Lab3 Write-up Questions

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1. The system consists of two sensors, the LiDAR, and the camera. The overall effective sampling time of the system is the longest sampling time between the two sensors. The LiDAR scans at around 300 rpm (or 1800 degrees/sec) and obtain 360 samples per round (or 1800 samples/sec = 1800 Hz sample rate, or 5 Hz scan rate). Even with a subscriber-based system where synchronization is not crucial. The smaller the sampling time / the higher the sampling rate is, the better the control system can respond to the changes in the inputs. As demonstrated during lectures, in discrete time, two PID controllers implemented with the same parameters behave very differently at different sampling rate. The controller with a higher sampling rate / lower sampling time not only has a lower chance of getting input signal aliasing (losing higher-frequency components of the signal), but also controls the system to fit/stabilize for input signals more robustly.
2. We used P/PI control. As differential control is not mission-critical in our control system. To be specific, our object (a frisbee) is rather large for the camera's field of view at reasonable LiDAR range (around 0.6 – 2 m). Any sudden angular movement of the robot will quickly overshoot and escalate into oscillatory rotation. On the other hand, integration is more crucial to us to smooth the robot movement and reduce overshoot. However, with only proportional control feedback we are able to achieve acceptable robot performance, no integration control is implemented in the code.
3. To deal with windup, we setup upper/lower limits for K_i and set K_i to zero every time the input is saturated. To deal with noise/fast change in the object's location, we filtered the sensor data to remove the high-frequency components. To reject disturbances with just a

proportional control, we can experimentally determine the K_p values with the best disturbance rejection under realistic operating conditions.

4. A system is unstable when its state variables will continuously increase without a bound. For such a system, any small disturbances in inputs will inevitably drag the system out of bounded state and goes to infinity/negative infinity/saturation. For our robot, it will rotate back and forth, trying to center the detected object in the field of view of the camera, but overshoots more and more, eventually lose track of the object in the field of view.
5. Obtain LiDAR and camera sensor data. Image processing the camera captured image data frame by frame and identify our object (a frisbee). The captured object coordinates on the image are published to the topic /object_coordinates with the following format.

   format:[top_left_x,top_left_y,bottom_right_x,bottom_right_y,length,width]

   The object coordinates $x_{top\ left}, x_{bottom\ right}$ on the image are translated to the start, end, and center angle $\theta_{left}, \theta_{right}, \theta_{center}$ in polar coordinates.

$$\theta_{left} = -\left(\frac{x_{top\ left}}{Length_{object}} - 0.5\right) \cdot 0.7\theta_{camera\ perception} - \theta_{error}$$

$$\theta_{right} = -\left(\frac{x_{bottom\ right}}{Length_{object}} - 0.5\right) \cdot 0.7\theta_{camera\ perception} - \theta_{error}$$

$$\theta_{object} = -\left(\frac{x_{center}}{Length_{object}} - 0.5\right) \cdot \theta_{camera\ perception}$$

   The LiDAR data with the start and end angle is used to obtain an average distance of the identified object. The start and end angles are converted into indexes $Bound_{left}, Bound_{right}$ of LaserScan.ranges[] in topic /scan and the average distance of the object d_{object} is published with its angle of deviation θ_{object} from the robot.

$$Bound_{left} = round\left(\frac{\theta_{left}}{\theta_{increment}} \cdot 1.0\right)$$

$$Bound_{right} = round\left(\frac{\theta_{right}}{\theta_{increment}} \cdot 1.0\right)$$

The distance d is feed into a proportional controller (with parameter K_p) to obtain the velocity vectors ω, v for the robot to approach and stop at a desired distance $d_{desired}$ from the object as shown in Figure 1.

$$tan\theta_{object} = \frac{\omega \cdot L}{v}$$

$$v = K_p(d - d_{desired})$$

$$\omega = \frac{v \cdot tan\theta_{object}}{L}$$

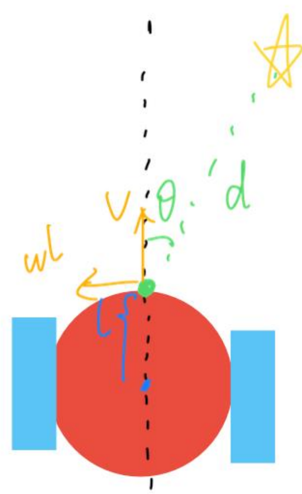

Figure 1