Introduction to Unmanned Vehicle Systems
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AUVSI Student Competition Homework

Deliverable 4:

Competition Name: Intelligent Ground Vehicle Competition (IGVC) with Rulebook 2019.
Challenge: Auto-Nav Course

1. Sensors/Sensor Fusion needed for the competition

The sensors are the absolute main components for the sub-systems functionalities including perception, localization, obstacle detection, lane detection and many more.

- **Vehicle Centric Sensing:**

The sensors which facilitate the stability of the system's health, operation and maintenance are known to be vehicle centric sensors. The internal sensors needed for the system are:

Thermocouple:

It is a temperature sensor, used to regulate the amount of cooling needed for an engine.

Voltmeter:

This is a voltage sensing meter used to monitor the amount of charge remaining on a battery. It basically maintains and prevents the battery life stability of the system.

- **External Vehicle Sensors:**

These sensors enable the system to estimate the position and orientation of the vehicle in the environment. The sensors also help the vehicle to sense the surrounding environment and, assists vehicle's decision-making capabilities by generating a perception mapping of its environment.

Encoders:

The magnetic encoders can be used to obtain wheel odometry. These encoders will be mounted on the back of each drive motor and use a Hall effect sensor coupled with a magnetic puck attached to the shaft of the motor to determine its speed and direction. This data is transmitted to the motor controllers, which use the odometry as feedback for their PID loops. Wheel odometry is also sent to the main computer for state estimation.

LIDARs

A 2D Light Detection And Ranging (LiDAR) is used as a range sensor. Time-off light technology is used to calculate the distance to an object from the vehicle. This sensor scans in front of the vehicle and is used for obstacle detection and avoidance algorithms. The LIDAR data is transmitted to the laptop via Ethernet using TCP/IP protocols.

3D Stereo Cameras

The vehicle needs at least 2 forward facing cameras slightly inclined to the left and right. The ZED Stereo Camera is used for obstacle detection, lane detection, and path planning. This stereo camera has a 110° viewing angle and a depth range of 0.5-20 meters. Like the LiDAR, the data from the stereo camera is uploaded to Point-Cloud Libraries. This sensor will work together with the LiDAR. The collected data is compared to the LiDAR data in order to create a more accurate path planned for the vehicle.

Inertial Measurement Unit (IMUs)

The nine degree of freedom inertial measurement unit is a combination of a 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer, proving feedback about the vehicle’s pitch, angular velocity, and directional orientation in real time. This IMU fuses the three separate sensors onboard and reports the vehicle’s orientation in three-dimensional (3D) space.

GPS

The GPS acts as an absolute location source for latitude, longitude, and heading information. The differential GPS system not only provides the robot’s latitude and longitude, but also its heading with a positional accuracy of less than 30 cm. The additional heading information is more accurate than a magnetometer’s north reading, giving the robot a more accurate heading.
In order to navigate between the given GPS waypoints, the sensor needs to be equipped with a GNSS receiver. This receiver will be used for GPS waypoint navigation during the challenge. The unit will connect via USB 3.1 to the on-board PC Unit and operates on 12 volts and has centimeter accuracy to ensure precise waypoint navigation.

- ## Sensor Fusion:

Since the UVS system perceives multiple sensor data readings for different functionalities or operations, the fusion of the sensor data (combining information from multiple sources) is important to acquire the optimal information about the environment perception for the vehicle's correct decision making. One of the most prominent applications of Sensor Fusion has been in Navigation.

A filter is applied to the sub-systems that integrates information from multiple sources in order to obtain complete global information.

- The **Extended Kalman Filter (EKF)** is the best possible approach for implementing sensor fusion in the UVS system.
- The Extended Kalman Filter (EKF) relaxes the requirement on linear models
- It Uses the Jacobian matrix as a locally linear approximation of the function
- If the system is non-linear but the uncertainty is Gaussian, the Extended Kalman Filter can be used usually.
- The filter equations are the same as for the standard Kalman Filter

Simplified kinematics for the UGV

$$\dot{x} = \frac{r}{2}\left(\hat{\omega}_L + \hat{\omega}_R\right)\cos\hat{\theta}$$
$$\dot{y} = \frac{r}{2}\left(\hat{\omega}_L + \hat{\omega}_R\right)\sin\hat{\theta}$$
$$\dot{\theta} = \frac{r}{b}\left(\hat{\omega}_L - \hat{\omega}_R\right)$$

$$\dot{x} = V\cos(\theta)$$
$$\dot{y} = V\sin(\theta)$$
$$\dot{\theta} = \Omega$$

Discretizing the equations:

$$\begin{aligned} \dot{x} &= Vcos(\theta) \\ \dot{y} &= Vsin(\theta) \\ \dot{\theta} &= \Omega \end{aligned} \quad \rightarrow \quad \dot{x} = \frac{x_{k+1} - x_k}{\Delta t} \quad \rightarrow \quad \begin{aligned} x_{k+1} &= x_k + V_k\cos(\theta_k)\Delta t \\ y_{k+1} &= y_k + V_k\sin(\theta_k)\Delta t \\ \theta_{k+1} &= \theta_k + \Omega_k\Delta t \end{aligned}$$

Adding linear and angular velocity terms

$$\begin{aligned} x_{k+1} &= x_k + V_k\cos(\theta_k)\Delta t \\ y_{k+1} &= y_k + V_k\sin(\theta_k)\Delta t \\ \theta_{k+1} &= \theta_k + \Omega_k\Delta t \\ V_{k+1} &= \frac{r}{2}\left(\omega_{L,k} + \omega_{R,k}\right) \\ \Omega_{k+1} &= \frac{r}{b}\left(\omega_{L,k} - \omega_{R,k}\right) \end{aligned}$$

$$s_k = \begin{bmatrix} x_k \\ y_k \\ \theta_k \\ V_k \\ \Omega_k \end{bmatrix}$$

$$s_{k+1} = f(s_k, a_k)$$

We need to calculate the Jacobian for the state transition matrix

$$F_{k+1} = \left.\frac{\partial f}{\partial s}\right|_{s_k, u_k} = \begin{bmatrix} 1 & 0 & -V_k\sin(\theta_k)\Delta t & \cos(\theta_k)\Delta t & 0 \\ 0 & 1 & V_k\cos(\theta_k)\Delta t & \sin(\theta_k)\Delta t & 0 \\ 0 & 0 & 1 & 0 & \Delta t \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Measurement matrix is linear assuming sensor unit conversions and frame transformations are performed previously

$$o_k = h(s_k) = H_k s_k$$

$$\begin{bmatrix} x_{GPS} \\ y_{GPS} \\ \theta_{Mag} \\ V_{Acc} \\ \Omega_{Gyro} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_k \\ y_k \\ \theta_k \\ V_k \\ \Omega_k \end{bmatrix}$$

Time Update

$$s_{k+1}^- = f(s_k, a_{k+1})$$
$$P_{k+1}^- = F_{k+1} P_k F_{k+1}^T + Q_{k+1}$$

Measurement Update

$$\delta_{k+1} = o_{k+1} - h(s_{k+1}^-)$$
$$K_{k+1} = P_{k+1}^- H_{k+1}^T \left(H_{k+1} P_{k+1}^- H_{k+1}^T + R_{k+1}\right)^{-1}$$
$$s_{k+1} = s_{k+1}^- + K_{k+1}\delta_{k+1}$$
$$P_{k+1} = \left(I - K_{k+1} H_{k+1}\right) P_{k+1}^-$$