INTRODUCTION TO VEHICLE NAVIGATION SYSTEM

LECTURE 5.1
SGU 4823
SATELLITE NAVIGATION
Navigation Systems

Navigation (Localisation) may be defined as the process of determining vehicle pose, that is:

- vehicle position
- vehicle orientation
- vehicle velocity

This is distinct from Guidance or Control which is the process of controlling a vehicle to achieve a desired trajectory.

An autonomous vehicular system generally must include these two basic competencies in order to perform any useful task.
An Historical Perspective

The first navigation techniques were used to estimate the position of a ship through dead reckoning, using observations of the ship's speed and heading.

Absolute information was used to provide a position fix. These fixes were obtained when well known natural or artificial landmarks were recognized.

In the open sea, natural landmarks are scarcely available, making an accurate position update not possible.

Techniques to determine Latitude were developed in the early 1550's by the Portuguese.

The determination of Longitude took another 300 years to be solved. The approaches were based on accurate prediction and observation of the moon and by knowing the time with enough accuracy to evaluate the Longitude.
A Modern Perspective

The previous slide introduced the essential elements of navigation, *Prediction and Correction.*

Prediction can be considered to be the use of a model or some description to provide dead reckoning information.

Correction is the process whereby the observation of landmarks (either natural or artificial) can reduce the location uncertainty inherent in dead reckoning.

It may be argued that with the advent of modern sensors such as the GPS that dead reckoning is no longer a necessary part of navigation. This is not true since there is no such thing as a perfect sensor. All sensors have some measure of error or uncertainty present within every measurement.

Similarly, if it were possible to perfectly model vehicle motion, external sensors would not be needed.
Therefore it is essential to understand not only the sensors used for navigation, but also the model used for prediction, as they both contribute to the accuracy of the position solution.

As both prediction and correction steps contain uncertainty, it is useful to pose navigation as an *Estimation problem*.

If the error in prediction, and the error in correction can be modeled as probability distributions then the Kalman filter can be used to fuse all available information into a common estimate that may then be used for guidance.
Navigation System Outline

Vehicle position tracking methods
It is essential that the navigation system correctly tracks the current vehicle position and displays it on the map. There are number of methods to track the current vehicle position:

1. Autonomous (dead reckoning)
2. GNSS (satellite) navigation and
3. Inertial

The above navigation methods are used in conjunction with each other.
**Autonomous Navigation (Dead Reckoning)**

This method determines the relative vehicle position based on the running track determined by the gyro and vehicle speed sensors located in the navigation system.

1. Gyro sensor  
Calculates the direction by detecting angular velocity. It is located in the radio and navigation assembly.

2. Vehicle speed sensor  
Used to calculate the vehicle running distance.
For a vehicle travelling in a 2-D space it is possible to compute the vehicle position at any instance provided the starting location and all previous displacement are known.

DR incrementally integrates the distance \( d(x,y) \) and direction \( \theta \) traveled relative to a known location.

\[
x_n = x_o + \sum_{i=0}^{n-1} d_i \cos \theta_i
\]

\[
y_n = y_o + \sum_{i=0}^{n-1} d_i \sin \theta_i
\]

\[
\theta_n = \sum_{i=0}^{n-1} \omega_n
\]
Basic Vehicle Navigation System (GPS + DR)
Vehicle Position Calculation
The navigation ECU calculates the current vehicle position (direction and current position) using the direction deviation signal from the gyro sensor and the running distance signal from the vehicle speed sensor and creates the driving route.

Map Display processing
The navigation ECU displays the vehicle track on the map by processing the vehicle position data, vehicle running track, and map data from the map disc.

Map Matching
The map data from the map disc is compared to the vehicle position and running track data. Then, the vehicle position is matched with the nearest road.
GPS Correction
The vehicle position is matched to the position measured by GPS. Then, the measurement position data from the GPS unit is compared with the vehicle position and running track data. If the position is widely different, the GPS measurement position is used.

Distance Correction
The running distance signal from the vehicle speed sensor includes the error caused by tire wear and slippage between the tires and road surface. Distance correction is performed to account for this. The navigation ECU automatically offsets the running distance signal to make up for the difference between it and the distance data of the map. The offset is automatically updated.
The combination of DR and GPS navigation makes it possible to display the vehicle position even when the vehicle is in places where the GPS radio wave cannot receive a signal. When only DR navigation is used, however, the mapping accuracy may slightly decline.

Navigation performed even where the GPS radio wave does not reach:
• In a tunnel
• In an indoor parking lot
• Between tall buildings
• Under an overpass
• On a forest or tree-lined path
Map Matching

The current driving route is calculated by DR (according to the gyro sensor and vehicle speed sensor) and GNSS navigation. This information is then compared with possible road shapes from the map data in the map disc and the vehicle position is set onto the most appropriate road.

The system compares the shape of the roads L1, L2 and L3 to the estimated running track after the vehicle makes a right turn. At point A, the vehicle position differs enough from the shape of L1 that the display switches to the road L2.
The Map Matching Problem
Geometric Point-to-Point Matching

One natural way to proceed is to match the point to the “closest” node or shape point in the network. Of course, the question then arises of how to define “close” and the most natural way to proceed is to use the Euclidean metric i.e the euclidean distance between two points $x$ and $y$ is given by:

$$||x - y||_2 = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2}.$$ 

In a point-to-point matching algorithm, one need only determine the distance between the node and vehicle position.

$P^t$ is closer to $B^1$ of street B even though clearly the vehicle is on street A
Geometric Point-to-Curve Matching

Perhaps the next most natural way to proceed is to attempt to identify the arc that is closest to the vehicle. Again, we must ask how to define “close” and the most common approach is to use the minimum distance from the point to the curve.
Inertial Sensors

Inertial sensors make measurements of the internal state of the vehicle. A major advantage of inertial sensors is that they are non-radiating and non-jammable and may be packaged and sealed from the environment. This makes them potentially robust in harsh environmental conditions.

Historically, Inertial Navigation Systems (INS) have been used in aerospace vehicles, military applications. However, motivated by requirements for the automotive industry, a whole variety of low cost inertial systems have now become available in diverse applications such as heading and attitude determination.

The most common type of inertial sensors are:

• **Accelerometers**: measure acceleration with respect to an inertial reference frame. This includes gravitational and rotational acceleration as well as linear acceleration.

• **Gyrosopes**: measure the rate of rotation independent of the coordinate frame.
**Inertial Measurement Unit (IMU)**

A IMU consists of at least three (triaxial) accelerometers and three orthogonal gyroscopes that provide measurements of acceleration in three dimensions and rotation rates about three axes.

The Physical implementation of inertial sensors can take on two forms:
- *Gimballed arrangement*
- *Strapdown*
GPS/INS Integration

Inertial sensors have been used in numerous applications for the past 50 years. This technology originally developed for military purposes has started to appear in industrial applications.

This has been possible due to the significant reduction in cost of inertial sensors. Unfortunately this reduction of cost comes with a substantial reduction in quality. These units without any aiding can only perform navigation for very short period of time.

The solution to this problem is aiding inertial systems with external information to maintain the error within certain bonds.

The most common aiding sensor for outdoor application has been the GPS in all its forms (autonomous / differential / RTK ). We will discuss various navigation architectures that fuse GPS, INS and modeling information in an optimal manner.
Navigation Architectures for Aided Inertial Navigation Systems

The navigation architecture depends on the types of sensors and models employed. For aided inertial navigation systems the inertial component can be:

- An Inertial Measurement Unit (IMU), which only provides the raw acceleration and rotation rate data
- An Inertial Navigation System (INS) providing position, velocity and attitude information

The aiding source can be:

- A sensor providing raw sensor information
- A navigation system providing the position, velocity and/or attitude information

The principle states of interest which are estimated by the filter, and hence which governs the type of model implemented, are the position, velocity and attitude of the vehicle, or the position, velocity and attitude errors.
Sensor Fusion

No single can provide completely accurate vehicle position navigation. Multisensor integration is required in order to provide the in-vehicle a complementary and redundant information of its location.

Integrated multisensor system have the potential to provide high levels of accuracy and fault tolerance.
The Kalman Filter

A consistent methodology for estimating position from navigation sensors is through the use of Kalman filtering and, for nonlinear systems, through the use of the extended Kalman filter.

The Kalman filter is a linear statistical algorithm used to recursively estimate the states of interest. The states of interest will usually consist of the vehicle pose and other relevant vehicle parameters.

In map building, the state vector can be augmented with feature positions, so that they too may be estimated. To aid in the estimation of the states, the Kalman filter requires that there be two mathematical models: the process model and the observation model.

These models correspond to prediction and correction respectively. For a linear system subject to Gaussian, uncorrelated, zero mean measurement and process noises, the Kalman filter is the optimal minimum mean squared error estimator. It also keeps track of the uncertainties in the estimates.
OCURRIO EL SABADO POR LA NOCHE CERCA DE CAPILLA.

Un hombre fallece tras hundirse su coche en la presa de La Serena
Un GPS indicó al conductor una vía cortada que conduce hasta el embalse. Un acompañante llegó a nado a la orilla y sufrió policontusiones. Residían en Sevilla.

GPS directs driver to death in Spain's largest reservoir
Satnav sends man down road that ends in La Serena, the biggest reservoir in the country
Monday 4 October 2010
Singapore Electronic Road Pricing (ERP)

ERP is an Electronic Road Pricing System used in managing road congestion. Based on a pay-as-you-use principle, motorists are charged when they use priced roads during peak hours. ERP rates vary for different roads and time periods depending on local traffic conditions. This encourages motorists to change their mode of transport, travel route or time of travel.

HOW DOES ERP WORK?

1. Cashcards are inserted into in-vehicle units (IU).
2. Each time a vehicle passes through an ERP gantry, ERP charges are deducted from your cashcard via short-range radio communication.