Target Tracking: Lecture 1
Course Info + Introduction to TT

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Course Info

- A total of 7 meetings
- Meet once a week for two hours on Wednesdays
- A: Algoritmen, S: Signalen, *16-18

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Outline

- Course info
- Introduction to Target Tracking

Course Info

This course is originally designed by Dr. Umut Orguner, former Assistant Prof. in our division.
The only book that covers most of it is

Book:

- A good reference in the long term if you are dealing with TT.
- Related section numbers to the lectures are given in the course web page (lectures).
- When a more detailed coverage or derivations are necessary, they will be provided in the class.
Course Info: Student responsibilities

- Get an overview on the subject before the class by reading the related sections in the book (see webpage of lectures).
- Do not indulge in the details in the book while reading, just try to get an overview.
- Complete the exercises and submit their small scale reports.

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Course Info: Optional

- For people who would like to do more and get more points (3hp), there is an opportunity to do a project.
- The aim of the projects is to gain additional knowledge on the tracking theory and algorithms.
- Depending on the amount of work required, you can work in groups, at most, of 2 people.

Project Subjects

We are going to implement most of the conventional algorithms with standard sensor models in the course. So possible project ideas are study and implementation of:

- Some conventional algorithm with unconventional sensors or targets (important probabilistic modeling work on the sensor and the target is required) e.g.,
  - extended targets
  - unresolved targets
- Some unconventional algorithm e.g.,
  - track before detect
  - (joint) integrated PDA
  - PF for MTT
  - random set based approaches (e.g., PHD, CPHD, MeMBer filters)

Procedure:

1. Project proposal (a ≤2 page document)
2. Progress report (halfway during the project)
3. Final report
**Course Info: Optional cont’d**

**Procedure:**
1. Project proposal (a \( \leq 2 \) page document)
2. Progress report (halfway during the project)
3. Final report
   - Any questions about the course?

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**Introduction to Target Tracking (TT)**

**Definition**

A **target** is anything whose state is of interest to us.

- State we are interested in can change with time with a certain dynamics which is itself unknown.
- Measurement origins are uncertain.
- There are false measurements \( P_{FA} > 0 \).
- Some measurements are missing \( P_D < 1 \).
- We generally have no initial guess or estimate.

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**A Conventional TT System**

- Measurement Processing
  - Gating & Association
  - Estimation & Prediction
  - Track Handling
- User Presentation Logic
- TRACKER
- USER

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**Tracking Examples**

- e.g.
Measurements

Definition

The term measurement contains all observed quantities included in a (possibly processed) report output from a sensor.

- Measurement (pre)processing generally includes a form of thresholding (measurement detection) process.
- Information loss during the thresholding is evident. In very low SNR scenarios, thresholding might not be used, which leads to Track Before Detect algorithms with high computation cost.
- We consider point or contact measurements.
- This means lots of processing that is out of hands of the TT-engineer. What is $P_D$, what is $P_{FA}$? Good modeling of measuring process must be obtained.

Types of point measurements:

- Kinematic measurements e.g.,
  - Position (pixel indices),
  - Range,
  - Range rate (radar doppler),
  - Bearing.
- Attribute measurements e.g.,
  - Signal strength,
  - Intensity,
  - Aspect ratio,
  - Target type.

Mostly, we are going to be concerned with only the kinematic measurements.
Types of measurement sources:
- One of targets that has been previously observed;
- A new target;
- False alarm (clutter).

Clutter
- A false measurement (false alarm or clutter) in tracking terminology generally refers to the concept of absence of persistency.
- In other words, a persistent false alarm (clutter) is considered a target to be tracked even if we are not interested in what or where it is.
- If one of our interesting targets gets in the vicinity of uninteresting false targets, we become prepared.

Target originated measurements:
- No sensor is perfect.
- In addition to sensor measurement noise $e_k$, there is a detection process with probability $P_D < 1$ in many sensors.
- Detection probability $P_D$ can be a characteristic of the sensor (raw measurement processing algorithm) as well as the target state, i.e., $P_D$ might depend on the specific target position and it can vary from target to target.
- It is generally difficult to find an exact formula for $P_D$.
- Approximations and heuristics abound.
- Every obtained measurement from the sensor includes two sources of information:
  1. Detection info $P_D$;
  2. The actual value of the measurement $y_k$.

Clutter:
- Non-persistent measurements which are not originated from a target.
- Prior information is important.
  - Clutter maps are sometimes existent.
  - Sensor (processing algorithm) characteristics — Some characteristics might be available from the manufacturer.
  - Experiments might be performed.
- The case of minimal prior info
  - Number of FAs in a region with volume $V$ is modeled as a Poisson distribution with clutter rate $\beta_{FA}$ (number of FAs per area per scan).
    $$ P_{FA}(m_{FA}^k) = \frac{\beta_{FA}^k V^m e^{-\beta_{FA}^k V}}{m_{FA}^k!} $$
    $$ p_{FA}(y_k) = \frac{1}{V} $$

- Spatial FA distribution: Uniform in every region with volume $V$. $\text{Range}$ $y_k = \sqrt{x_k^2 + y_k^2} + e_k$
- Log range (received signal strength (RSS)) $y_k = \alpha \log \left((x_k^2 + y_k^2)\right) + \beta + e_k$
- Bearing only $y_k = \arctan\left(\frac{y_k}{x_k}\right) + e_k$
Targets: Tracks

Definition

A track is a sequence of measurements that has been decided or hypothesized by the tracker to come from a single source.

- Usually, instead of the list of actual measurements, sufficient statistics is held e.g., mean and covariance in the case of a KF, particles in the case of a PF.
- Generally each arriving measurement must start a track. Hence tracks must be classified and must not be treated equally.

Track types: According to their different life stages, tracks can be classified into 3 cases.

- Tentative (initiator): A track that is in the track initiation process. We are not sure that there is sufficient evidence that it is actually a target or not.
- Confirmed: A track that was decided to belong to a valid target in the surveillance area. This is one end of initiation process.
- Deleted: At the other end of the initiation process, this is a track that is decided to come from all random F.As or a target which can no longer be detected. All of its info should be deleted.

Targets: Types

We can characterize targets considered in target tracking into categories depending on their size with respect to sensor resolution (depends on target-sensor distance too).

- Point target: A target that can result in at most a single measurement.
  - This means its magnitude is comparable to sensor resolution.
  - However, an extended target can also be treated as a point target by tracking its centroid or corners.
- Extended target: A target that can result in multiple measurements at a single scan.
- Unresolved targets: This denotes a group of close targets that can collectively result in a single measurement in the sensor.
- Dim target: This is a target whose magnitude is below sensor resolution. These can be tracked much better with track before detect (TBD) type approaches.

Targets: Modeling

General state space model

\[ x_k = f(x_{k-1}) + w_k \]

Example models

- (Nearly) constant velocity model
  \[
  x_k \triangleq \begin{bmatrix} x_k \\ v_k \end{bmatrix} = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_{k-1} \\ v_{k-1} \end{bmatrix} + \begin{bmatrix} T^2/2 \\ T \end{bmatrix} a_k
  \]
  where \( a_k \sim \mathcal{N}(0, \sigma_a^2) \) is a white noise.

- (Nearly) constant acceleration model
  \[
  x_k \triangleq \begin{bmatrix} x_k \\ v_k \\ a_k \end{bmatrix} = \begin{bmatrix} 1 & T & T^2/2 \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{k-1} \\ v_{k-1} \\ a_{k-1} \end{bmatrix} + \begin{bmatrix} T^2/2 \\ T \\ 1 \end{bmatrix} \eta_k
  \]
  where \( \eta_k \sim \mathcal{N}(0, \sigma_\eta^2) \) is a white noise.
(Nearly) Coordinated turn model, i.e., nearly constant speed, constant turn rate model

State with Cartesian velocity

\[ x_k \triangleq [x_k \ y_k \ u^x_k \ u^y_k \ \omega_k]^T. \]

\[
x_k = x_{k-1} + T \begin{bmatrix}
T^2/2 & 0 & 0 \\
0 & T^2/2 & 0 \\
0 & 0 & T \\
0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
\sin(\omega_{k-1} T) \\
\cos(\omega_{k-1} T) \\
\sin(\omega_{k-1} T) \\
\cos(\omega_{k-1} T)
\end{bmatrix}
\eta_k
\]

There are versions with polar velocity.

This model is a little different than the model in the book. It was taken from [Bar-Shalom (2001)].
**Targets & Measurements**

**Definition**

**Association** is the process of assigning measurements to existing tracks or existing tracks to measurements (measurement-to-track association vs. track-to-measurement association).

- In a classical air traffic control (ATC) application, there are hundreds of targets and measurements.
- Possible combinations are incredibly many.
- Not all of the possible associations are physically feasible.
- One must exclude these highly unlikely combinations from further consideration as soon as possible.

**Gating** is the process of using the sufficient statistics of a track to exclude the possibility of assigning a measurement to the track. The region in the measurement space that the measurements are allowed to be assigned to the target is called as the **gate**.

- Using maximum velocity assumptions about the target can give coarse gates.
- More detailed gates are formed using the predicted measurement means and innovations (measurement prediction) covariances of the track.

Even if gating reduces the number possible association combinations, there still remains some association uncertainty. These are handled by some other association algorithms:

- Nearest neighbors (NN) (single, in general, non-global (local) hard decision)
- Global nearest neighbors (GNN) (single unique hard decision)
- (Joint) probabilistic data associations (JPDA) (soft decisions, i.e., no decision or decision with probabilities)
- Multi hypothesis tracking (MHT) (making hard but multiple decisions and keeping them until sufficient evidence arrives)

What association algorithm to use depends on the SNR of the system and amount of computational resources that can be allocated to association.
Multiple Sensors: Decentralized Tracking Case

Issues we will mostly neglect

- Registration issues.
- Detection of biases and their compensation between various sensors.
- Out of sequence measurements: Measurements delayed in the communication which arrive into the fusion center after a more current measurement from the same source has already been processed.

Architecture Issues:

- Centralized approach is optimal.
- Communication constraints make it unattractive because measurement communication rates are generally higher than track communication rates.
- Some of the computations can also be distributed in the decentralized case.
- System’s susceptibility to failures in the tracking center is also an important issue.

References


