Scout project

1. Introduction

A large boat is crossing an unsecured area and sends two (or more) AUVs in front of it. These AUVs will be named *scouts*. They are equipped with sensors (for instance sonar, cameras, microphones, ...) and are able to send an alarm to the captain of the boat when something wrong is detected. We assume the following

- the scouts and the mother boat are able to communicate using the sound with a low flow rate (say 1Kb per second).
- Each crafts (the boat and the scouts) has a compas, a loch (to measure the speed), a pressure sensor, and a clock which is assumed to be perfect.
- All crafts are able to measure the distances between each of them using the sound. Since all crafts are moving, the measured distance between crafts corresponds the distances at different times (since the emission time and reception time is different).
- The distances between each craft is always inside the interval $[10, 1000]$ meters.
- The captain wants the scouts to be at a desired position expressed in the frame of the boat.

The goal of this project is to build a software using Moos and Morse which implements a distributed control strategy. The localization should be performed using interval-based observers.

2. Models

Boat model. The boat is described by the following state equations

$$\left\{\begin{array}{rcl} \dot{x} & = & v\cos\psi \\ \dot{y} & = & v\sin\psi \\ \dot{v} & = & 0.01\cdot(u_1 - v^2) \\ \dot{\psi} & = & 0.01\cdot v\cdot u_2 \end{array}\right.$$

where u_1 is correspond the the propulsion, u_2 to the rudder, ψ is the heading and (x, y) are the coordinates of its center. This model is 90% kinematic and 10% dynamic. It will be use to describe the behavior of a boat.

Scout model. Each scout is a torpedo like robot which obeys to the following state equations

$$\begin{cases} \dot{p}_x &= v\cos\theta\cos\psi \\ \dot{p}_y &= v\cos\theta\sin\psi \\ \dot{p}_z &= -v\sin\theta \\ \dot{v} &= u_1 - 0.1\cdot v^2 \\ \dot{\psi} &= \frac{\sin\varphi}{\cos\theta}\cdot v\cdot u_2 + \frac{\cos\varphi}{\cos\theta}\cdot v\cdot u_3 \\ \dot{\theta} &= \cos\varphi\cdot v\cdot u_2 - \sin\varphi\cdot v\cdot u_3 \\ \dot{\varphi} &= -0.1\cdot\sin\varphi + \tan\theta\cdot v\cdot(\sin\varphi\cdot u_2 + \cos\varphi\cdot u_3) \end{cases}$$

where j is the scout number (the number of the mother boat is $j=0$). The state vector for the jth scout is $\mathbf{x}^j = \left(\mathbf{p}^j, v^j, \psi^j, \theta^j, \varphi^j\right)$ where $\mathbf{p}^j$ is the position of the AUV, v^j is the speed, ψ^j is heading φ^j is the roll and θ^j is the pitch. Again, this model is 90% kinematic and 10% dynamic. It is valid only if a robust low level controller is implemented.

For simplicity, we will assume that all the controls (for the scouts and the boat) satisfy $u_i \in [-1, 1]$. The controls u_i will be automatic for the scouts, and controlled by a human (here the captain) for the boat.

3. Scout controllers

Saturation and Sawtooth function. In what follows, we will use the saturation function given by

$$\sigma(x) = \frac{2}{\pi}\text{atan}(x).$$

We also define the sawtooth function as

$$\tau(\theta) = \frac{2}{\pi}\cdot\text{atan}\left(\tan\frac{\theta}{2}\right)$$

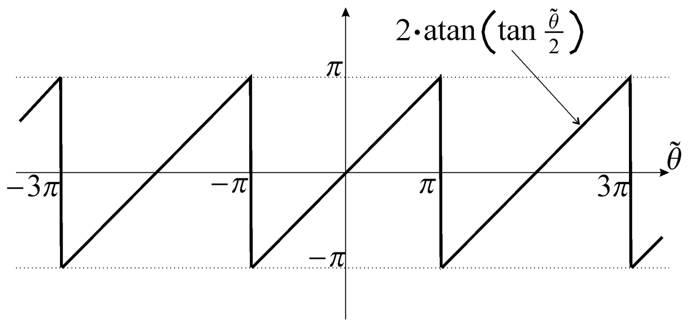
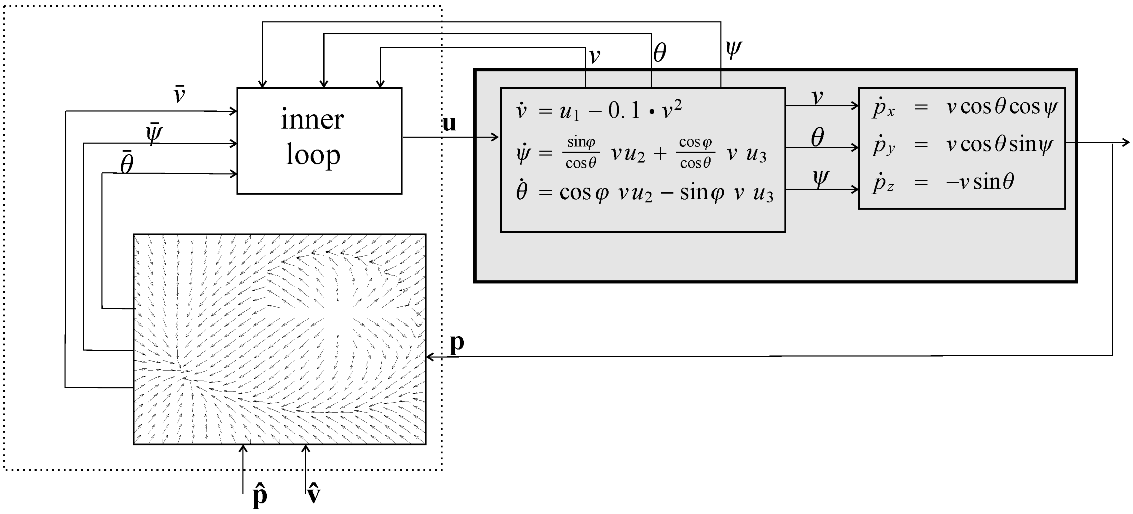


Figure 3.1: Sawtooth function

Inner loop. The jth scout $\mathcal{S}^j$ has an IMU which returns the Euler angles (heading ψ^j, roll φ^j, pitch θ^j). We also have an observer which returns an estimate $\hat{\mathbf{p}}^j$ of the scout position. If we want the robot to go at a desired speed $\bar{v}^i$, with the desired heading $\bar{\psi}^j$ and a desired vertical pitch $\bar{\theta}^j$, a natural proportional control strategy is

$$\begin{cases} u_1^j &= \sigma\left(\bar{v}^j - v^j\right) \\ u_2^j &= \tau\left(\bar{\psi}^j - \psi^j\right) \\ u_3^j &= \tau\left(\bar{\theta}^j - \theta^j\right) \end{cases}$$



Once, the inner loop is active we can consider that the scout motion is described by

$$\begin{cases} \dot{p}_x^j &= \bar{v}^j \cos\bar{\theta}^j \cos\bar{\psi}^j \\ \dot{p}_y^j &= \bar{v}^j \cos\bar{\theta}^j \sin\bar{\psi}^j \\ \dot{p}_z^j &= -\bar{v}^j \sin\bar{\theta}^j \end{cases}$$

Field. A vector field is a function which associates to a point $\mathbf{p}^j$, corresponding the position of the jth scout, a vector $\left(\bar{v}^j, \bar{\psi}^j, \bar{\theta}^j\right)$ to be followed. Consider a point $\mathbf{q}^j$ fixed in the robot frame. It corresponds to the place where we want the jth scout to be. From the Varignon formula, we have

$$\dot{\mathbf{q}}^j = \dot{\mathbf{p}}^0 + \boldsymbol{\omega}^0 \wedge \left(\mathbf{q}^j - \mathbf{p}^0\right),$$

where

$$\mathbf{p}^0 = \begin{pmatrix} x^0 \\ y^0 \\ 0 \end{pmatrix}, \ \dot{\mathbf{p}}^0 = \begin{pmatrix} v^0 \cos\psi^0 \\ v^0 \sin\psi^0 \\ 0 \end{pmatrix} \text{ and } \boldsymbol{\omega}^0 = \begin{pmatrix} 0 \\ 0 \\ \dot{\psi}^0 \end{pmatrix}.$$

The artifical potential will be chosen as

$$V\left(\mathbf{p}^j\right) = -\dot{\mathbf{q}}^{j\mathrm{T}} \cdot \mathbf{p}^j + \left\|\mathbf{p}^j - \mathbf{q}^j\right\|^2$$

which corresponds to a uniform field potential plus an attractive quadratic potential. The corresponding field is

$$\mathbf{w}^j = \dot{\mathbf{q}}^j - 2\left(\mathbf{p}^j - \mathbf{q}^j\right)$$

$$\begin{pmatrix} \bar{v}^j \\ \bar{\psi}^j \\ \bar{\theta}^j \end{pmatrix} = \begin{pmatrix} \|\mathbf{w}\| \\ \operatorname{atan2}(w_y^j, w_x^j) \\ \sigma\left(q_z^j - p_z^j\right) \end{pmatrix}$$

Controller. The resulting controller admits as inputs some kinematic information on the boat $\left(v^0, \psi^0, \dot{\psi}^0\right)$, the desired position for the scout, $\mathbf{q}^j_{\mathcal{R}_{\mathrm{boat}}}$ expressed in the boat frame, and an estimation $\mathbf{p}^j_{\mathcal{R}_{\mathrm{boat}}}$ for the position in the boat frame.

Controller (in: $v^0, \psi^0, \dot{\psi}^0, \mathbf{p}^j_{\mathcal{R}_{\mathrm{boat}}}, \mathbf{q}^j_{\mathcal{R}_{\mathrm{boat}}}$, out: $\mathbf{u}^j$)	
1 $\quad \mathbf{R}_{\psi^0} = \begin{pmatrix} \cos\psi^0 & \sin\psi^0 & 0 \\ -\sin\psi^0 & \cos\psi^0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$	from the boat to the world frame
2 $\quad \dot{\mathbf{q}}^j = \begin{pmatrix} v^0\cos\psi^0 \\ v^0\sin\psi^0 \\ 0 \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ \dot{\psi}^0 \end{pmatrix} \wedge \underbrace{\left(\mathbf{R}_{\psi^0} \cdot \mathbf{q}^j_{\mathcal{R}_{\mathrm{boat}}}\right)}_{(\mathbf{q}^j - \mathbf{p}^0)_{\vert\mathcal{R}_{\mathrm{world}}}}$	expressed in the world frame
3 $\quad \mathbf{e}^j = \mathbf{R}_{\psi^0} \cdot \left(\mathbf{q}^j_{\mathcal{R}_{\mathrm{boat}}} - \mathbf{p}^j_{\mathcal{R}_{\mathrm{boat}}}\right)$	error in the world frame
4 $\quad \mathbf{w}^j = \dot{\mathbf{q}}^j + 2\left(\mathbf{q} - \mathbf{p}\right)$	wanted speed vector in the world frame
5 $\quad \bar{v}^j = \|\mathbf{w}\|$	desired speed
6 $\quad \bar{\psi}^j = \operatorname{atan2}(w_y^j, w_x^j)$	desired heading
7 $\quad \bar{\theta}^j = \sigma(e_z^j)$	desired pitch
8 $\quad u_1^j = \sigma\left(\bar{v}^j - v^j\right)$	
9 $\quad u_2^j = \tau\left(\bar{\psi}^j - \psi^j\right)$	
10 $\quad u_3^j = \tau\left(\bar{\theta}^j - \theta^j\right)$	