Introductory mini projects 2020

```
assignement   ::= expression .
expression  ::= term | term ("+" | "-") term
term ::= factor | factor ("*" | "/") factor
factor   ::= ["-"] (identifier | integerConstant)
```

Figure 1: Input grammar for Project 1.

Project 1: Parsing and Abstract Syntax Trees.

The intention of this project is to use the C programming language in order to create a parser for the grammar shown in Figure 1. The grammar describes arithmetic expressions between identifiers and integer constants. Identifiers can be any non-null alphanumeric expressions with without spaces. The arithmetic operations use the conventional operator precedence from mathematics. The parser must be able to store the parsed information as a binary Abstract Syntax Tree (AST).

The input to the parser should be the path of the input filename, provided as the first argument of the C binary. The output of the C program must be the structure of the generated AST printed in the standard output of the program, or an error message in case that the input does not include a valid expression.

Notes: You can use any preferable parsing technique, including the use of parsing software packages such as flex/bison (though not recommended). You can change the grammar of Figure 1 to another equivalent representation. You are free to choose the form of the printing of the AST, including the order of traversal of the tree (Depth-First, Breadth-First, etc.). The deliverable is an archive file with all the necessary source code files and a Makefile for their compilation. Feel free to also include any example input files.

Project 2: State estimation of a pendulum.

In this project, we examine the state estimation of a vertical pendulum. Figure 2 shows a damped pendulum with angle of displacement θ from the resting point, acceleration due to gravity G, length of the rod L, and damping constant B with units of $\mathrm{kg\,s^{-1}}$, M the mass of the pendulum's bob, and t the elapsed time. Equation 1 describes the dynamics of the oscillation:

$$\frac{\mathrm{d}^2\theta}{\mathrm{d}t^2} + \frac{B}{M}\frac{\mathrm{d}\theta}{\mathrm{d}t} + \frac{G}{L}\sin(\theta) = 0. \qquad (1)$$

The goal of state estimation in an embedded system attached to the pendulum bob is to estimate the true value of θ from noisy measurements of the angular speed $\frac{\mathrm{d}\theta}{\mathrm{d}t}$. We define the state of the example system as the vector of the angle θ and the derivative $\frac{\mathrm{d}\theta}{\mathrm{d}t}$. The Z axis of the gyroscope on the pendulum's mass measures $\frac{\mathrm{d}\theta}{\mathrm{d}t}$. The goal of the project is to generate a Kalman filter which tracks the state using measurements from a gyroscope attached to the mass of the pendulum. The Kalman filter [1] is one method to estimate the state of a dynamic system from noisy measurements of signals that are related to the state being estimated. We will use the extended Kalman filter since Equation 1 includes the sin function, making it nonlinear. To design the filter, we must specify the *process* and *measurement* models of the pendulum.

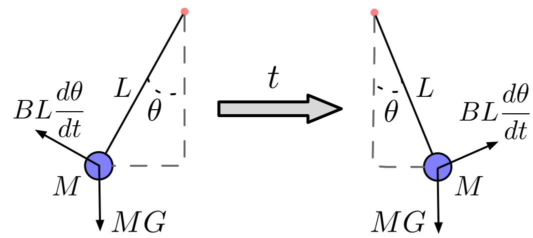


Figure 2: Damped pendulum with angle of displacement θ from the resting point, acceleration due to gravity G, rod length L, damping constant B and drag force $BL\frac{\mathrm{d}\theta}{\mathrm{d}t}$ [2].

For the *process* model of the pendulum we convert Equation 1 to two state prediction equations: one for the angular displacement and one for the angular speed. We assume a small amount of time Δt between two successive cycles of the filter and use Δt, to linearize the prediction equations. Equations 2 and 3 summarize the *process* model of the pendulum.

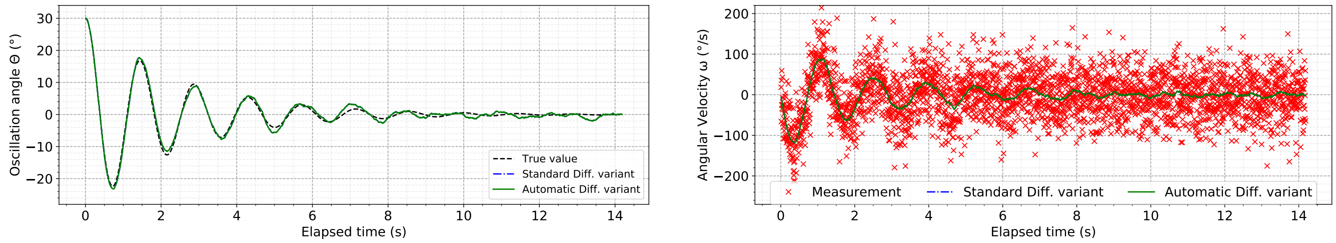
$$\theta_k = \theta_{k-1} + \omega_{k-1}\Delta t. \qquad (2)$$

$$\omega_k = \omega_{k-1} + \frac{B}{M}\omega_{k-1}\Delta t - \frac{G}{L}\sin(\theta_{k-1})\Delta t. \qquad (3)$$

The deliverable of the project is to evaluate state estimation of a pendulum with drag, length equal to $0.5\,\mathrm{m}$ and damping factor equal to $0.8\,\mathrm{kg\,s^{-1}}$. The initial angle displacement should be 30° and the measurement noise variance equal to $0.8\,\mathrm{rad^2/s^2}$.

We provide an input csv file (**`pendulum_input.csv`**) with trace from the simulation of the aforementioned pendulum. The csv file includes the following columns:

- **Timestamp:** Timestamp of a measurement.
- **displacement_truth:** The actual displacement *theta* of the pendulum with respect to its vertical axis at the specific timestamp.
- **speed_noisy:** The noisy measurement of *dtheta* that the filter samples from the gyroscope attached on the mass of the pendulum.
- **speed_truth:** The actual speed *dtheta* of the mass of the pendulum at the specific timestamp.
- **acc_truth:** The actual acceleration of the mass of the pendulum at the specific timestamp.



(a) Estimation of oscillation angle over time.

(b) Estimation of angular velocity over time.

Figure 3: State estimation of a pendulum with drag. Initial displacement is 30°, measurement noise variance 0.8 rad^2/s^2**, and length 0.5** m**.**

You should develop a program in any language of preference which must be able to parse the input trace file and implement an Extended Kalman filter that predicts the state vector, i.e., the displacement ($theta$) and speed ($dtheta$) values of the oscillation of the pendulum. The output of the program should be a csv file named **`pendulum_ekf_result.csv`**, with columns **`time, theta, dtheta, theta_cov, dtheta_cov`**, where **`theta_cov`** and **`dtheta_cov`** are the covariances of **`theta`** and **`dtheta`**, respectively. We provide a python script (**`plot.py`**), which takes as input both the csv files and produces the plots of oscillation angle and angular velocity over time as Figure 3 shows.

References

[1] Rudolph Kalman. E. 1960. a new approach to linear filtering and prediction problems. *Transactions of the ASME–Journal of Basic Engineering*, 82:35–45, 1960.

[2] Pirooz Mohazzabi and Siva P Shankar. Damping of a simple pendulum due to drag on its string. *Journal of Applied Mathematics and Physics*, 5(01):122, 2017.