EECS192 Lecture 6
Feb. 25, 2020

Announcements

1. 3/3 Quiz 3: TSL1401 line camera
2. CalDay Sat. April 18 10 am @ UCB
3. 3. HW 1 due 3/3

Topics

- Upcoming checkpoints
- Q2 Solution
- Velocity Control (recap)
- HW1 Track Detection (recap)
- Steering control (intro)
- Telemetry logging

Upcoming Checkpoints

2/21 C4: easy, work ahead!
C4.2: Line camera image capture with exposure control.
C4.4.4 Line camera calibration: measure track lateral displacement in mm
HW 1 line detection (due 3/3)

2/28 C5: may be harder, mounting, prototyping velocity sensor, writing control code
C5.3: BBBL, motor driver, velocity sensor mounted to car
C5.4: Basic track detection and wheels turn toward track (benchtop)
C5.5: basic velocity sensor, estimation and benchtop control: 3 m/s.

3/6 C6.3: The vehicle must complete the figure-8 course completely autonomously in under 3 minutes.
C6.3.4: running with velocity control

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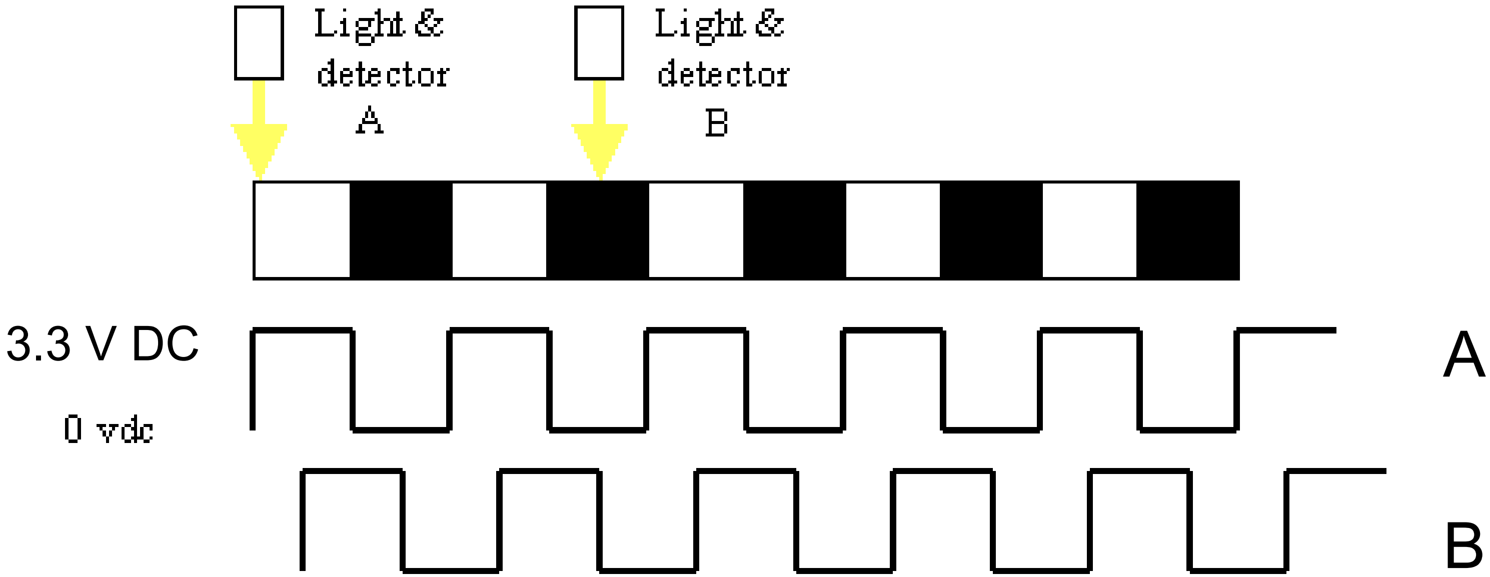
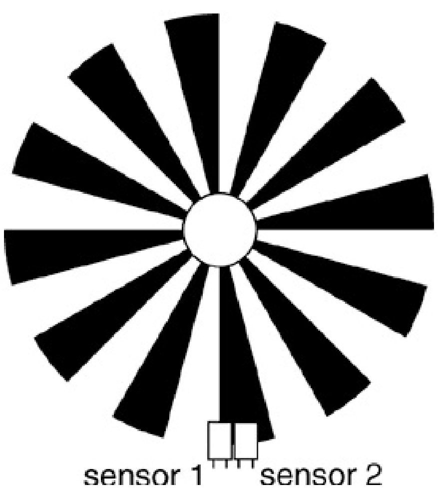
Quadrature Encoder



https://www.sinotech.com/wp-content/uploads/quadrature-encoder.gif

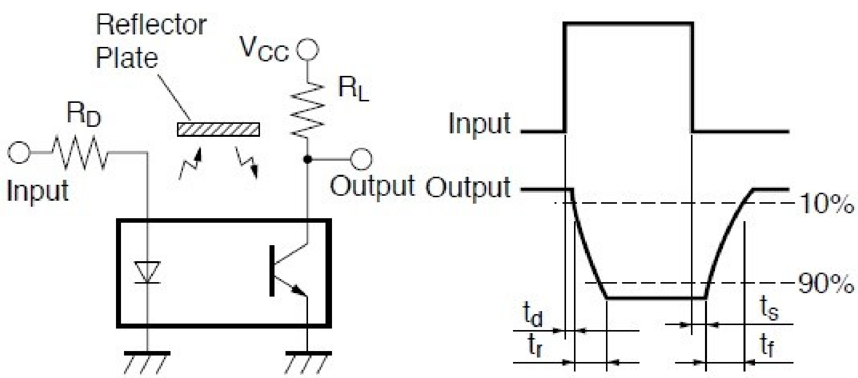


Fab suggestion: aluminum foil covered with black paper with slots. 4 slots probably enough. Note: sensors can be placed where convenient- don't need to look at same slot.

http://codeforfree.weebly.com/uploads/1/0/1/6/10160088/5858962_orig.png

Sharp GPS260

Fig.9 Test Circuit for Response Time



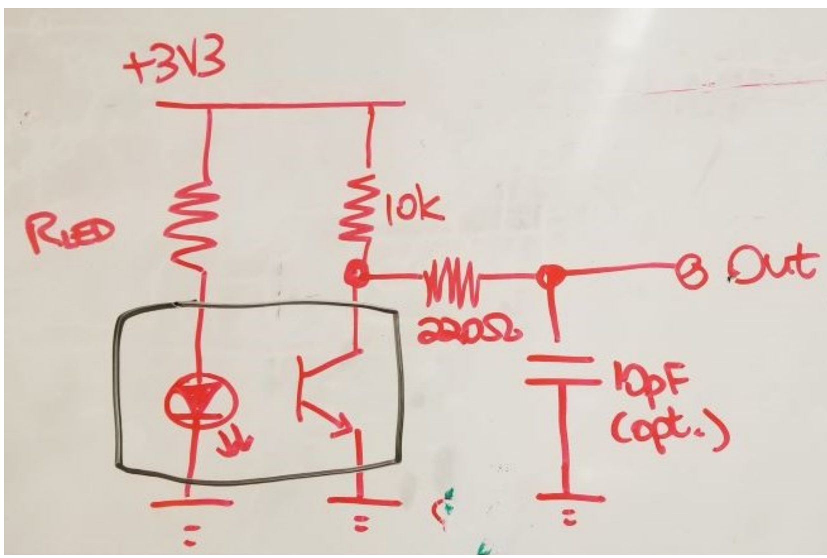
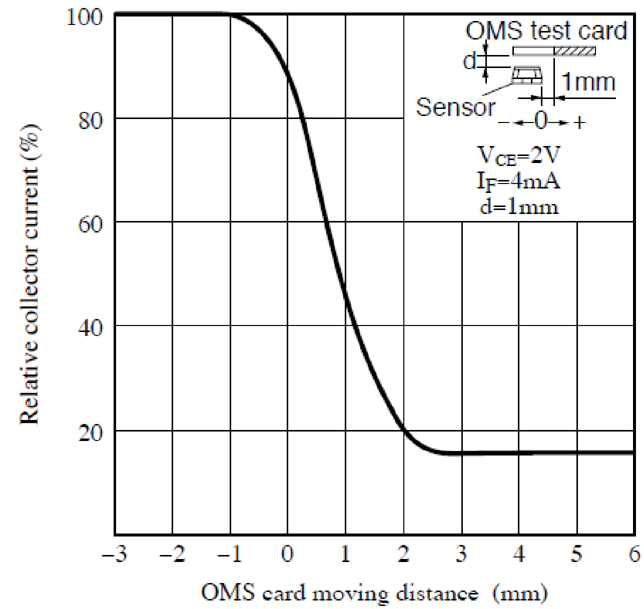
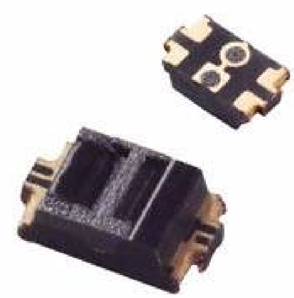


Fig.13 Detecting Position Characteristics (2)

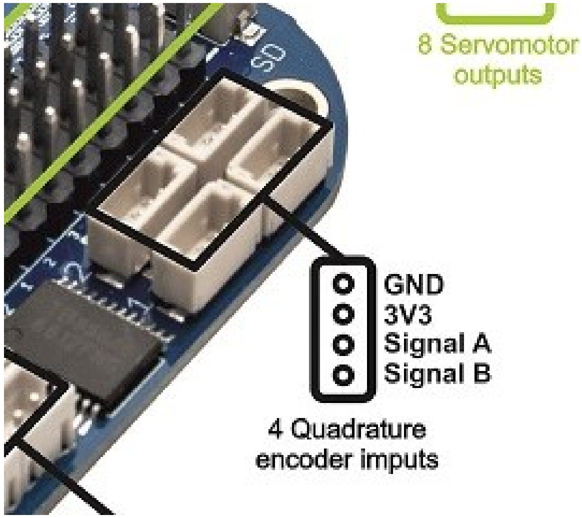


- Choose current 4 mA in LED
- Vcc = 3.3 V
- May want regulated/clean voltage for Vcc



100 us response time

Beagle Bone Blue Quad Encoder

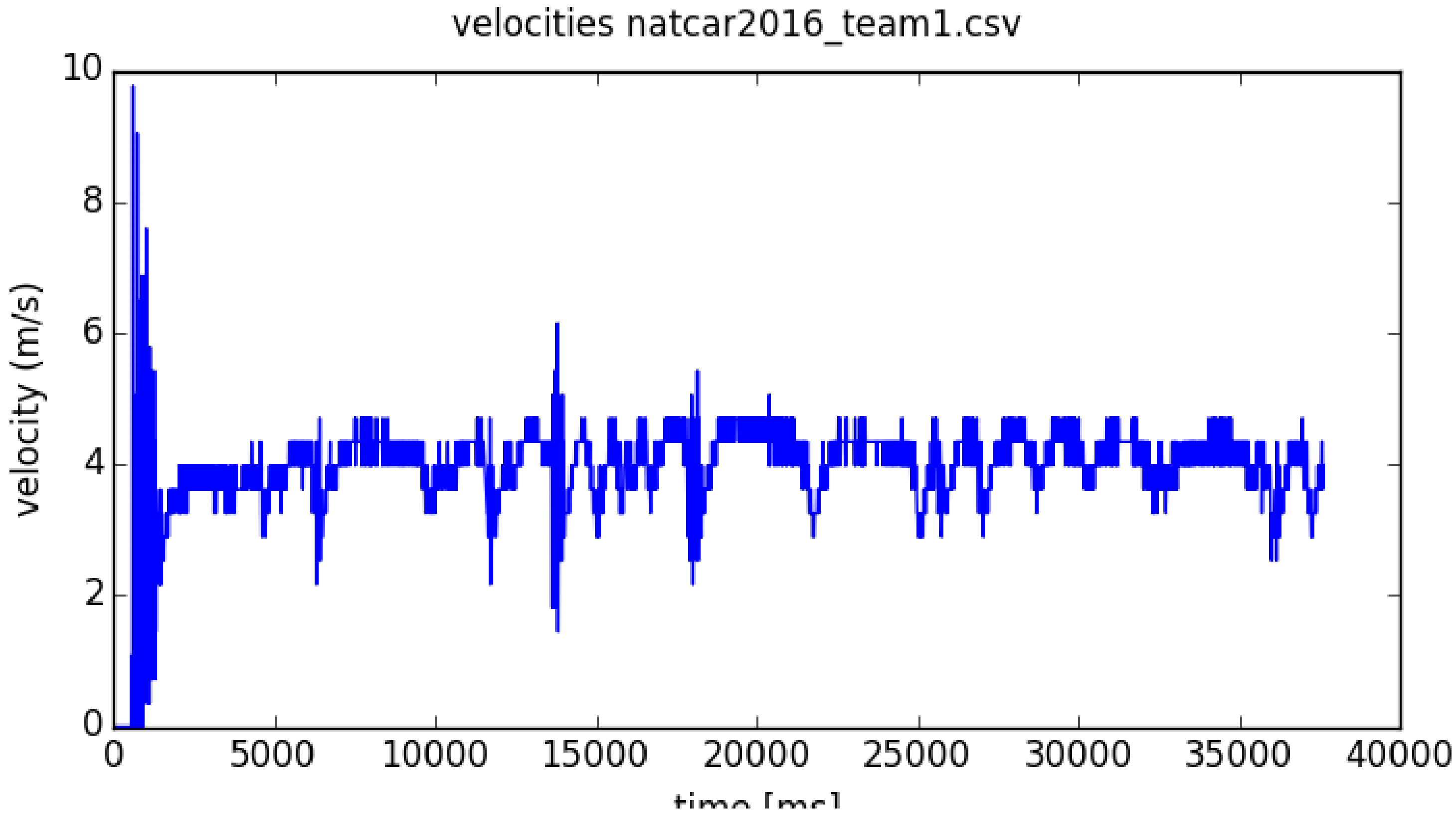


int rc_encoder_read (int ch)

Returns
The current position (signed 32-bit integer)
or -1 and prints an error message is there is a problem.
Ch 1-3 are available
Examples:
rc_test_encoders.c.

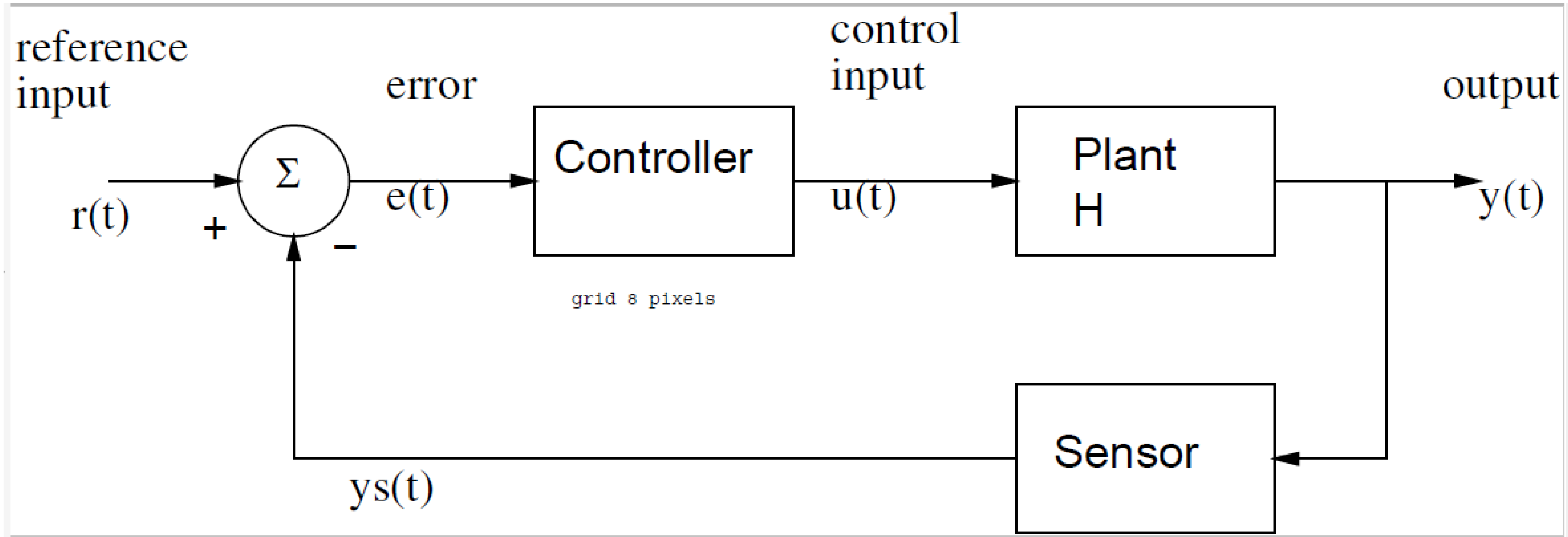
Velocity Sensing

- On board: estimating $\Delta x/\Delta T$



Note: care about velocity sensing usually at cruise speed (also stopping)

Velocity control overview



On board…

Proportional control:

U = kp*e = kp* (r-y);

Here: r is desired velocity, U is PWM %

Proportional + integral control

```
U = kp*e + ki * e_sum;
e_sum = e_sum + e;
```

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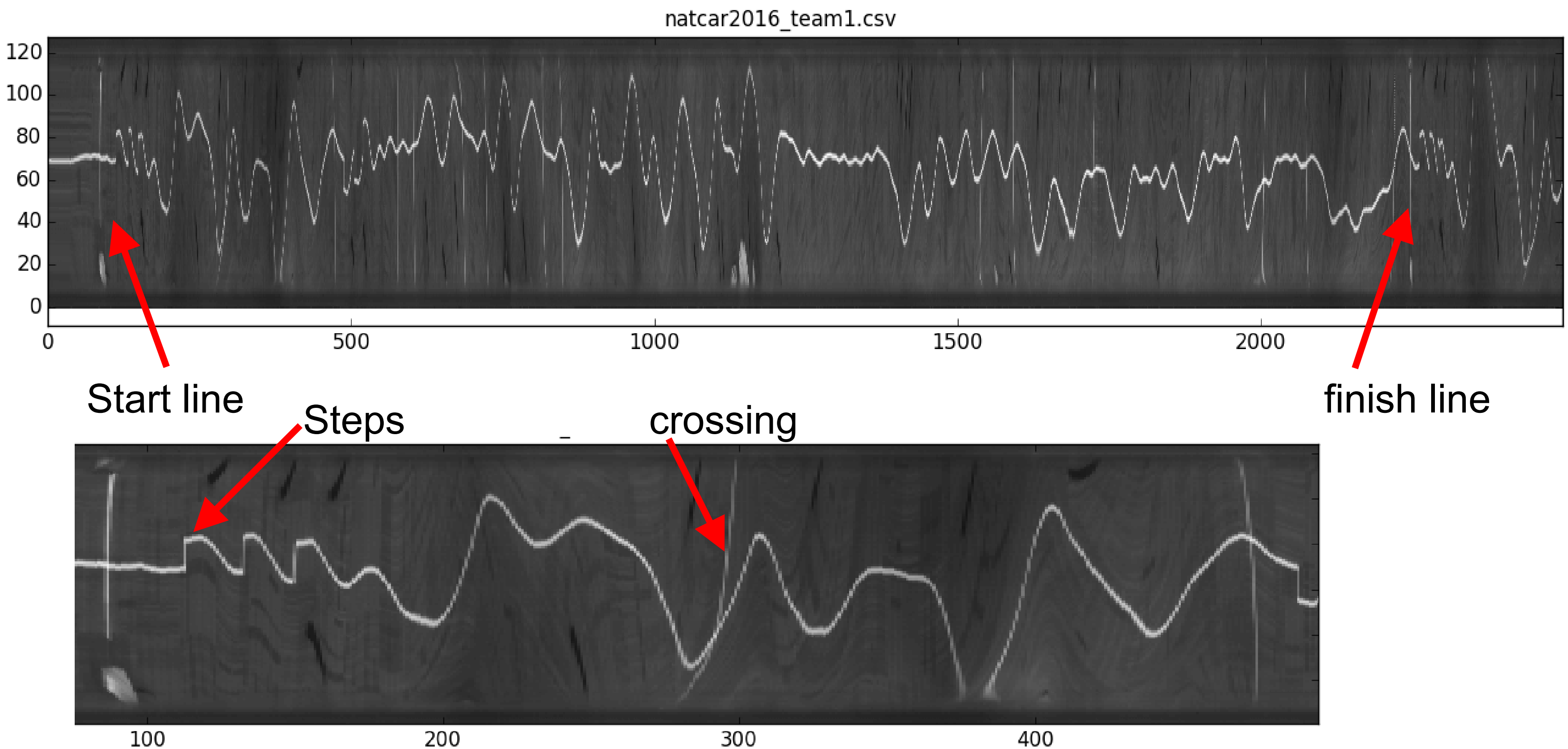
Python Template for Track Finding

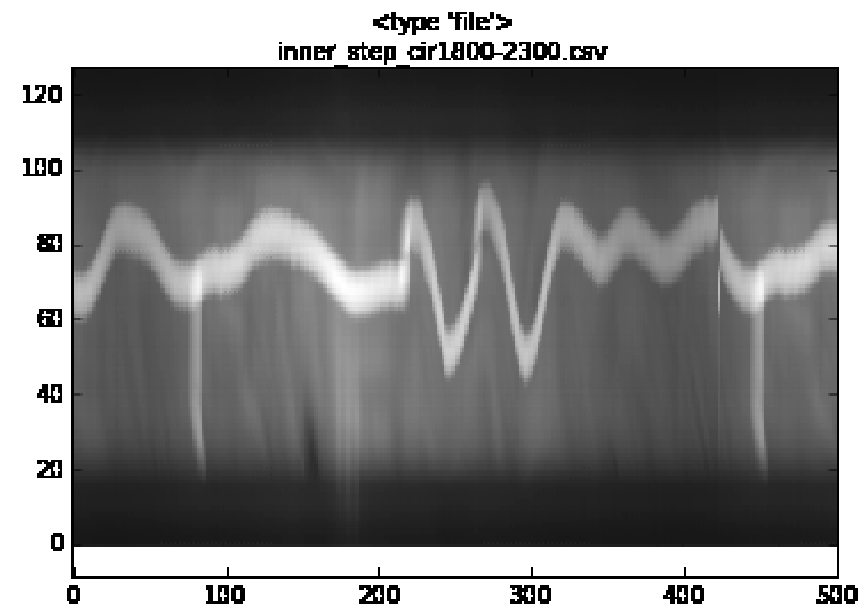
track_center_list - A length n array of integers from 0 to 127.
Represents the predicted center of the line in each frame.
track_found_list - A length n array of Booleans {10,100}.
Represents whether or not each frame contains a detected line.
cross_found_list - A length n array of Booleans {10,100}.
Represents whether or not each frame contains a crossing.



Possible algorithms for line detection

e.g. scipy.signal.filter. Many options. Here 3 suggestions:

- Subtraction- to find left and right edge of line (ok if not noisy, somewhat lighting invariant)
- Difference of gaussians (idea is to smooth then differentiate)
- Correlation (best match position for known features)
  - scipy.signal.correlate



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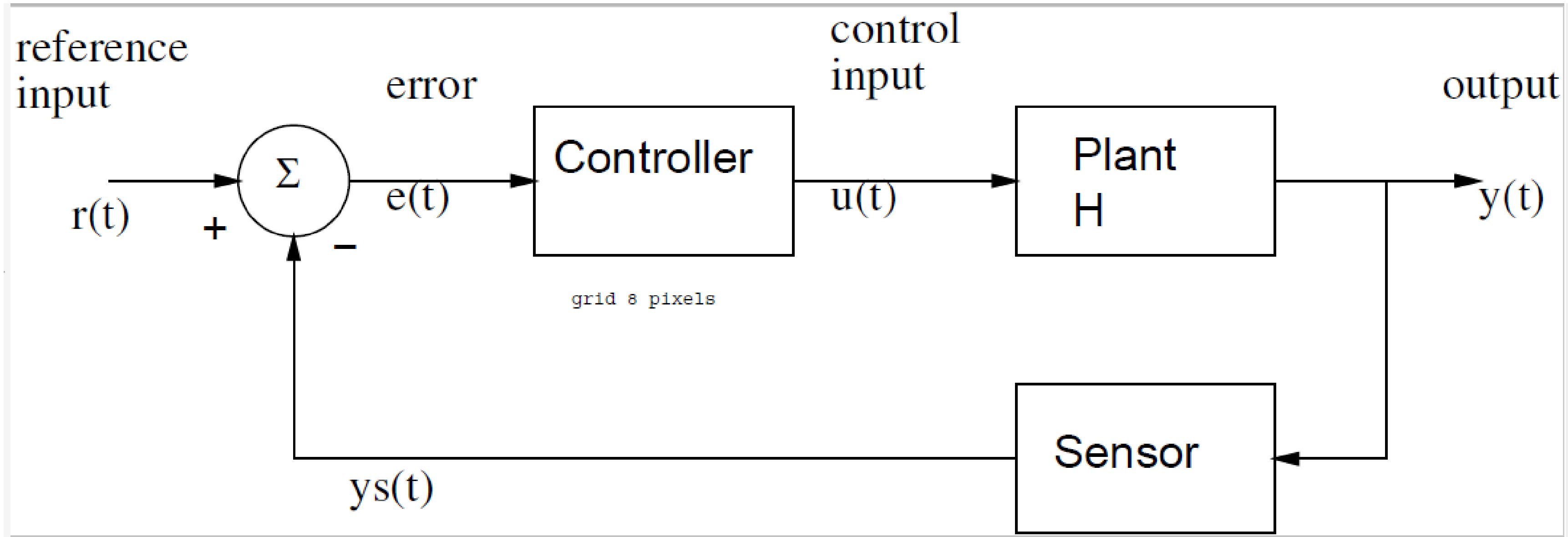
Steering Control overview



On board…

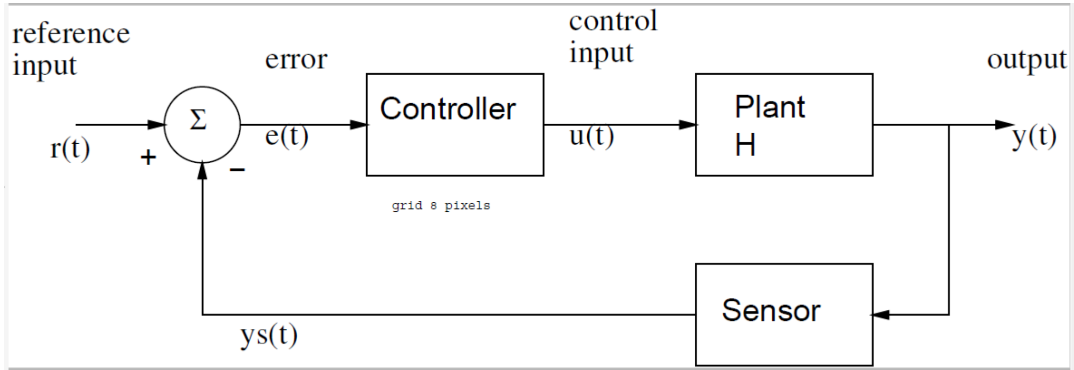
Proportional control:

U = kp*e = kp* (r-y);

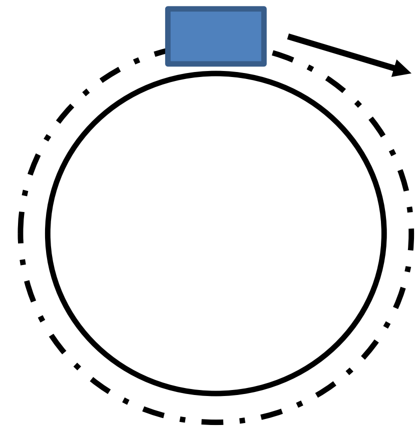
Proportional + integral control

```
U = kp*e + ki * e_sum;
e_sum = e_sum + e;
```

Bicycle Steering Control



Note steady state error:
car follows larger radius

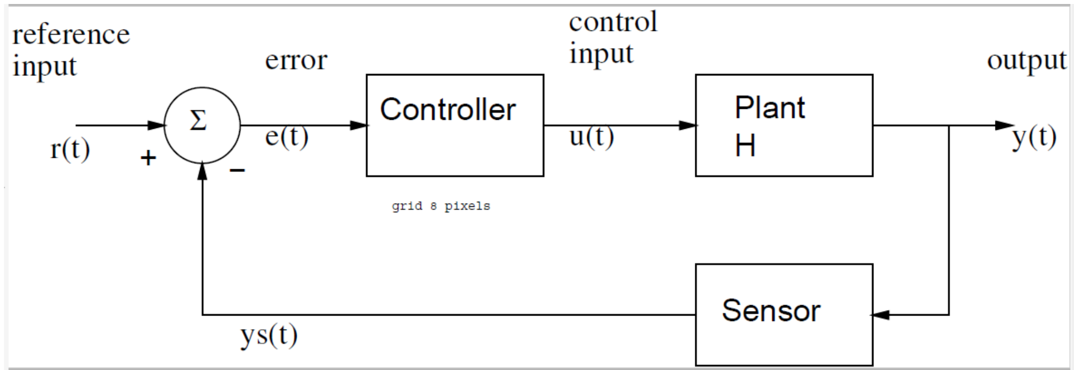


Proportional control:
r = 0 (to be on straight track)
δ=u = kp*e

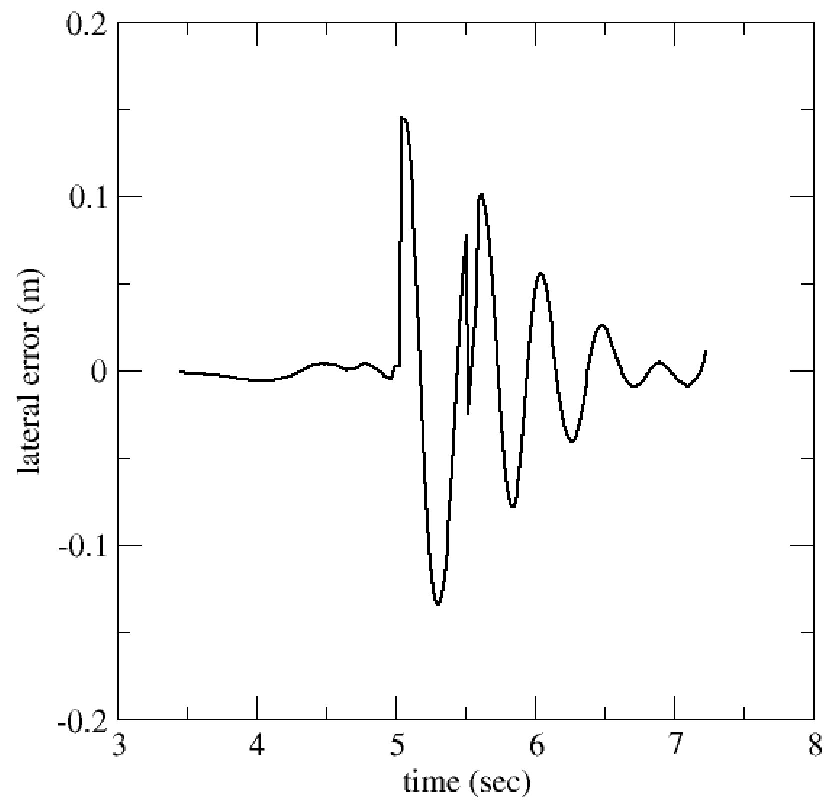
Proportional+derivative

P+I+D

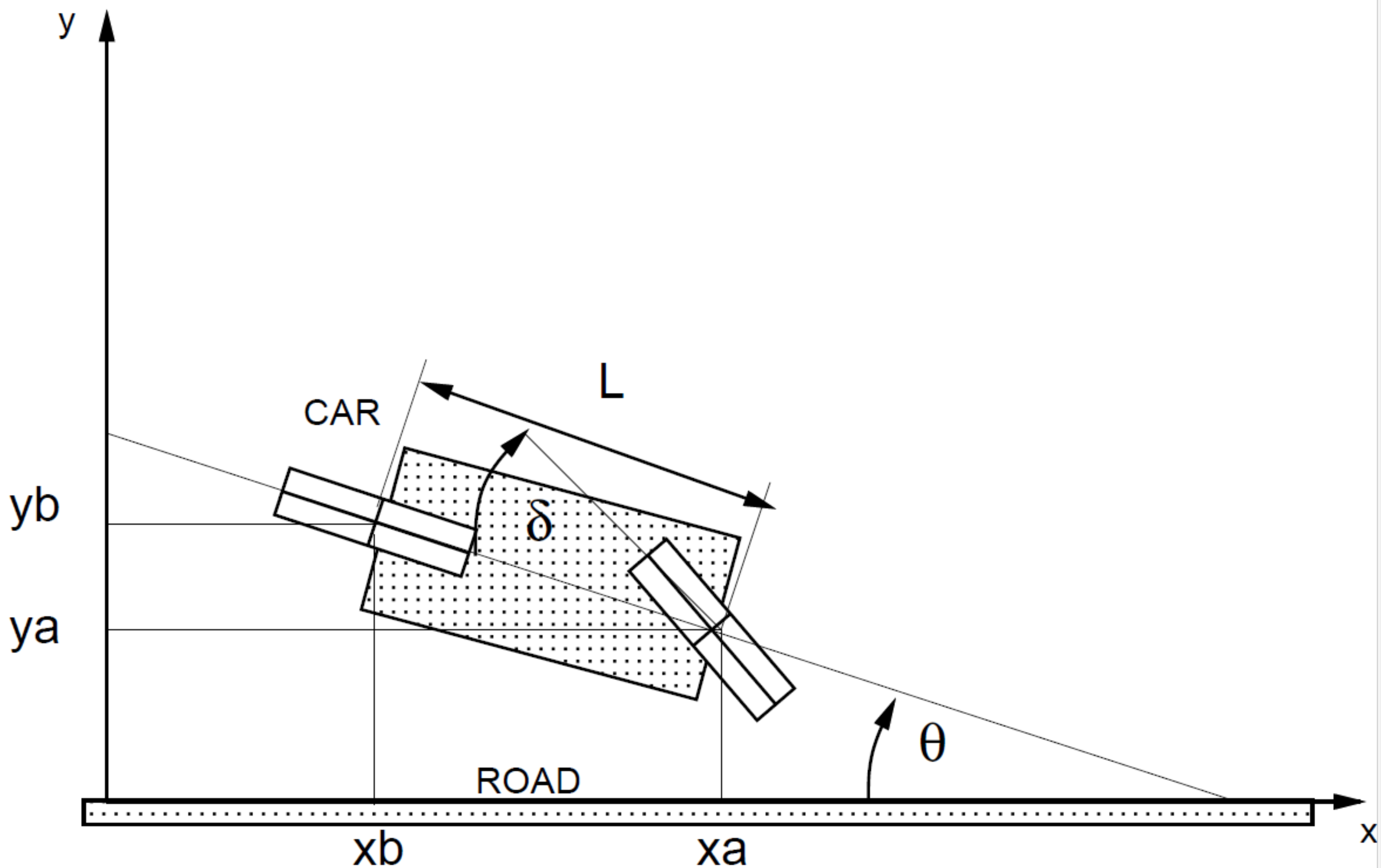
Steering Control- PD



Example under-damped steering:

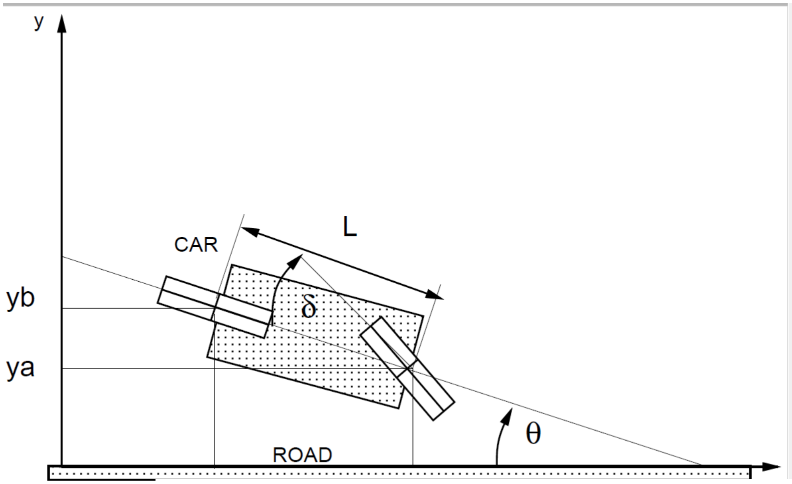


Bicycle Steering Model



Equations On board

Bicycle Steering Model



Proportional control:

$$\delta(t) = k_p y_a(t)$$

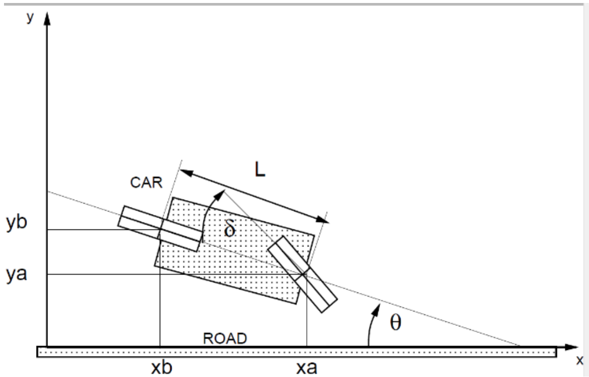
$$\ddot{y}_a + V k_p \dot{y}_a(t) + \frac{V^2}{L} k_p y_a(t) = 0.$$

Eigenvalues:

$$\lambda_{1,2} = \frac{V}{2}\left(-k_p \pm \sqrt{k_p^2 - \frac{4k_p}{L}}\right)$$

On board

Bicycle Steering Model



Proportional control: $\delta(t) = k_p y_a(t)$

$$\ddot{y}_a + V k_p \dot{y}_a(t) + \frac{V^2}{L} k_p y_a(t) = 0.$$

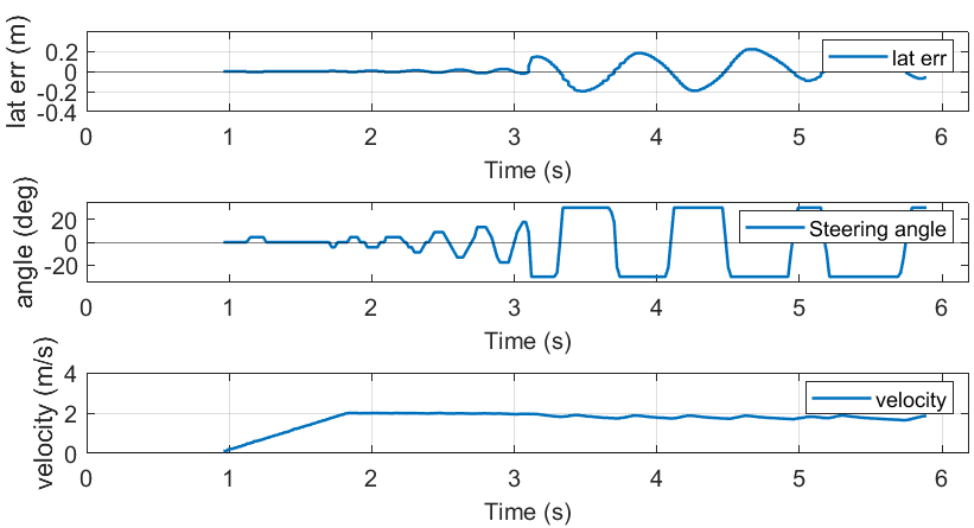
Eigenvalues: $$\lambda_{1,2} = \frac{V}{2}\left(-k_p \pm \sqrt{k_p^2 - \frac{4k_p}{L}}\right)$$

Critical damping: $\lambda_1 = \lambda_2$ ➔

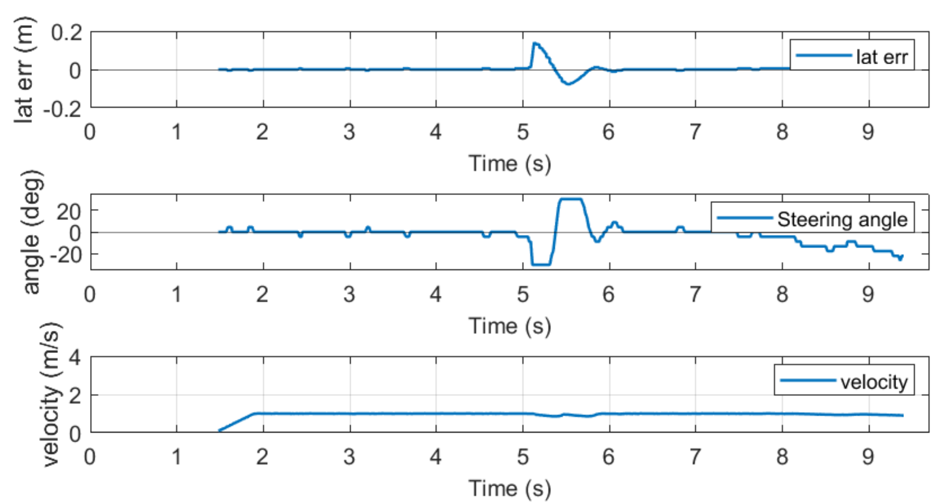
$k_p^2 = 4\ k_p/L$ or $k_p = 4/L = 4/0.3$ m = 13 rad/m = 760 deg/m

At 2 m/s, doesn't work well- servo saturates, also simulation dynamics…

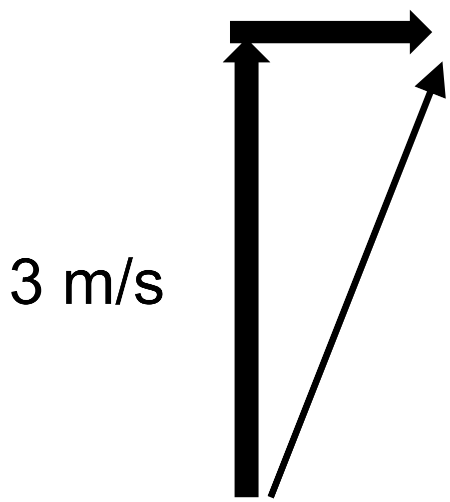
2 m/s k_p =800 deg/m Kd = 0

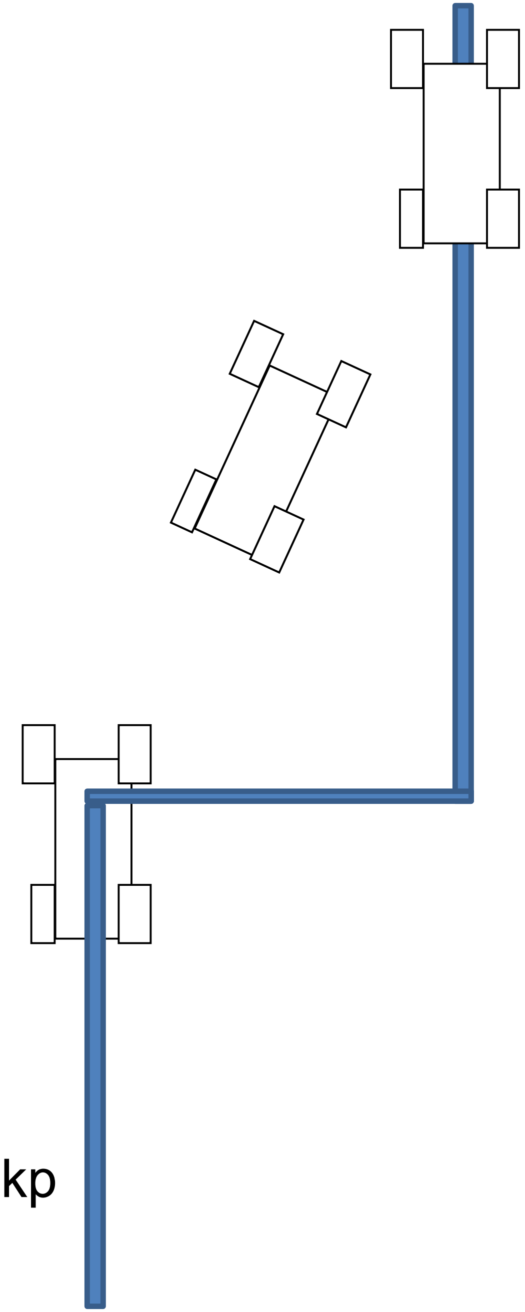


1 m/s k_p =800 deg/m Kd = 0



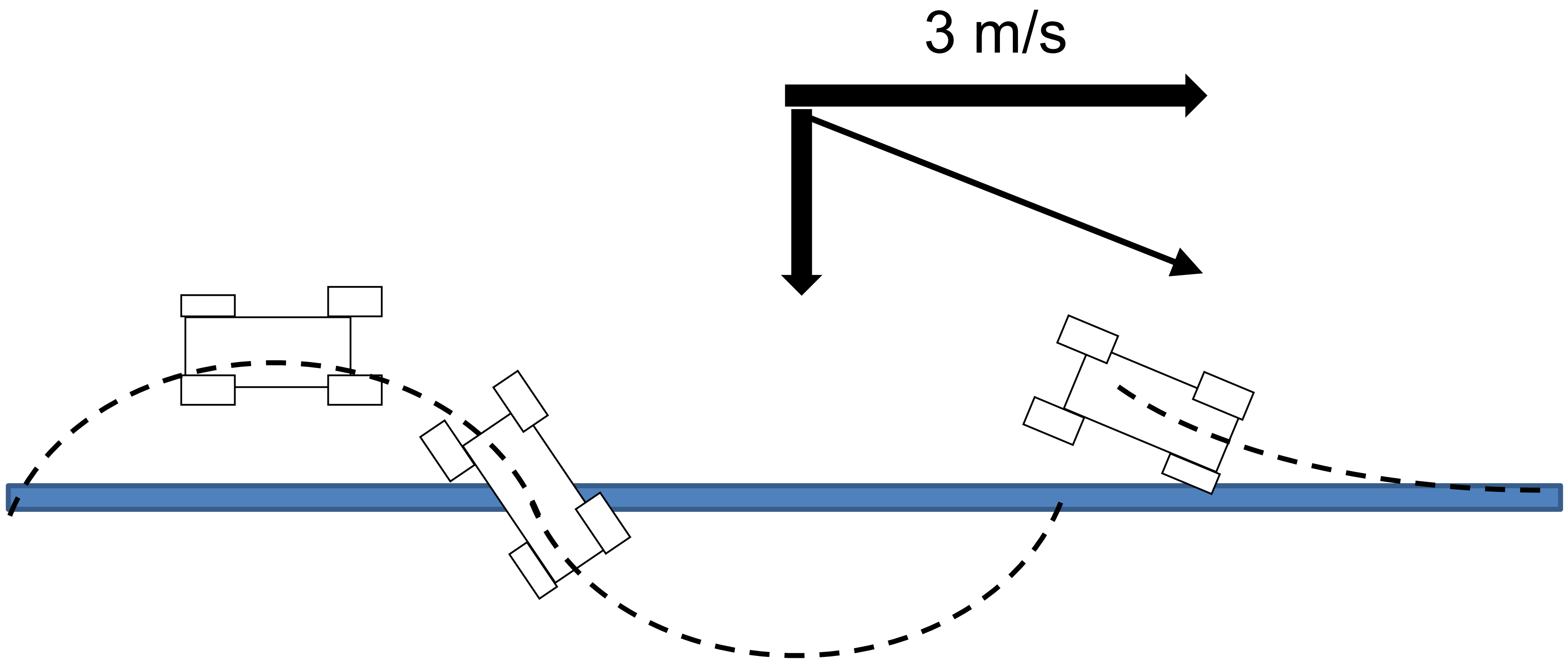
PD parameters





Step: 15 cm
Choose step response 1m = 300 ms
Then lateral velocity = 15 cm/300 ms = 0.5 m/sec
At mid point:
$\delta = 0 = kp\ 7.5\ \text{cm} + kd\ 0.5\ \text{m/sec} \Rightarrow kd \sim [0.15\ \text{sec}]\ kp$

PD parameters



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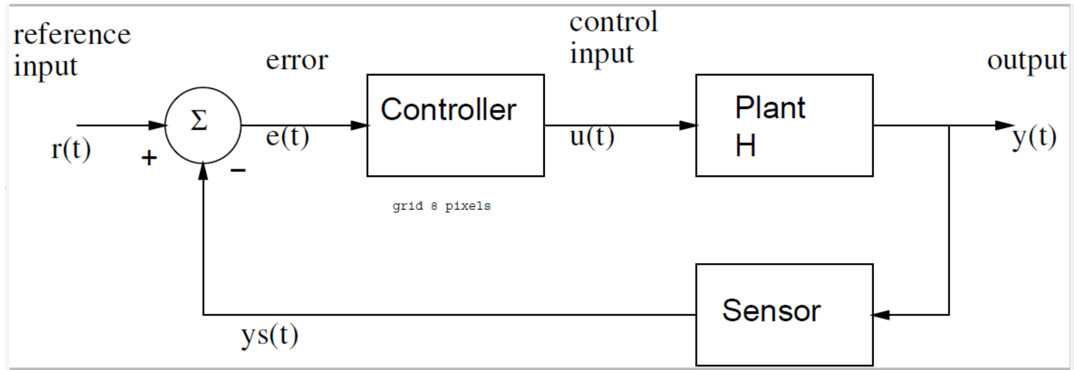
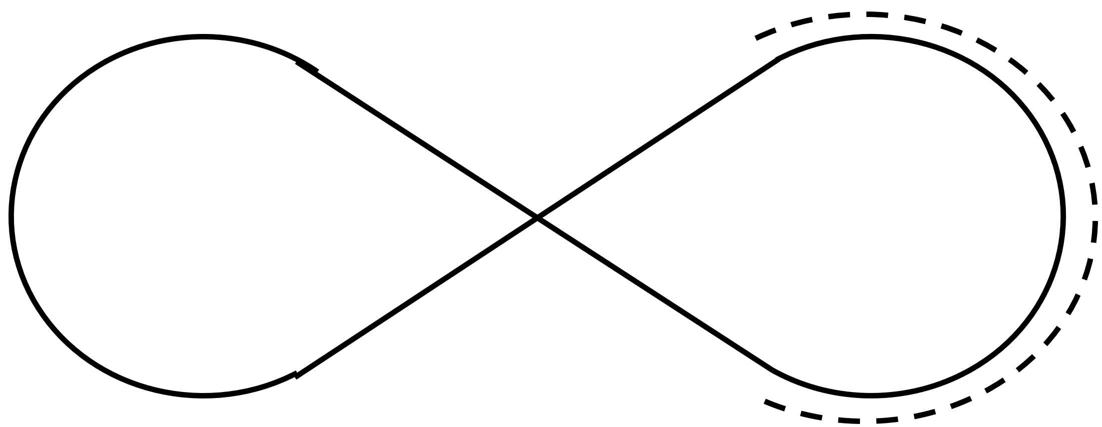
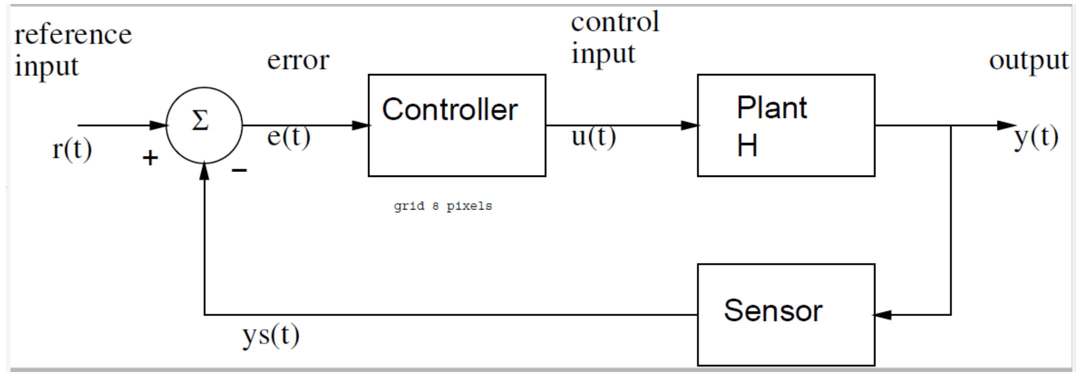
Proportional + Integral

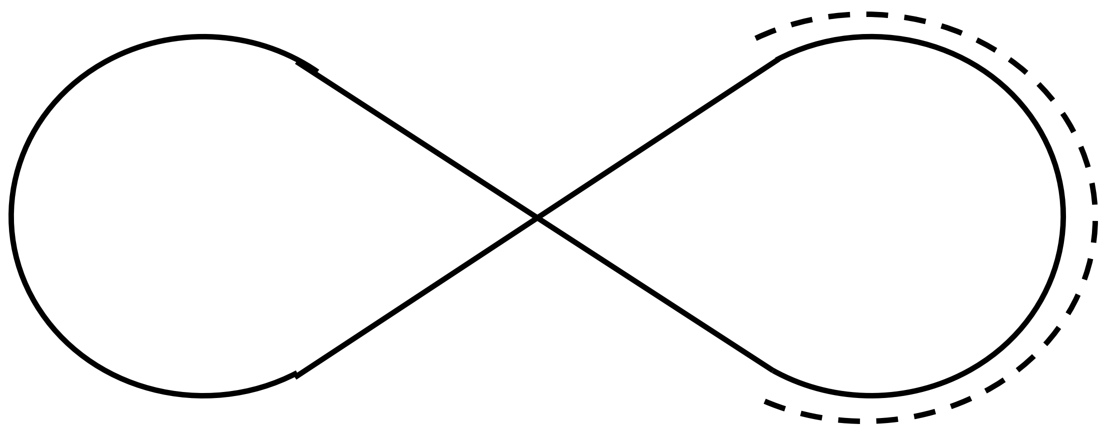




On board Anti-windup

Feedforward





On board

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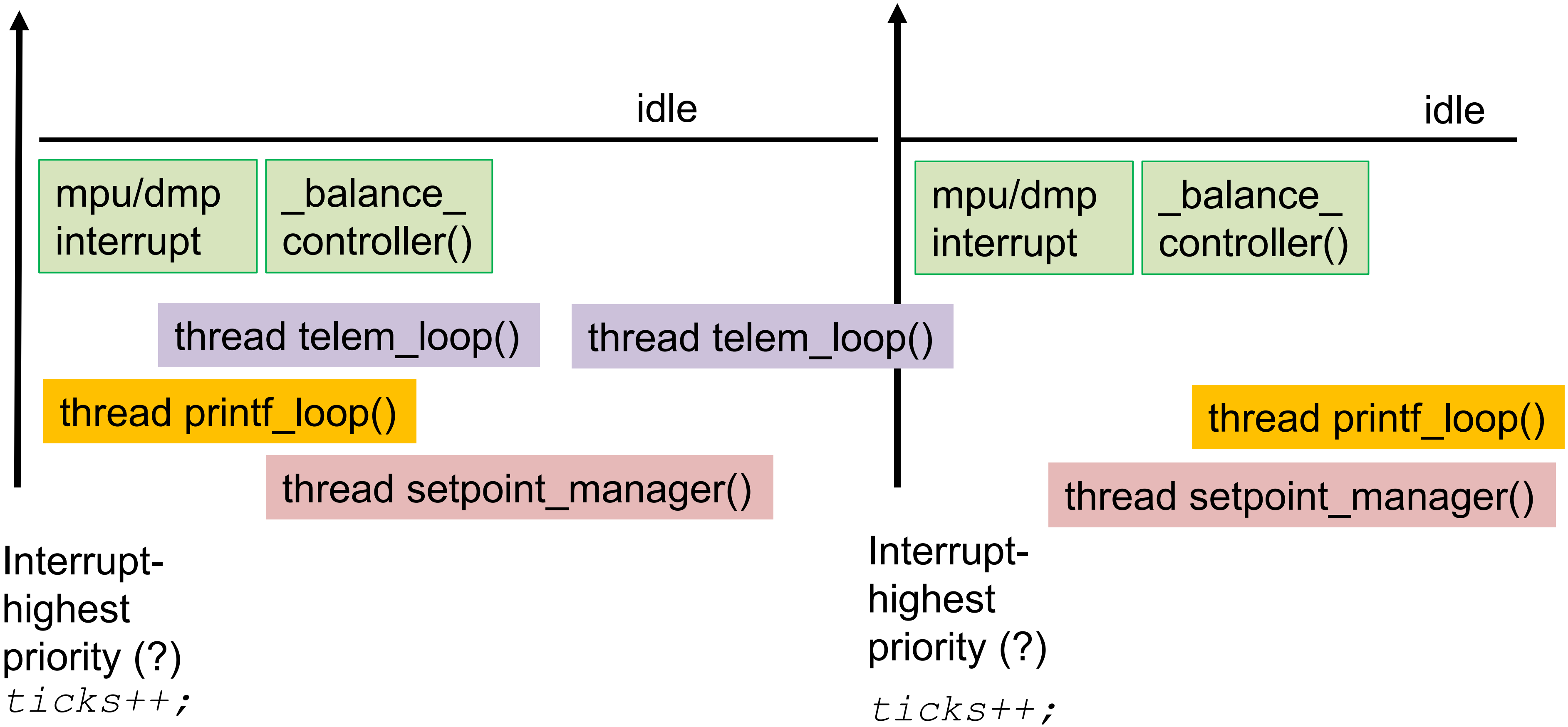
TimingTest.c: how long does fprintf take?

```
while(rc_get_state()!=EXITING)
{  // just data for csv format
        current_time = rc_nanos_since_boot() - start_time;
        old_tick = ticks;
        fprintf(logfile, "%ld, ", old_tick);  // pass value which not changing by other process
        current_time_f = ((double) current_time)/ 1e6; // milliseconds
        run_time_f = ((double) run_time)/1000.0; // us

        fprintf(logfile,"%8.3lf, %8.3lf, ", current_time_f, run_time_f);
        fprintf(logfile, "%" PRIu64 ", ",current_time);
        fprintf(logfile, "%" PRIu64 "\n",run_time);

        end_time = rc_nanos_since_boot() - start_time;
        run_time = end_time - current_time;
        while(old_tick == ticks)
        { rc_usleep(100); // sleep 100 us
        }
  }
```

run_time: min 20 us, typical 30-50 us, <u>max 6600 us</u>

Software Notes

Read sensors → process → output ….. Idle ……. Read sensors → process → output



Threads are asynchronous wrt interrupt!

`rc_pthread_set_process_niceness() ?`

rc_balance2.c using gyro/MPU

When new data is ready in the buffer, the IMU sends an interrupt to the BeagleBone triggering the buffer read followed by the execution of a function of your choosing set with the rc_mpu_set_dmp_callback() function.

```
// set up mpu configuration
rc_mpu_config_t mpu_config = rc_mpu_default_config();
mpu_config.dmp_sample_rate = SAMPLE_RATE_HZ;

// start mpu
if(rc_mpu_initialize_dmp(&mpu_data, mpu_config))

// this should be the last step in initialization
// to make sure other setup functions don't interfere
rc_mpu_set_dmp_callback(&__balance_controller);

// idle while sensing and control done elsewhere
while(rc_get_state()!=EXITING){
      rc_usleep(200000);  }
```

rc_balance2.c __balance_controller()

```
static void __balance_controller(void)
{ticks++;
 end_time = rc_nanos_since_boot();
 run_time = end_time - start_time;
// time since previous interrupt

/************************************************************
* STATE_ESTIMATION
* read sensors and compute the state
************************************************************/
cstate.wheelAngleL =
(rc_encoder_eqep_read(ENCODER_CHANNEL_L) * 2.0 * M_PI) \
/(ENCODER_POLARITY_L * GEARBOX * ENCODER_RES);
/*****************************************************
* Send signal to motors
*****************************************************/
dutyL = cstate.d1_u - cstate.d3_u;
rc_motor_set(MOTOR_CHANNEL_L, MOTOR_POLARITY_L * dutyL);
}
```

rc_balance2.c: threads

// Note that using anything other than SCHED_OTHER with priority 0 is only available to root

int main(**int** argc, **char** *argv[])
{ int c;
  pthread_t setpoint_thread = 0;
  pthread_t printf_thread = 0;
  pthread_t telem_thread = 0;
…
// print thread to print to screen without blocking main

```
rc_pthread_create(&printf_thread, __printf_loop, (void*) NULL,
SCHED_OTHER, 0);
```

…

// start balance stack to control setpoints

```
rc_pthread_create(&setpoint_thread, __setpoint_manager,
(void*) NULL, SCHED_OTHER, 0);
```

…

// telemetry thread to log to file

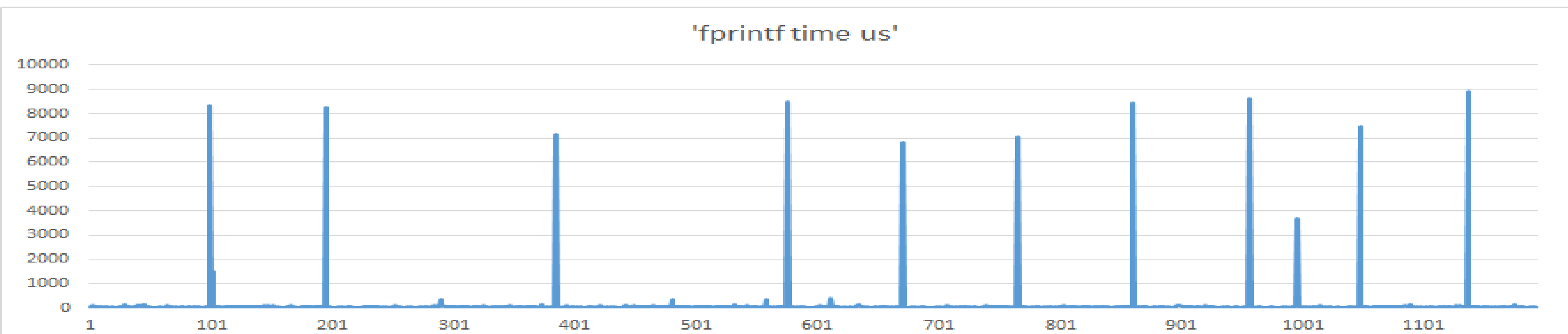
```
rc_pthread_create(&telem_thread, telem_loop, (void*) NULL,
SCHED_OTHER, 0);
// telem loop could write to file
```

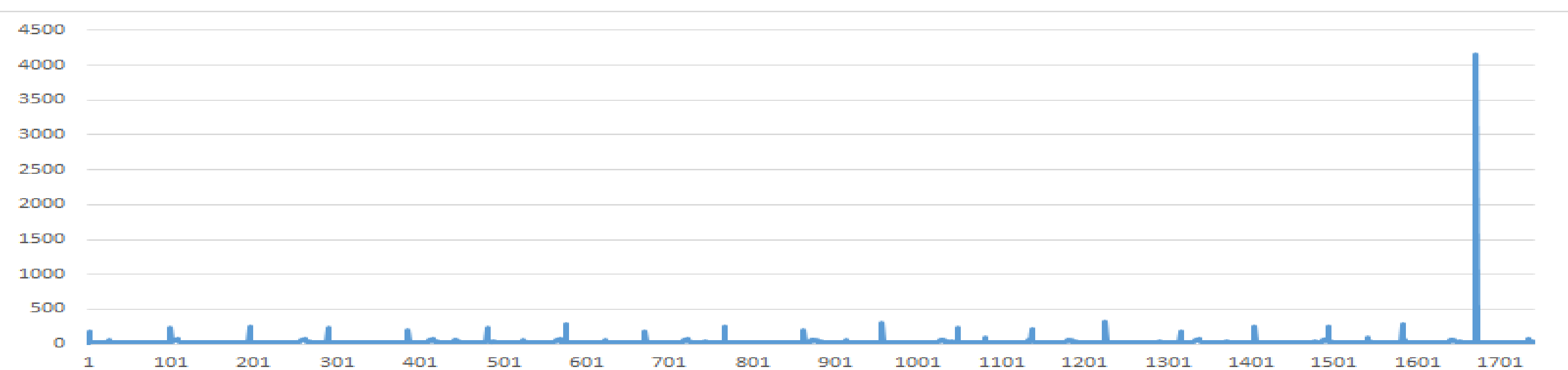
Example logging thread

```
// telemetry thread to log to file
void* telem_loop(__attribute__ ((unused)) void* ptr)
{       long old_tick=0; uint64_t initial_time, current_time;
        printf("telem thread\n"); fflush(stdout); // empty buffer
        initial_time = rc_nanos_since_boot();
        while(rc_get_state()!=EXITING)
        {       current_time = rc_nanos_since_boot();
                old_tick = ticks;
                fprintf(logfile, "%ld, ", old_tick);  // pass value
which not changing by other process
                fprintf(logfile, "%10.3f, ",
                        (double)(current_time-initial_time)/1e6);
                fprintf(logfile,"%8.3f, ", cstate.yaw);
                fprintf(logfile,"%8.3f, %8.3f",
                        cstate.dutyL, cstate.dutyR);
                fprintf(logfile, "%8.3f\n", cstate.vBatt);
                while(old_tick == ticks)
                { rc_usleep(100); // sleep 100 us
                }
        }
        rc_usleep(1000000 / PRINTF_HZ);
        return NULL;
}
```

Debian Processes/Delay

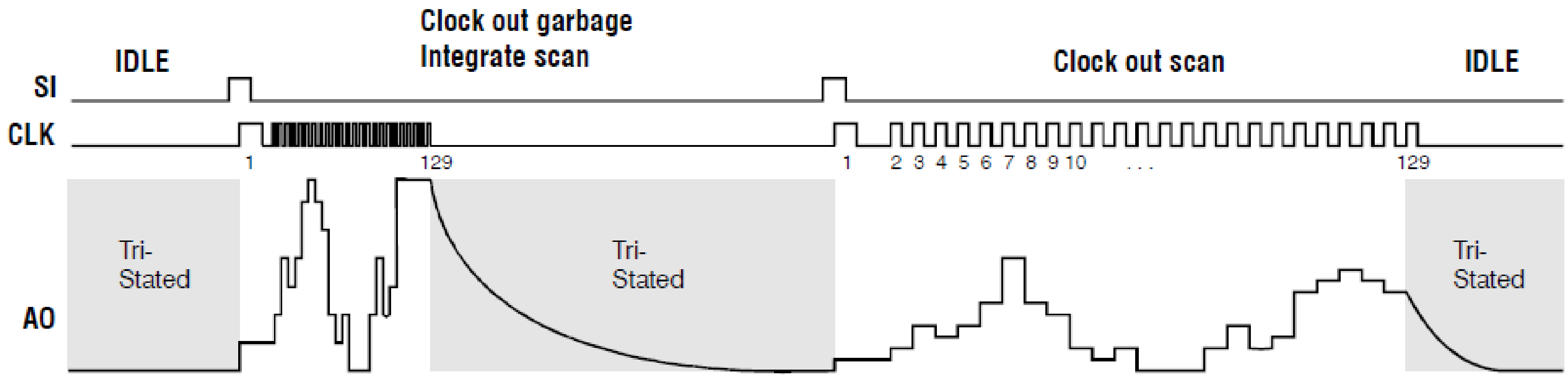
```
htop
# systemctl disable avahi-daemon
# systemctl stop avahi-daemon


sudo kill -9 {avahi-daemon, rc_battery_monitor,
apache2}.
```



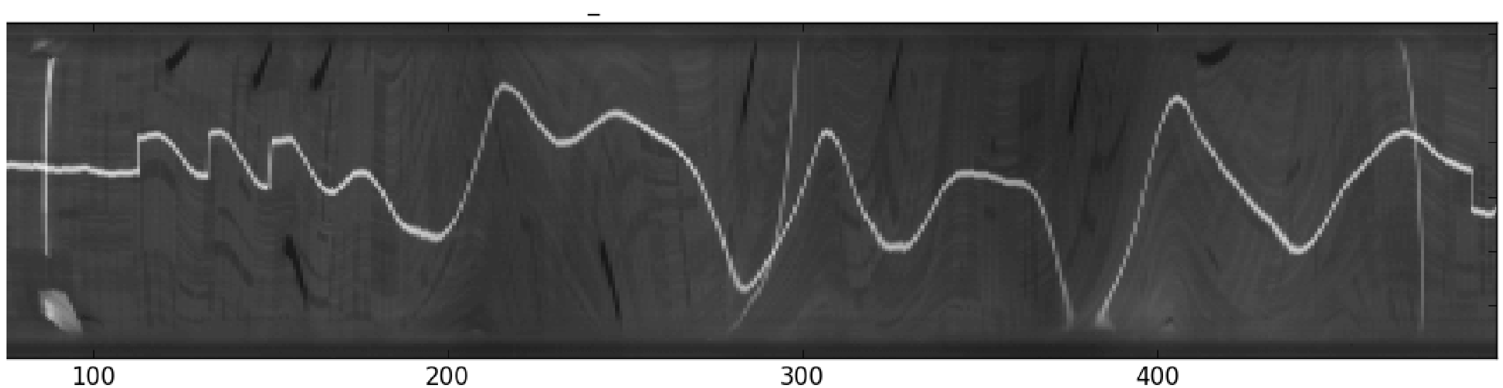


Extra Slides

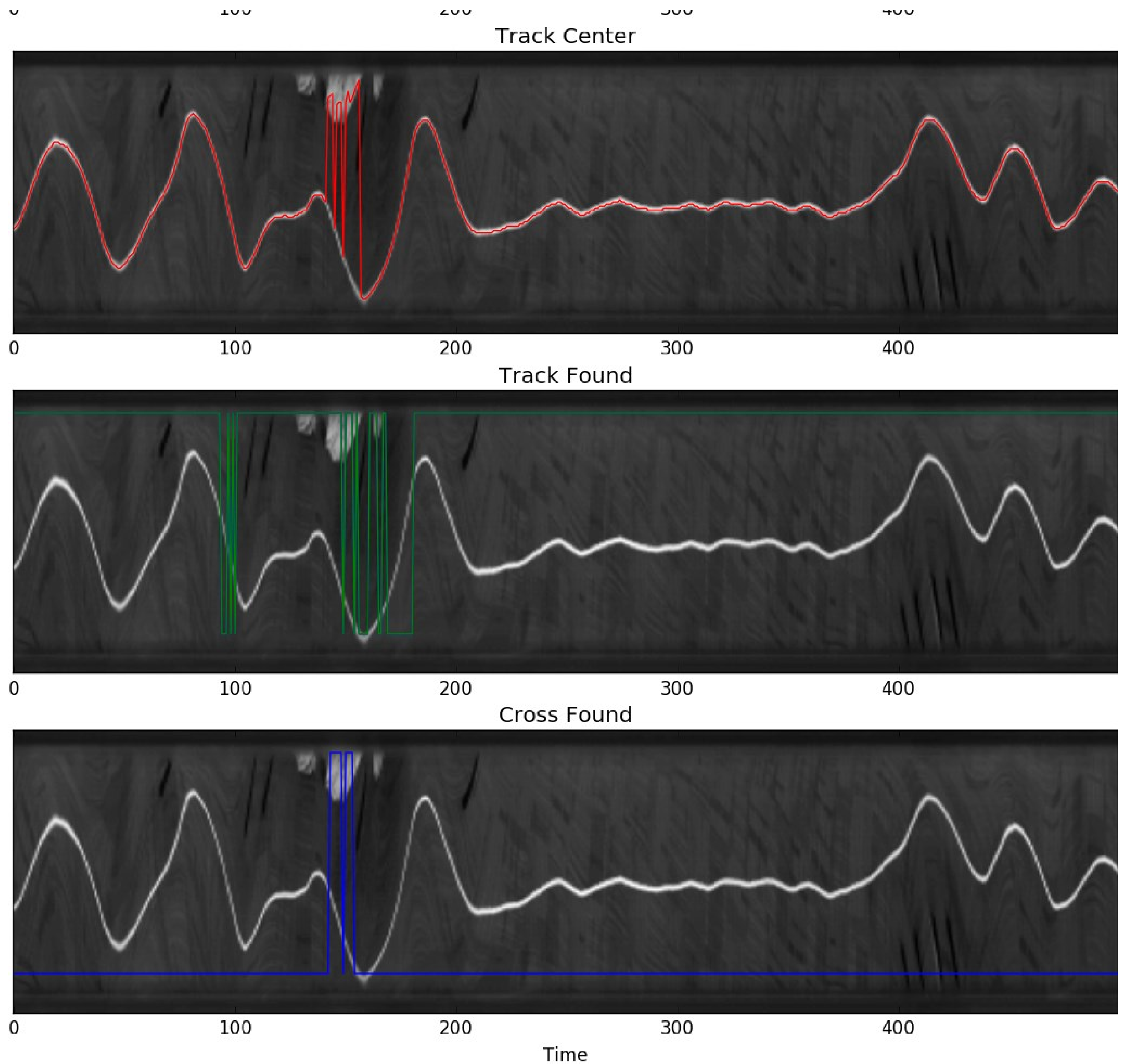
Automatic Gain Control



In all the discussion that follows, we will be using one-shot imaging.



- Choose exposure time based on average illumination
- Keep frame rate constant e.g. read sensor twice 1+4 ➔ 4 +1 ms
- (Constant time is important for control- will see later)

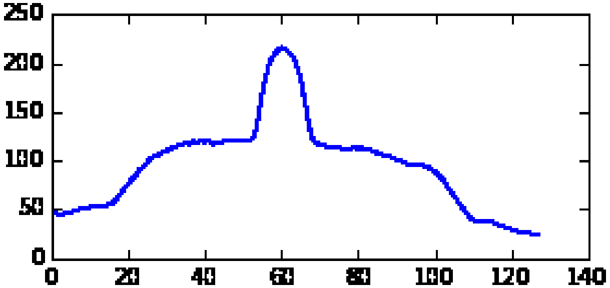


Track Center
Track Found
Cross Found
0
100
200
300
400
Time

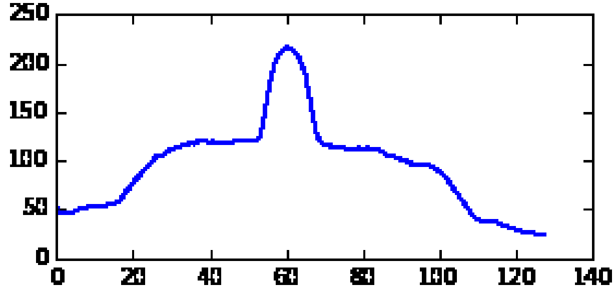
Alternative #1 frame subtraction

TSL 1401 line sensor 8 bit

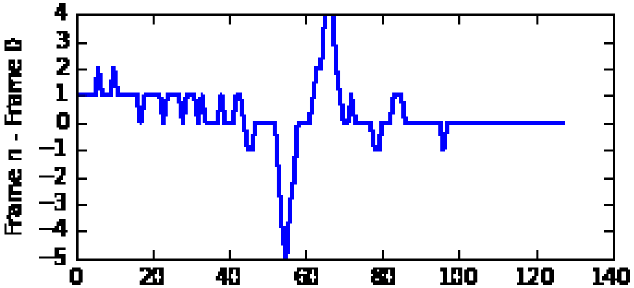
Frame 0



Frame 1



Frame 1-Frame 0



Frame 0

Frame 2

Frame 2-Frame 0

Notes: peak shows edge of track. Noisy, only 1 pixel resolution.

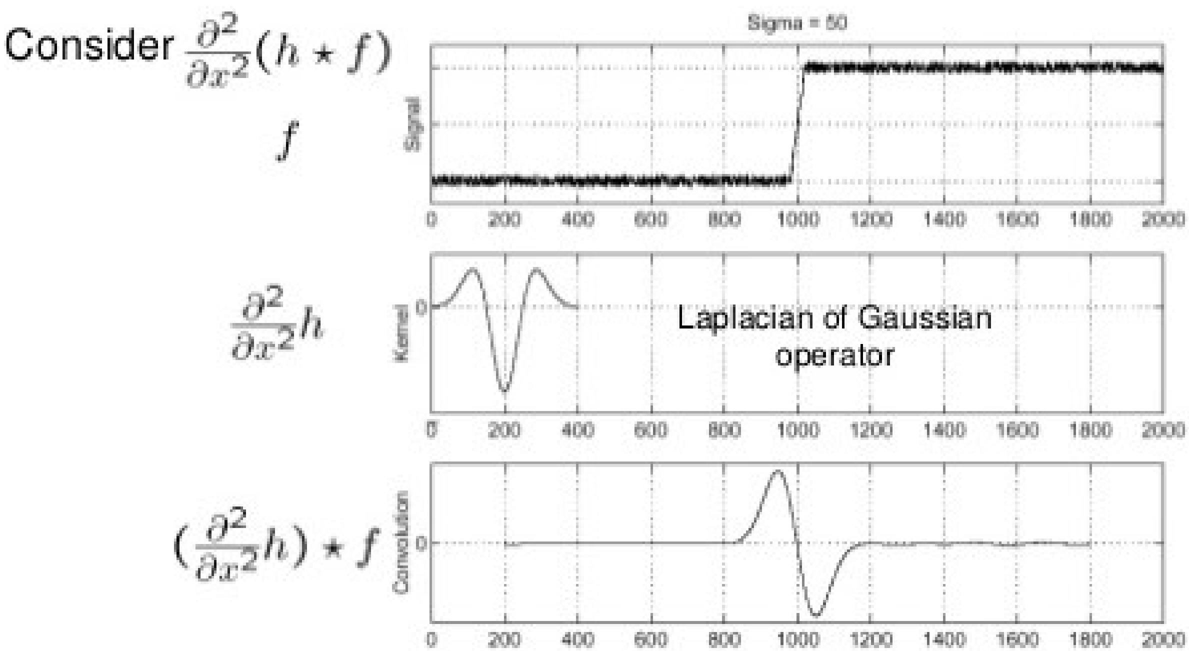
Alternative #2 Difference of Gaussians

Laplacian of Gaussian

$$\triangle[G_\sigma(x,y) * f(x,y)] = [\triangle G_\sigma(x,y)] * f(x,y) = LoG * f(x,y)$$

Convolve with Difference of Gaussians kernel (approx. to LoG)

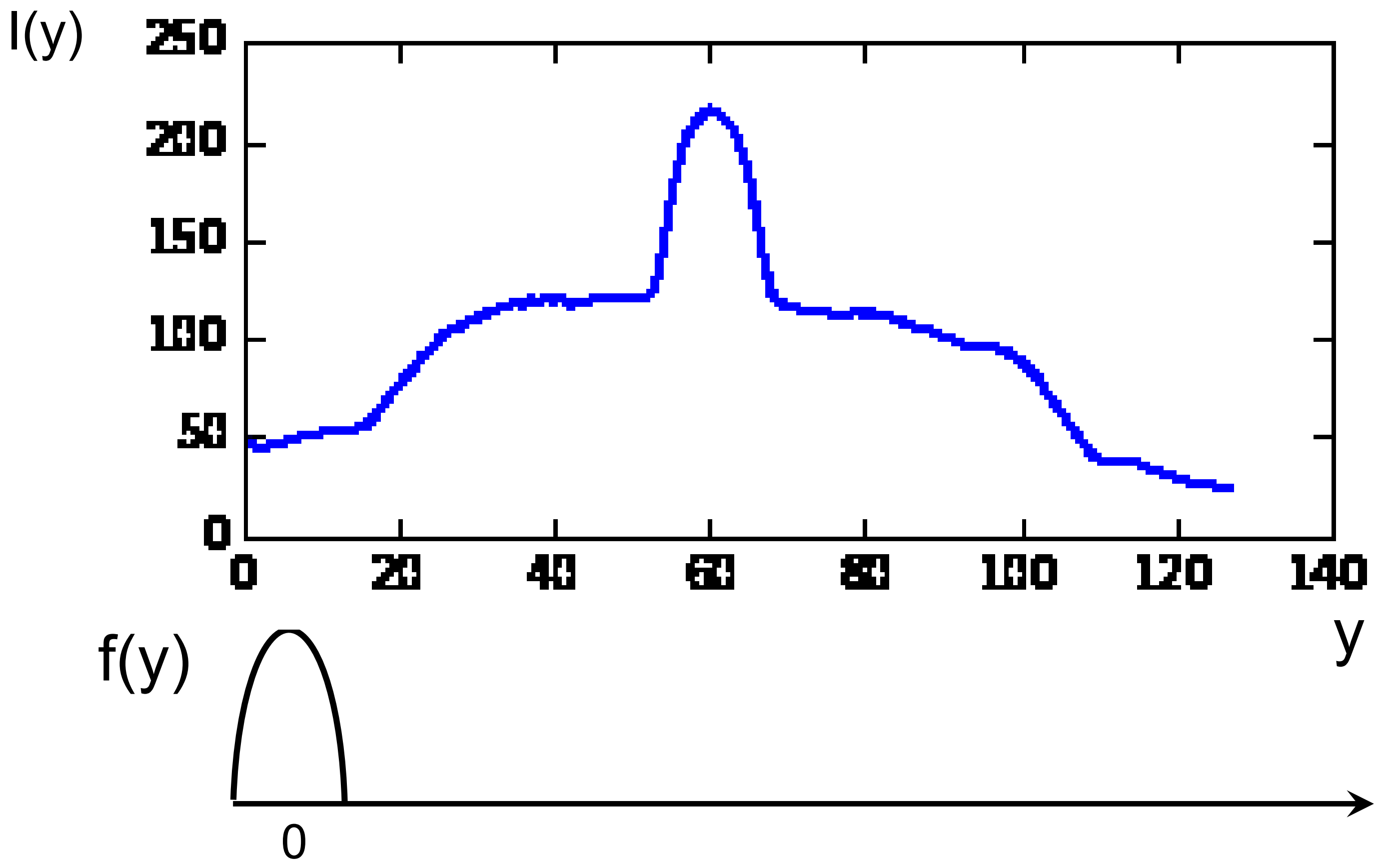
$$\Gamma_{\sigma_1,\sigma_2}(x) = I * \frac{1}{\sigma_1\sqrt{2\pi}}\, e^{-(x^2)/(2\sigma_1^2)} - I * \frac{1}{\sigma_2\sqrt{2\pi}}\, e^{-(x^2)/(2\sigma_2^2)}.$$



https://image.slidesharecdn.com/cbirfeatures-150705141111-lva1-app6892/95/cbir-features-47-638.jpg?cb=1436105787

Notes: zero crossing is edge location

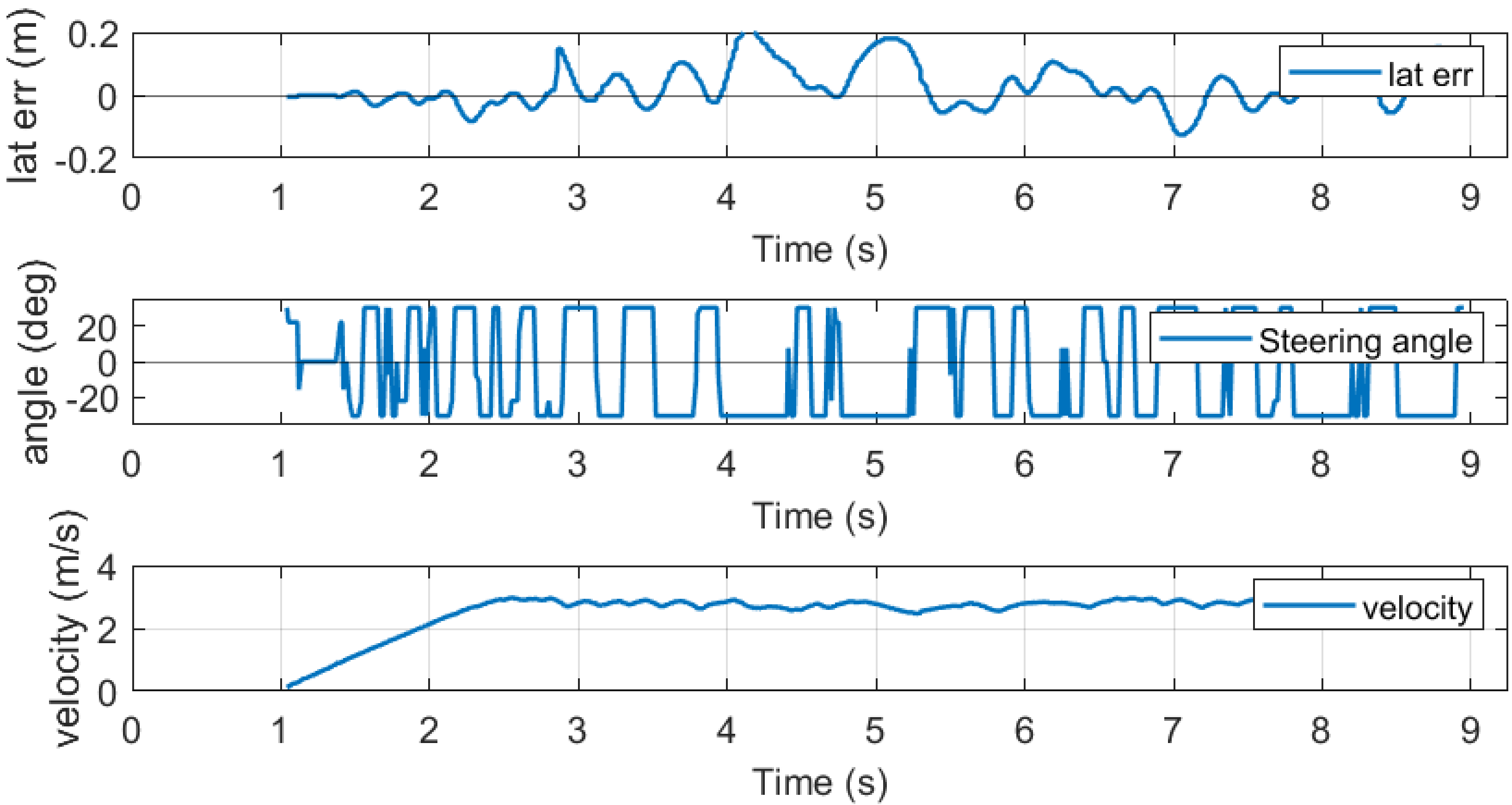
Alternative #3 Correlation



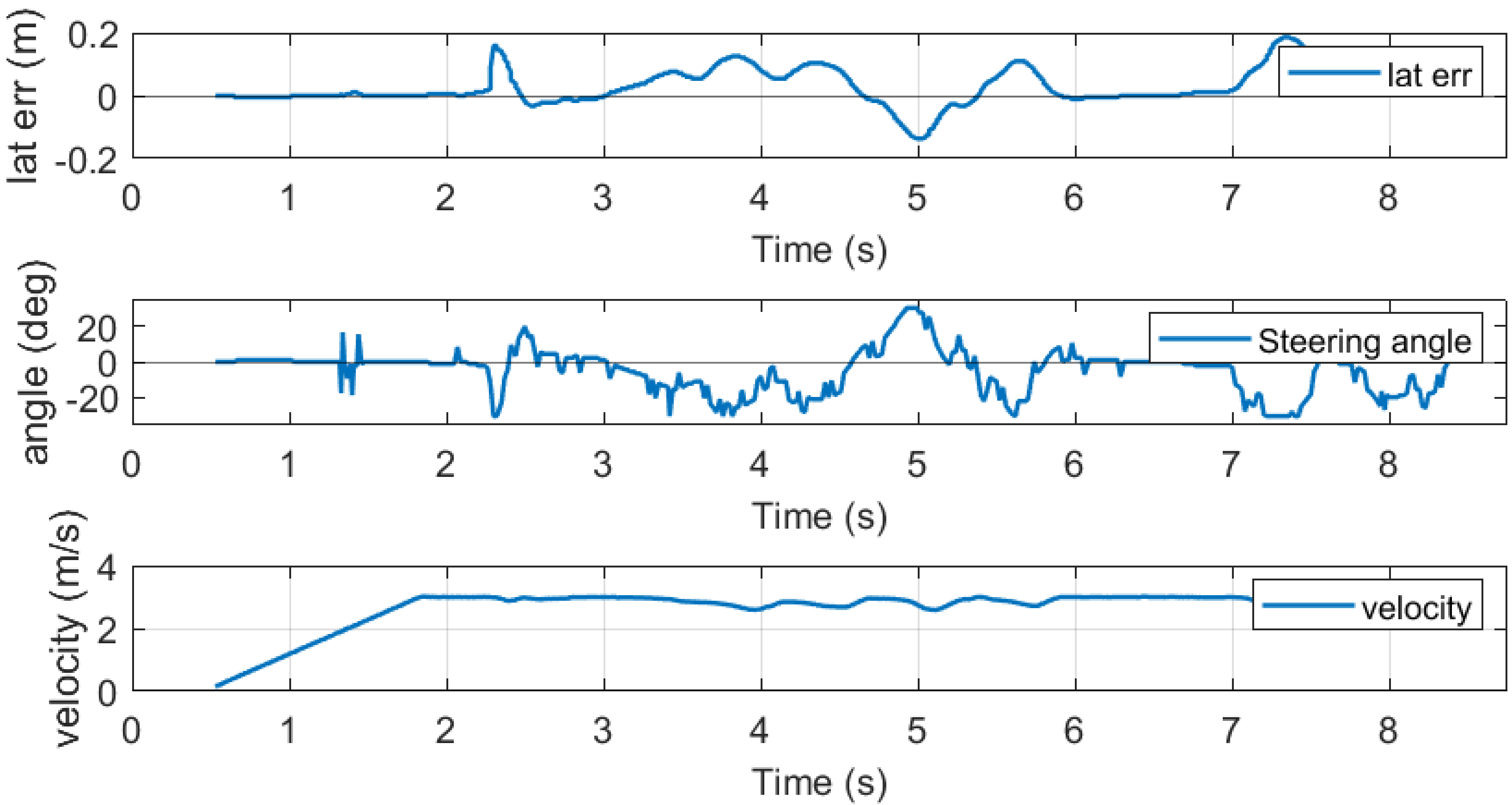
$$\underset{\Delta y}{\arg\min} \;\; \| I(y) - f(y - \Delta y) \|_2$$

Notes: normalize, find by least squares or search. Can use $\Delta y(n-1)$ to initialize

Proportional + derivative control.
Kp = 40 deg/cm, 70 rad/m
Kd = 1000 deg/(m/sec)
V=3 m/s, slew rate 600 deg/0.16 sec
NOTE: = bang-bang!
What is problem with bang bang?
Break servo, nonlinear (unstable)

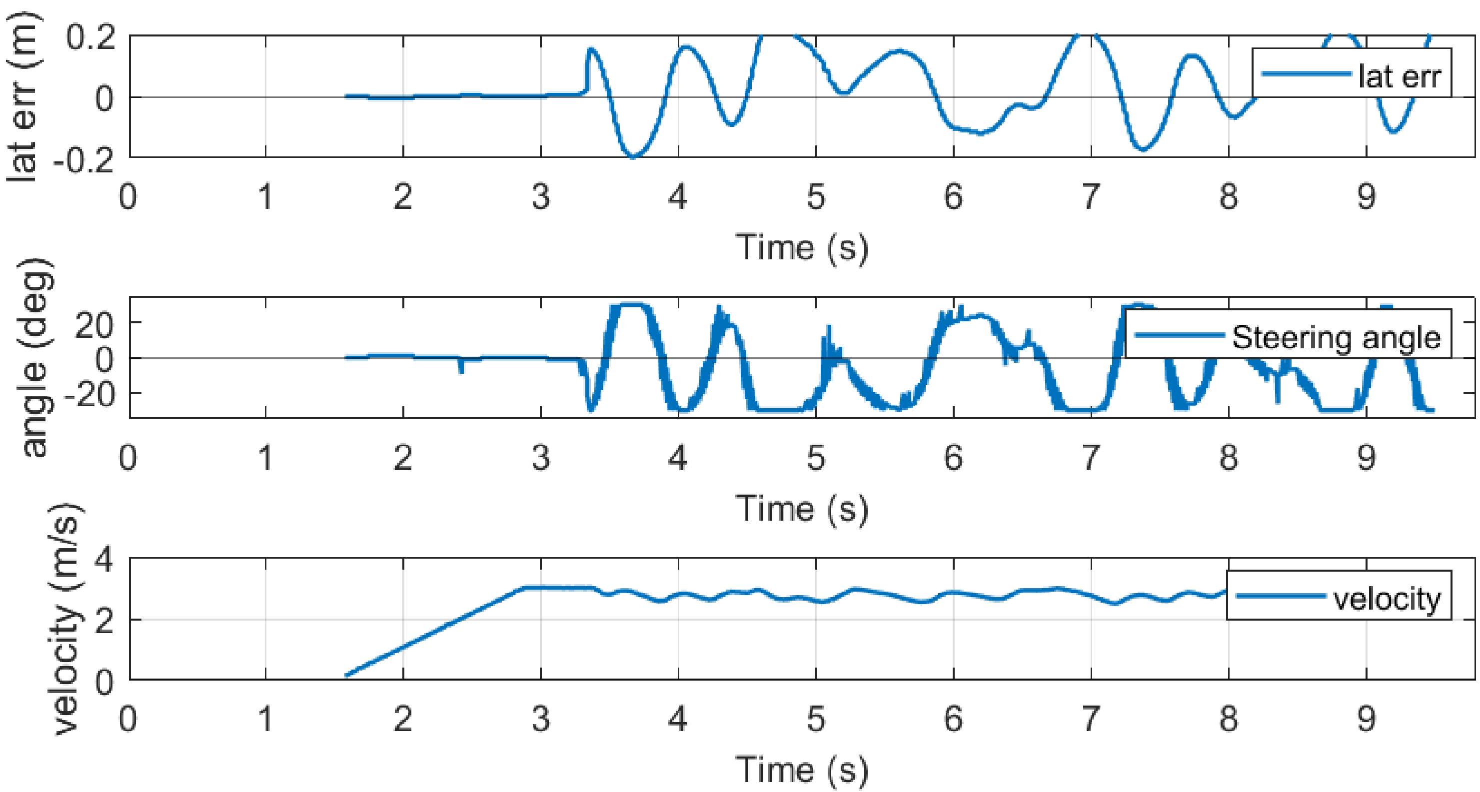


Proportional + derivative control.
Kp = 200 deg/m,
Kd = 30 deg/(m/sec) = (0.15 sec) Kp
V=3 m/s, slew rate 600 deg/0.16 sec
NOTE: = not bang-bang

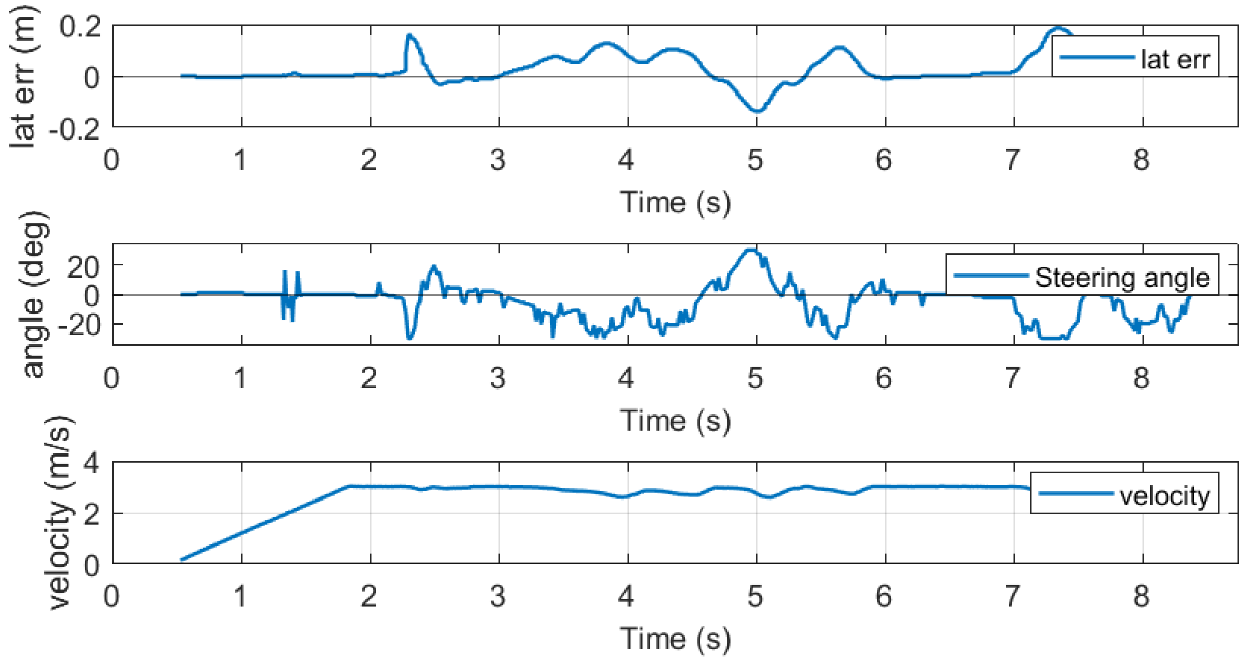


Proportional + derivative control.
Kp = 200 deg/m, Kd = 30 deg/(m/sec)
V=3 m/s NOTE: NO STEERING DELAY, no deadband

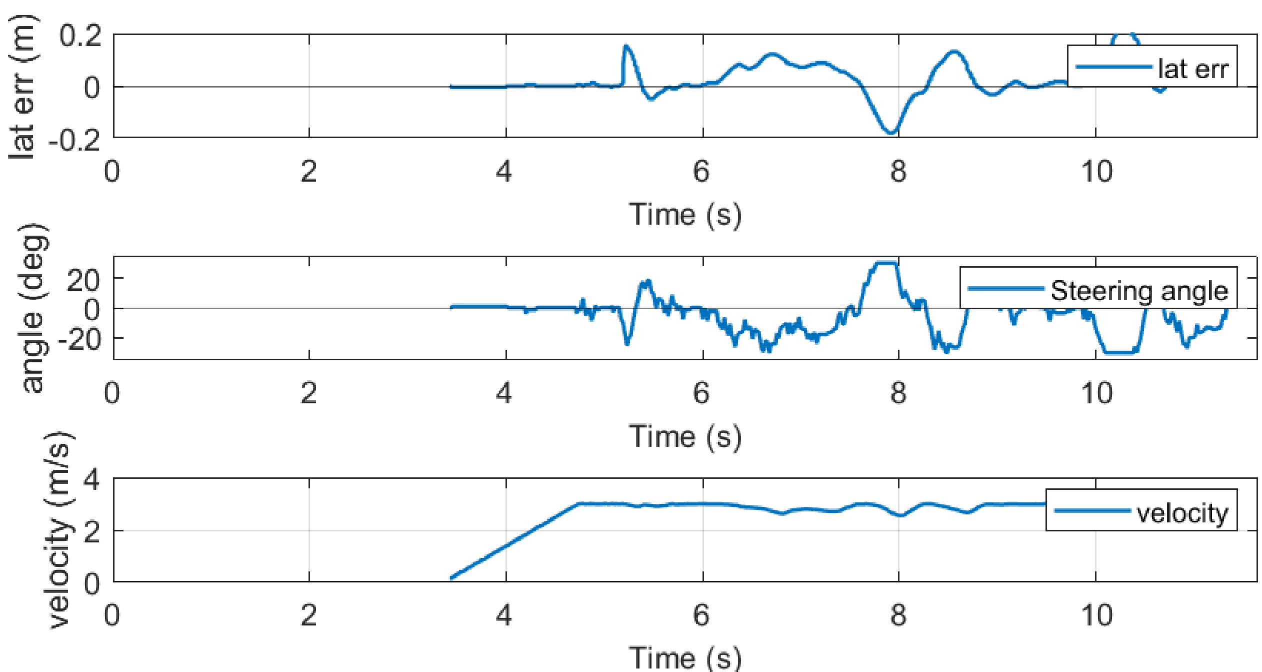
```
def set_steering_fast(self, angle_cmd, dt):
      self.steering_state = angle_cmd # update state
      self.vr.simxSetFloatSignal('steerAngle',
         angle_cmd*(math.pi/180.0), vrep.simx_opmode_oneshot)
      return(angle_cmd)
```



Kp = 200 deg/m, Kd = 30 deg/(m/sec). V=3 m/s



Slew 600 deg/160 ms



Slew 60 deg/160 ms