ELEC 3224 — Introduction to GNC Systems

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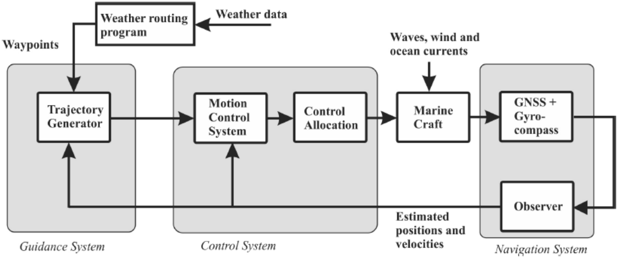
Introduction



Block Diagram of a Guidance, Navigation and Control (GNC) System.

- Overall Block Diagram (marine example but applicable to other areas (with changes)).

Introduction

- **A motion** control system consists of **three independent blocks** – guidance, navigation and control.
- The interact through **data and signal transmission.**
- The **guidance system** makes use of estimated (or, if possible, directly measured) positions and velocities.
- This is a closed-loop guidance system.
- A guidance system that only uses reference feedforward is an **open-loop guidance system.**

Introduction

- **Guidance** is the action of the system that continuously computes the reference (desired) position, velocity and acceleration of the vehicle to be used by the motion control system.
- The resulting data is provided to the human operator or the **navigation system.**
- A guidance system consists (in essence) of i) **motion sensors,** ii) **external data,** e.g., weather data, and iii) a computing system.

Introduction

- The controller collects and processes the information and then feeds the results to the motion control system.
- May include advanced optimization to compute the **optimal trajectory or path** for the vehicle to follow.
- Options include fuel optimisation, minimum time navigation, collision, formation control...
- **Motion control** determines the necessary control forces and moments to be provided by the vehicle to meet the control objective.
- The desired control objective is usually taken in conjunction with the guidance system.

Setpoint Regulation, Trajectory-Tracking and Path-Following Control

- Motion control systems must be well defined to satisfy the requirements for safe/effective operation of the vehicle.
- **Three Important Control Objectives:**
- **Setpoint Regulation:** the most basic guidance system is a constant input or setpoint provided by a human operator. The resulting controller is a **regulator,** e.g., station keeping, constant height etc.
- **Trajectory-Tracking Control:** the **position and velocity of the vehicles should track desired time-varying position and velocity signals.**

Setpoint Regulation, Trajectory-Tracking and Path-Following Control

- The corresponding feedback controller is a **trajectory-tracking controller.**
- Tracking control can be used for course-changing maneuvers, speed changing and attitude control (etc)
- **Path-Planning Control:** Used where it is required to follow **a pre-defined path independent of time (no temporal constraints.** Also no restrictions are placed on the temporal propagation along the path. Typically used for ships in transit between continents or AUVs for sea bed mapping.

Underactuated and Fully Actuated Vehicles

- It is straightforward to control a fully actuated vehicle but underactuation places limits on the control objectives that can be satisfied.
- **Definition: Degrees of Freedom (DOF)** – the set of independent displacements and rotation that completely determine the displaced position and orientation of the vehicle.
- A vehicle that **can move freely in 3-D space has maximum 6 DOFs.**
- These are three translational and three rotational components.
- **A Fully actuated vehicle operating in 6 DOF must be equipped with actuators that can produce independent forces and moments in all directions.**

Underactuated and Fully Actuated Vehicles

- To simulate the motion of such a vehicle a total 12 ordinary differential equations are needed as

$$\text{order} = 2 \times \text{DOF}$$

- Control systems for **under and fully actuated** vehicles are designed by defining a **workspace** in which the control objective is specified.
- **Definition: The *n*-dimensional configuration space is the space of possible positions and orientations that a vehicle may attain in the possible presence of external constraints.**
- The **configuration can be uniquely described by an *n*-dimensional vector of generalised co-ordinates, i.e., the least number of co-ordinates needed to specify the state of the system.**

Underactuated and Fully Actuated Vehicles

- It there exist h **geometric constraints:**

$$h_i(\eta) = 0, \; i = 1, \ldots, h$$

  the possible motions of the vehicle is restricted to a $(n - h)$ dimensional manifold.

- **Example** – 6 **DOF motion:** the displacements and rotations are described by 6 generalised positions and velocities:

$$\begin{aligned} \eta &= \begin{bmatrix} x & y & z & \phi & \theta & \psi \end{bmatrix}^T \in \mathbb{R}^3 \times S^3 \\ \nu &= \begin{bmatrix} u & v & w & p & q & r \end{bmatrix}^T \in \mathbb{R}^6 \end{aligned}$$

Underactuated and Fully Actuated Vehicles

- The angles ϕ, θ and ψ are defined on the interval $S = [0, 2\pi]$.
- This system is 12th order.
- For a vehicle restricted to operate in the horizonal plane $n = 3$ generalised positions and velocities are required:

$$\begin{aligned} \eta &= \begin{bmatrix} x & y & \psi \end{bmatrix}^T \in \mathbb{R}^3 \times S^3 \\ \nu &= \begin{bmatrix} u & v & r \end{bmatrix}^T \in \mathbb{R}^6 \end{aligned}$$

- This system is 6th order.

Configuration Space

- **Definition:** A vehicle is **underactuated if it has less control inputs than generalised co-ordinates.**
- **Definition:** A vehicle is **fully actuated it has the same (or a greater) number of control inputs than generalised co-ordinates.**
- A vehicle that operates in n DOF has a configuration space of n.
- Consider a marine craft with actuators only in surge, sway and yaw (not heave, i.e., veritcally up and down).
- This craft is **underactuated and the design of a motion control system for horizontal plane motion can be achieved using only three control inputs.**

Configuration Space

- Underwater vehicles that have actuators that produce **independent forces and moments in 6 DOF are fully actuated.**
- **Definition:** The workspace is a reduced space of dimension (m) less than $2\times$ DOF (of dimension, say, m) in which the control objective is defined.