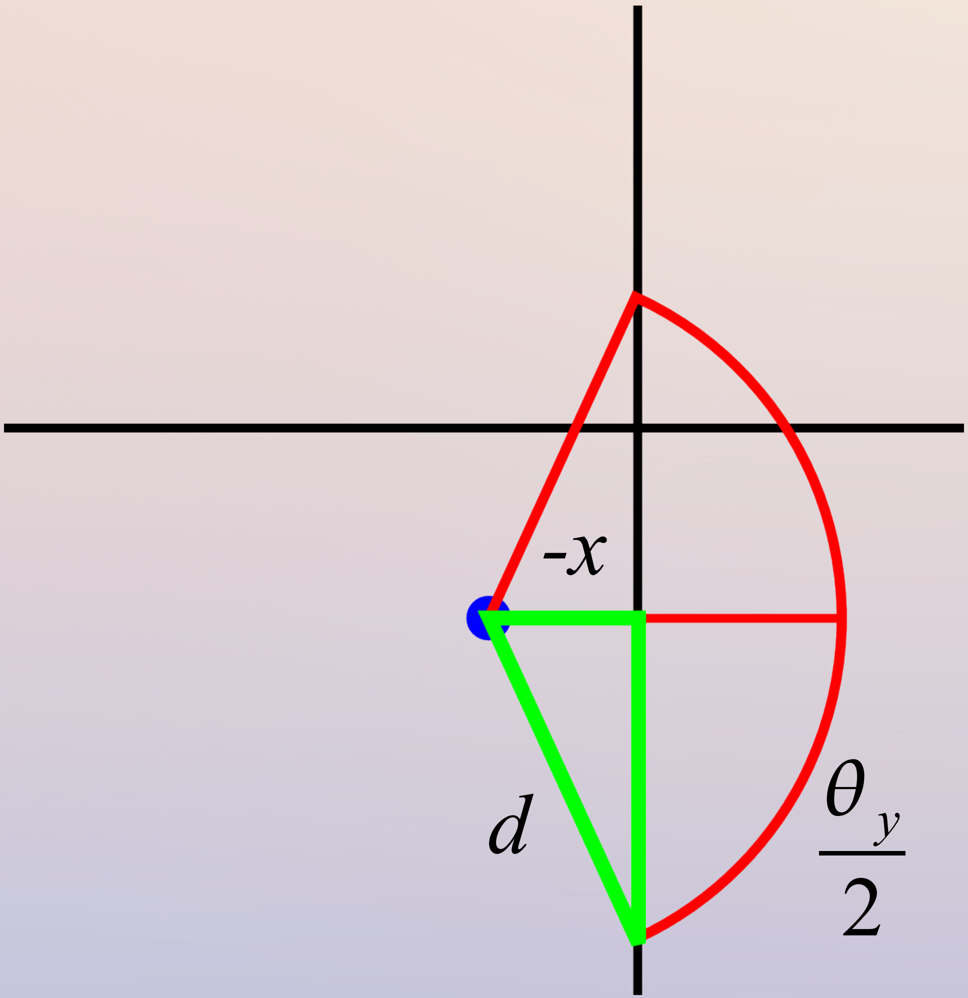
- Using basic trigonometry on the triangle in green, it can be shown that:

$$x = -d\cos\left(\frac{\theta_y}{2}\right)$$

where d is the distance from the light sensor to the center of rotation



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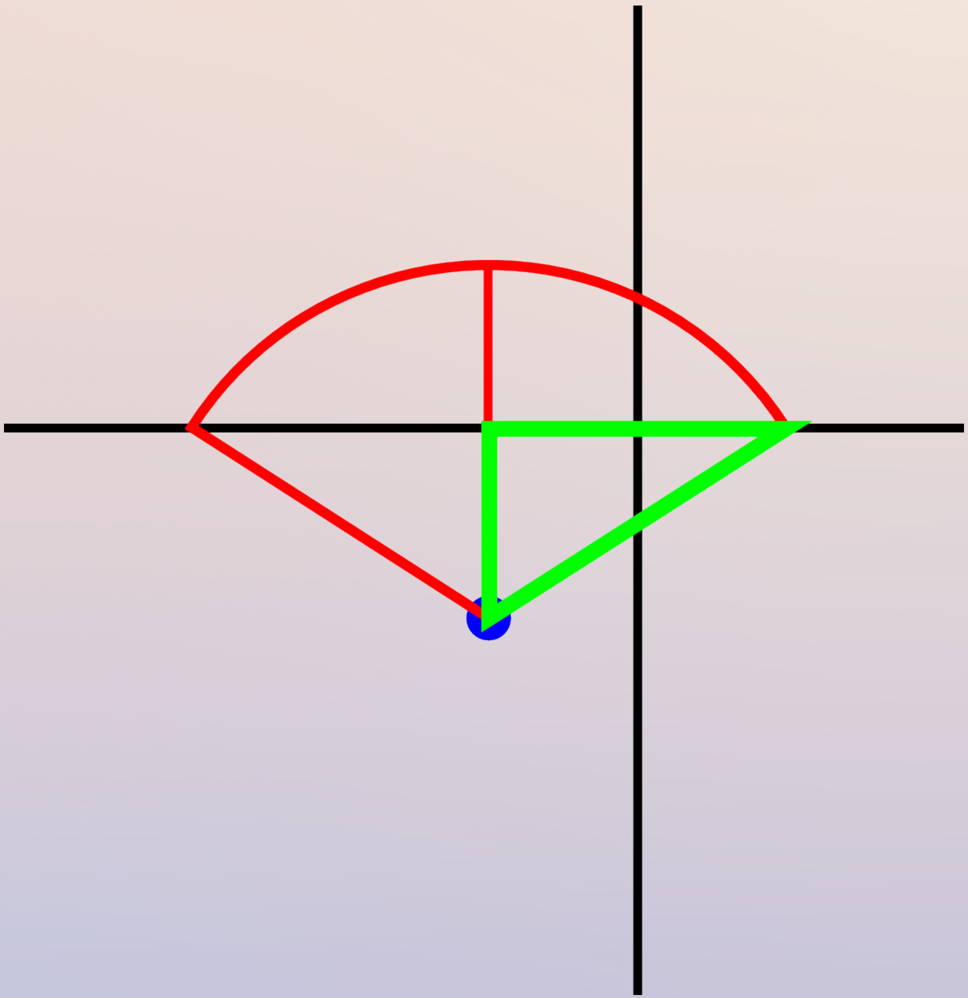
- And similarly for the *x*-axis, we define θ_x



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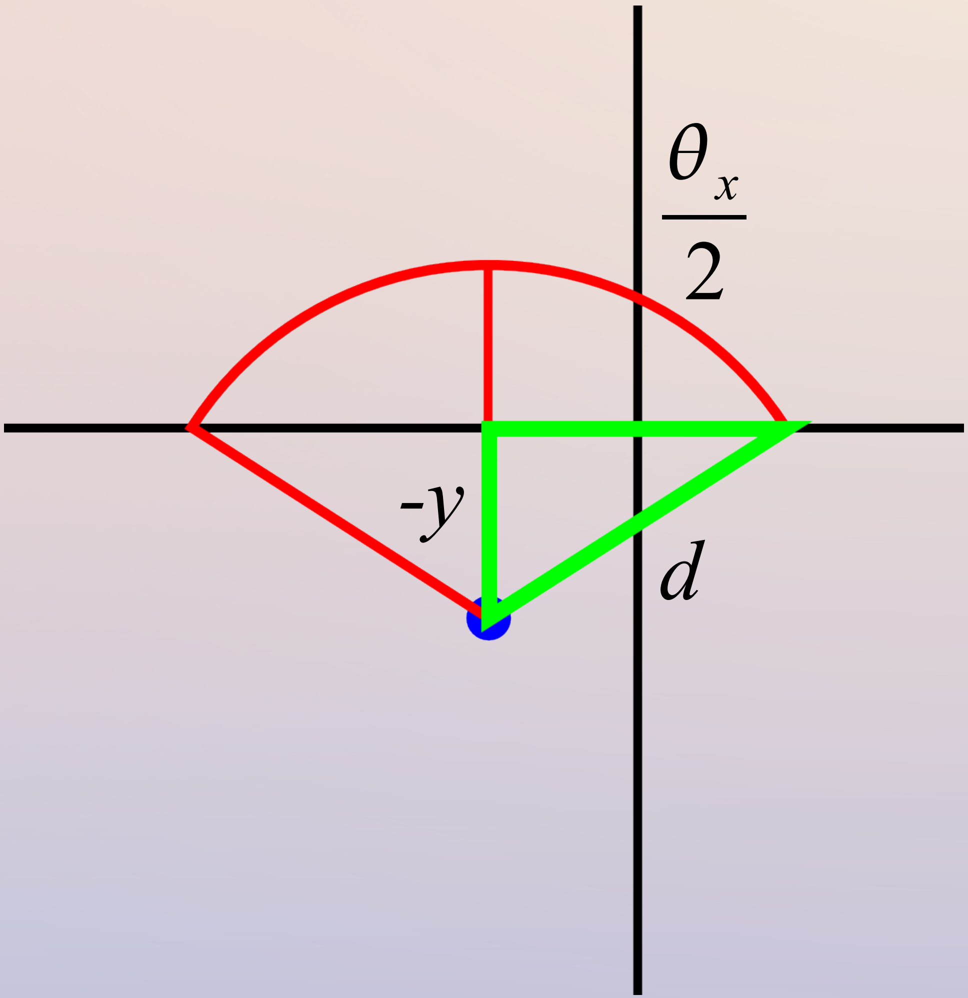
- Yielding the equation:

$$y = -d\cos\left(\frac{\theta_x}{2}\right)$$



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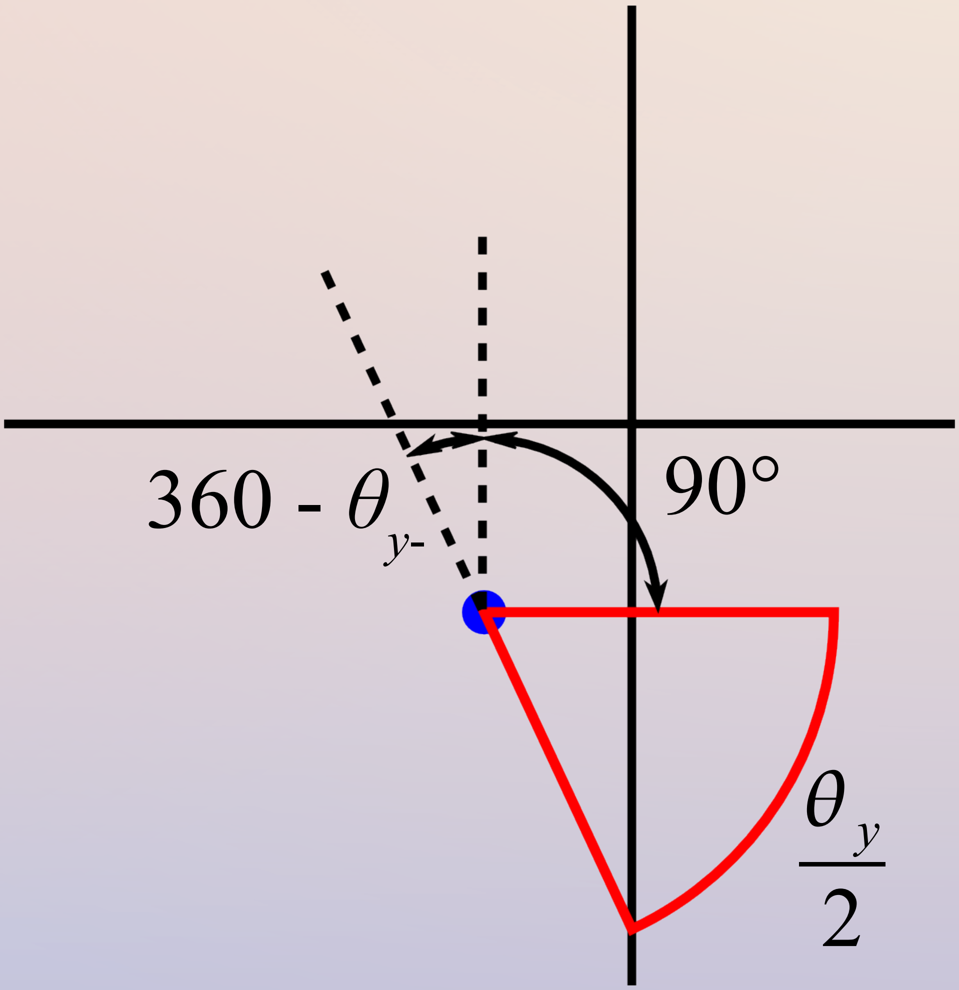
- Finally, if θ_{y-} is the heading of the robot reported by the odometer when the light sensor's path intersects the negative y-axis, then solving:

$$90 = \Delta\theta + (\theta_{y-} - 180) - \frac{\theta_y}{2}$$

for $\Delta\theta$ will yield the angle by which to correct the robot's heading



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- For the correction of the robot's heading, θ_{y+}, θ_{x-}, and θ_{x+} may also be used, however using θ_{y+} is equivalent to using θ_{y-},and similarly for θ_{x+} and θ_{x-}
- Consequently, taking the average of the values $\Delta\theta$ from solving the two equations (one for each axis) may yield a better result
- Be wary of the wraparound from 359° to 0° when performing these calculations
- Note that there is no need using this process to move the robot to the origin

Summary

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- First, the ultrasonic sensor, an inherently low-resolution sensor, was used to get a rough approximation of the robot's orientation
- This approximation need only be sufficiently accurate to position the robot such that the light sensor localization succeeds (see slide 21)
- Then, the light sensor, a higher resolution sensor, was used to determine the position of the robot with higher accuracy on the field