reWRITE

EE149/249A Project Report, Fall 2015
Reia Cho, CJ Geering, Nathaniel Mailoa, Rachel Zhang

I. Introduction

II. Bill of Materials

III. System

A. LightBlue Bean

B. BNO055 Absolute Orientation Sensor Breakout Board

C. Li-Ion Battery

D. Force Sensor

E. Button and LED Sequin

IV. Casing

V. Position Reconstruction

A. IMU Sensor Data

B. Filtering and Thresholding

C. Transformation to Fixed Reference Frame

D. Velocity Adjustment

E. Tip Position Reconstruction

F. Plotting

VI. Quantitative Analysis and Scheduling

VII. Mode of Operation

VIII. Acknowledgements

We would like to acknowledge the following individuals for their support and contribution in this project.

- Trung Tran, *National Instruments*
- Prof. Sanjit Seshia, *UC Berkeley*
- Matthew Weber, *UC Berkeley*
- Eric Kim, *UC Berkeley*
- Casey Rogers, *UC Berkeley 3D Modeling Club*

IX. Appendix 1: LightBlue Bean code

```
#include <Wire.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_BNO055.h>
#include <utility/imumaths.h>

#define LED (0)
#define FORCE_SENSOR (1)
#define BUTTON (3)

Adafruit_BNO055 bno = Adafruit_BNO055();

uint8_t sys, gyroCal, accelCal, magCal = 0;
long time = 0;
boolean button = 0;
boolean sync = 0;
int do_loop = 0;
boolean debug = 0;
byte count = 0;
byte cur_count = 0;
char buff[60] = {0};
int reading_no = 0;
int ax = 0;
int ay = 0;
int az = 0;
int ex = 0;
int ey = 0;
int ez = 0;
boolean force = 0;

imu::Vector<3> accel;
imu::Vector<3> euler;


// Timer ISR to trigger reading
ISR(TIMER1_COMPA_vect){
  do_loop = 1;
  count++;
}


void setup(void){
  // Set to red for calibration
  Bean.setLed(255,0,0);

  sync = 0;
  do_loop = 0;
  reading_no = 0;
  count = 0;

  pinMode(LED, OUTPUT);
  pinMode(BUTTON, INPUT);
  pinMode(FORCE_SENSOR, INPUT);

  cli();            // disable global interrupts
```

```
  TCCR1A = 0;       // set entire TCCR1A register to 0
  TCCR1B = 0;       // same for TCCR1B

  // set compare match register to desired timer count:
  OCR1A = 117;      // 15ms period

  // turn on CTC mode:
  TCCR1B |= (1 << WGM12);

  // Set CS10 and CS12 bits for 1024 prescaler:
  TCCR1B |= (1 << CS10);
  TCCR1B |= (1 << CS12);

  // enable timer compare interrupt:
  TIMSK1 |= (1 << OCIE1A);
  sei();            // enable global interrupts

  // Start serial communication
  Serial.begin(57600);
  Serial.println("Orientation Sensor Raw Data Test"); Serial.println("");

  /* Initialise the sensor */
  if(!bno.begin())
  {
    /* There was a problem detecting the BNO055 ... check your connections */
    Serial.print("Ooops, no BNO055 detected ... Check your wiring or I2C ADDR!");
    while(1);
  }

  delay(1000);

  bno.setExtCrystalUse(true);

}


void loop(void){
  if (do_loop){
    // Get data from IMU, force sensor and button
    cur_count = count;
    bno.getCalibration(&sys, &gyroCal, &accelCal, &magCal);
    accel = bno.getVector(Adafruit_BNO055::VECTOR_LINEARACCEL);
    euler = bno.getVector(Adafruit_BNO055::VECTOR_EULER);
    force = digitalRead(FORCE_SENSOR);
    button = digitalRead(BUTTON) | (force << 1);

    // If just got synced
    if (sync == 0 && gyroCal == 3 && accelCal == 3 && magCal == 3){
      buff[0] = char(1 << 7);
      buff[1] = char(sys << 6 | accelCal << 4 | gyroCal << 2 | magCal);
      buff[11] = char(cur_count);

      Serial.write((const unsigned char*)buff, 12);
      Serial.flush();
      Bean.setLed(246, 255, 0);
      reading_no = 0;
```

```
    // Wait for confirmation from PC
    while (Serial.read() != '1');

    // Wait for button press
    Bean.setLed(0,0,255);
    while (digitalRead(BUTTON) != 1);
    while (digitalRead(BUTTON) != 0);
    Bean.setLed(0,255,0);

    sync = 1;
  }
  else {
    // If not synced yet
    if (sync == 0){
      // Set calibration packet in buffer
      buff[12*reading_no] = char(1 << 7);
      buff[12*reading_no+1] = char(sys << 6 | accelCal << 4 | gyroCal << 2 |
          magCal);
      buff[12*reading_no+11] = char(cur_count);

      // Turn on LED based on calibration state
      if (gyroCal == 3 && magCal == 3){
        if (accelCal == 0) Bean.setLed(0,0,0);
        if (accelCal == 1) Bean.setLed(73,243,243);
        if (accelCal == 2) Bean.setLed(242,189,73);
      }

    }
    else {
      // Format data for packeting
      ax = int(accel.x()*100) & 0xfff;
      ay = int(accel.y()*100) & 0xfff;
      az = int(accel.z()*100) & 0xfff;

      ex = int(euler.x()*100);
      ey = int(euler.y()*100);
      ez = int(euler.z()*100);

      // Set data packet in buffer
      buff[12*reading_no] = char(1 << 7 | button << 4 | ax >> 8);
      buff[12*reading_no+1] = char(ax & 0xff);
      buff[12*reading_no+2] = char(ay >> 4);
      buff[12*reading_no+3] = char((ay & 0xf) << 4 | (az >> 8) & 0xf);
      buff[12*reading_no+4] = char(az & 0xff);
      buff[12*reading_no+5] = char(ex >> 8);
      buff[12*reading_no+6] = char(ex & 0xff);
      buff[12*reading_no+7] = char(ey >> 8);
      buff[12*reading_no+8] = char(ey & 0xff);
      buff[12*reading_no+9] = char(ez >> 8);
      buff[12*reading_no+10] = char(ez & 0xff);
      buff[12*reading_no+11] = char(cur_count);

      // User feedback for force sensor on LED Sequin
      if(force) digitalWrite(LED, HIGH);
      else digitalWrite(LED, LOW);
```

```
      }

      reading_no++;
      // If buffer filled with 5 readings, send to PC
      if (reading_no > 4) {
        Serial.write((const unsigned char*)buff, 60);
        reading_no = 0;
      }
    }
    // Reset ISR signal
    do_loop = 0;
  }
}
```

X. Appendix 2: Python code

```
import numpy as np
import matplotlib.pyplot as plt
import math
import sys
import serial
import glob
import time
import re
import os


# Data arrays
ax = np.array([])
ay = np.array([])
az = np.array([])
vx = np.array([])
vy = np.array([])
vz = np.array([])
x = np.array([])
y = np.array([])
z = np.array([])
t = np.array([])
tipx = np.array([])
tipy = np.array([])
forceSensor = np.array([])

# Constant parameters
len_pen = 0.1
accel_thres = 0.15
accel_time_lim = 0.1
scale_factor = [10/9.5, 10/7.5]

# Number of readings per processing loop
CHUNKS = 20


def serial_ports():
  """Lists serial ports
  Raises:
  EnvironmentError:
```

```
      On unsupported or unknown platforms
  Returns:
      A list of available serial ports
  """
  if sys.platform.startswith('win'):
    ports = ['COM' + str(i + 1) for i in range(256)]
  elif sys.platform.startswith('linux') or sys.platform.startswith('cygwin'):
      # this is to exclude your current terminal "/dev/tty"
    ports = glob.glob('/dev/tty[A-Za-z]*')
  elif sys.platform.startswith('darwin'):
    ports = glob.glob('/dev/tty.*')
  else:
    raise EnvironmentError('Unsupported platform')
  result = []
  for port in ports:
    try:
      s = serial.Serial(port)
      s.close()
      result.append(port)
    except (OSError, serial.SerialException):
      pass
  return result



def run():
  global ax,ay,az,vx,vy,vz,x,y,z,t,v_anchor,tipx,tipy,forceSensor
  print("reWRITE Position Reconstruction")

  # Connect to serial port
  ports = serial_ports()
  if ports:
    print("Available serial ports:")
    for (i,p) in enumerate(ports):
      print("%d) %s"%(i+1,p))
  else:
    print("No ports available. Check serial connection and try again.")
    print("Exiting...")
    return
  portNo = input("Select the port to use: ")
  ser = serial.Serial(ports[int(portNo)-1])
  ser.baudrate=57600
  ser.timeout=10

  # Reset variables
  cur_idx = 0
  mean_x = 0
  mean_y = 0
  mean_z = 0
  last_ax = 0
  last_ay = 0
  last_az = 0
  base_ex = 0
  base_ey = 0
  base_ez = 0
  base_time = 0
```

```
# Calibration constants
last_zero = [1,1,1]
first_nonzero = [0,0,0]
last_forceOn = -1
lpf_alpha = 0.9
hpf_alpha = 0.99
cal_pow = 2
failcount = 0

ser.flush()

# Calibration stage
calibrated = 0
if (sys.argv[2] == 'c'):
  calibrated = 1

while(calibrated != 1):
  try:
    line = (ser.read(12))
    c = line[1]
    # Print calibration status
    print(str((c & 0xc0) >> 6) + str((c & 0x30) >> 4) + str((c & 0x0c) >> 2) +
       str(c & 0x03))
    if ((c & 0x3f) == 0x3f): calibrated = 1
  except:
    pass

print("Recording in 3...")
time.sleep(1)
print("2...")
time.sleep(1)
print("1...")
time.sleep(1)
print("Start")
ser.write('1'.encode())
ser.flushInput()
print(ser.inWaiting())

# Start plot
plt.ion()
fig = plt.figure()
figA = fig.add_subplot(111)
figA.set_xlabel('x')
figA.set_ylabel('y')

# Throw away first 20 data points
for i in range(20):
  line = ser.read(12)

# Main loop
while(True):
  print(cur_idx)
  ex = np.zeros(CHUNKS)
  ey = np.zeros(CHUNKS)
  ez = np.zeros(CHUNKS)
```

```
tax = np.zeros(CHUNKS)
tay = np.zeros(CHUNKS)
taz = np.zeros(CHUNKS)
count = 0

# Populate 20 data points
while count < CHUNKS:
  if (failcount > 20):
    print("Failed more than 20 times")
    exit()
  try:
    line = ser.read(12)

    # Populate force sensor and button data
    force = (line[0] >> 5) & 0x1;
    button = (line[0] >> 4) & 0x1;

    # Populate acceleration data
    axt = (line[0] & 0xf) << 8 | line[1]
    if (axt & 0x800): axt = -1*int((axt ^ 0xfff) + 1)
    axt = axt/100

    ayt = line[2] << 4 | (line[3] >> 8)
    if (ayt & 0x800): ayt = -1*int((ayt ^ 0xfff) + 1)
    ayt = ayt/100

    azt = (line[3] & 0xf) << 8 | line[4]
    if (azt & 0x800): azt = -1*int((azt ^ 0xfff) + 1)
    azt = azt/100

    # Populate Euler angle data
    ezt = line[5] << 8 | line[6]
    ezt = int(ezt)/100

    eyt = line[7] << 8 | line[8]
    if (eyt & 0x8000): eyt = -1*int((eyt ^ 0xffff) + 1)
    eyt = int(eyt)/100

    ext = line[9] << 8 | line[10]
    if (ext & 0x8000): ext = -1*int((ext ^ 0xffff) + 1)
    ext = int(ext)/100

    # Populate timestamp data
    timetemp = int(line[11])
    if t != [] and timetemp+base_time - t[-1] < 0:
      base_time = base_time + 256
    timetemp = timetemp + base_time

    # Acceleration high-pass, low-pass and thresholding
    temp = float(axt)
    if (cur_idx == 0 and count == 0):
      mean_x = temp
    mean_x = mean_x * hpf_alpha + temp * (1-hpf_alpha)
    temp = temp - mean_x
    last_ax = last_ax*lpf_alpha + temp*(1-lpf_alpha)
    tax[count] = last_ax if abs(last_ax) > accel_thres/3 else 0
```

```
      temp = float(ayt)
      if (cur_idx == 0 and count == 0):
        mean_y = temp
      mean_y = mean_y * hpf_alpha + temp * (1-hpf_alpha)
      temp = temp - mean_y
      last_ay = last_ay*lpf_alpha + temp*(1-lpf_alpha)
      tay[count] = last_ay if abs(last_ay) > accel_thres/3 else 0

      temp = float(azt)
      if (cur_idx == 0 and count == 0):
        mean_z = temp
      mean_z = mean_z * hpf_alpha + temp * (1-hpf_alpha)
      temp = temp - mean_z
      last_az = last_az*lpf_alpha + temp*(1-lpf_alpha)
      taz[count] = last_az if abs(last_az) > accel_thres/3 else 0

      # Convert Euler angles to deltas in radians
      if (cur_idx == 0 and count == 0):
        ex[count] = 0
        ey[count] = 0
        ez[count] = 0
        base_ez = ezt
        base_ey = eyt
        base_ex = ext
      else:
        ez[count] = -(ezt - base_ez)/360*2*math.pi
        ey[count] = (eyt - base_ey)/360*2*math.pi
        ex[count] = (ext - base_ex)/360*2*math.pi

      # Save timestamp and force sensor data
      t = np.append(t, timetemp)
      forceSensor = np.append(forceSensor, force)

      # If button is pressed, clear figure
      if(button):
        figA.cla()

      count = count + 1

    except:
      failcount = failcount + 1
      pass

  # Convert IMU frame of reference to real coordinates
  sex = np.sin(ex)
  sey = np.sin(ey)
  sez = np.sin(ez)
  cex = np.cos(ex)
  cey = np.cos(ey)
  cez = np.cos(ez)

  ax = np.append(ax, cey*cez*tax + (sex*sey*cez - cex*sez)*tay + (cex*sey*cez +
      sex*sez)*taz)
  ay = np.append(ay, cey*sez*tax + (sex*sey*sez + cex*cez)*tay + (cex*sey*sez -
      sex*cez)*taz)
```

```
    az = np.append(az, -sey*tax + sex*cey*tay + cex*cey*taz)

    # Process absolute acceleration data
    for i in range(cur_idx, cur_idx+CHUNKS):
      if (i == 0):
        vx = np.array([0])
        vy = np.array([0])
        vz = np.array([0])
        x = np.array([0])
        y = np.array([0])
        z = np.array([0])
        v_anchor = np.array([1])
        continue

      timestep = (t[i] - t[i-1])*15/1000

      # Update velocity
      vx = np.append(vx, vx[i-1]+ax[i-1]*timestep)
      vy = np.append(vy, vy[i-1]+ay[i-1]*timestep)
      vz = np.append(vz, vz[i-1]+az[i-1]*timestep)

      # Update position
      x = np.append(x, x[i-1]+vx[i-1]*timestep)
      y = np.append(y, y[i-1]+vy[i-1]*timestep)
      z = np.append(z, z[i-1]+vz[i-1]*timestep)

      # Calibrate x velocity if more than accel_time_lim with no x accel
      if (abs(ax[i]) <= accel_thres):
        if first_nonzero[0] != -1 and last_zero[0] == -1:
          last_zero[0] = i
      else:
        last_zero[0] = -1
        if first_nonzero[0] == -1:
          first_nonzero[0] = i

      if (last_zero[0] != -1 and (t[i] - t[last_zero[0]]) > accel_time_lim*1000/15)
         :
        for j in range(first_nonzero[0], last_zero[0]+1):
          timestep = (t[j] - t[j-1])*15/1000
          vx[j] = vx[j] - ((j-first_nonzero[0])/(last_zero[0]-first_nonzero[0]))**
              cal_pow*vx[last_zero[0]]
          x[j] = x[j-1] + vx[j-1]*timestep
        for j in range(last_zero[0], i+1):
          vx[j] = 0
          x[j] = x[j-1]
        first_nonzero[0] = i-1
        last_zero[0] = -1


      # Calibrate y velocity if more than accel_time_lim with no y accel
      if (abs(ay[i]) <= accel_thres):
        if first_nonzero[1] != -1 and last_zero[1] == -1:
          last_zero[1] = i
      else:
        last_zero[1] = -1
        if first_nonzero[1] == -1:
```

```
          first_nonzero[1] = i

      if (last_zero[1] != -1 and (t[i] - t[last_zero[1]]) > accel_time_lim*1000/15)
        :
        for j in range(first_nonzero[1], last_zero[1]+1):
          timestep = (t[j] - t[j-1])*15/1000
          vy[j] = vy[j] - ((j-first_nonzero[1])/(last_zero[1]-first_nonzero[1]))**
              cal_pow*vy[last_zero[1]]
          y[j] = y[j-1] + vy[j-1]*timestep
        for j in range(last_zero[1], i+1):
          vy[j] = 0
          y[j] = y[j-1]
        first_nonzero[1] = i-1
        last_zero[1] = -1


      # Calibrate z velocity if more than accel_time_lim with no z accel
      if (abs(az[i]) <= accel_thres):
        if first_nonzero[2] != -1 and last_zero[2] == -1:
          last_zero[2] = i
      else:
        last_zero[2] = -1
        if first_nonzero[2] == -1:
          first_nonzero[2] = i

      if (last_zero[2] != -1 and (t[i] - t[last_zero[2]]) > accel_time_lim*1000/15)
        :
        for j in range(first_nonzero[2], last_zero[2]+1):
          timestep = (t[j] - t[j-1])*15/1000
          vz[j] = vz[j] - ((j-first_nonzero[2])/(last_zero[2]-first_nonzero[2]))**
              cal_pow*vz[last_zero[2]]
          z[j] = z[j-1] + vz[j-1]*timestep
        for j in range(last_zero[2], i+1):
          vz[j] = 0
          z[j] = z[j-1]
        first_nonzero[2] = i-1
        last_zero[2] = -1


    # Compute tip position from IMU position
    tipx = np.append(tipx, x[cur_idx:]*scale_factor[0] - len_pen*sey)
    tipy = np.append(tipy, y[cur_idx:]*scale_factor[1] - len_pen*sex)

    # Plot if we go from force sensor on to off
    if (last_forceOn != -1):
      first_zero_f = None
      for idx in range(cur_idx, cur_idx+CHUNKS):
        if forceSensor[idx] == 0:
          first_zero_f = idx
          break
      if (first_zero_f):
        figA.plot(tipx[last_forceOn:first_zero_f -5], tipy[last_forceOn:first_zero_f
            -5], 'blue')
        plt.axis('equal')
        last_forceOn = -1
        fig.canvas.draw()
```

```
    if (last_forceOn == -1):
      first_zero_f = None
      for idx in range(cur_idx, cur_idx+CHUNKS):
        if forceSensor[idx] == 1:
          first_zero_f = idx
          break
      if(first_zero_f):
        last_forceOn = first_zero_f

    cur_idx = cur_idx + CHUNKS

    # Time limit of 10000 samples
    if (cur_idx >= 10000):
      break

  # Keep plot on
  plt.show()

run()
```