Fusion of optical and electromagnetic tracking systems using the federated Kalman Filter

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Introduction

The aim of this diploma thesis is a fusion of optical and electromagnetic tracking systems with the motivation of improving guidence techniques for minimal inversive surgery. I will combine different tracking systems with different properties like accuracy and availability. The intuitive solution for fusion of two systems would be using the more accurate one if available and switch to the second one when the data of the more accurate are not available. Within this work I will try to get an even better result by statistically combining the two systems with help of several (federated) Kalman Filters.

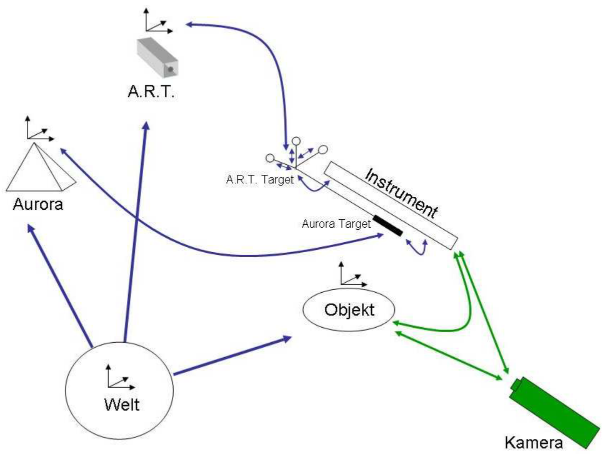

Figure 1: Environment of a multi-tracking system

Tracking systems

The two tracking systems I will combine are optical and electromagnetic tracking. Optical systems may track objects provided with reflective markers by sending flashes of infrared light onto the scenery. Two synchronized cameras recive the echo of these flashlights and compute very precise 3D-Data about the location of the markers. Clear limit of this technique is where occurs an interruption of the line-of-sight between the cameras and the object to be tracked. Besides it cannot be applied to instruments with a non-rigid transformation between sensor and marker.

Mostly used systems during surgery are electromagnetic tracking systems like they don't have the constraint of a line-of-sight. They generate a magnetic field by a transmitter. A measurement device can calculate position and orientation of sensors within this field. Thus there are received

continuous signals of the tracked object. But on the other hand electromagnetic trackers never get to a similar accuracy as optical trackers.
To get better results it is possible to create hybrid tracking systems, to benefit the advantages of each tracking method and get rid of its shortcomings at the same time. In my work I will create such a hybrid system on the basis of statistically fusion. (compare [2] and [1])

The discrete Kalman Filter Algorithm

A very common tool for sensor fusion is the Kalman Filter. It is a modelbased method for state estimation and may be used for process and time-dependent measurement systems. With the purpose to make estimations for following states and minimize the mean error it uses a form of feedback control in two steps as seen in figure 2 The

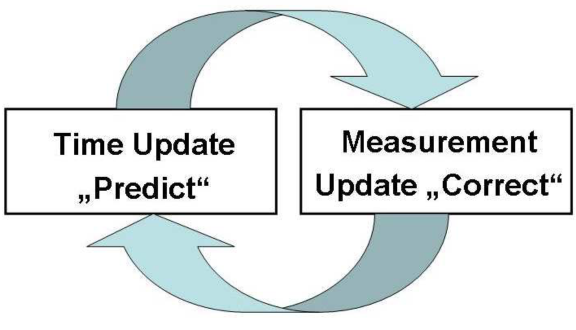

Figure 2: "Kalman loop" of estimation (predict) and update (correct)

recursivity is one of the attractive parts of the Kalman Filter because its no longer necessary to operate on all data directly but the current estimation is conditioned on all of the past measurements recursively. Thus this process will lead to refinement of the mechanism of estimation.(compare [5]))

Mathematics

These are the specific equations for the time and measurement updates. We define $\hat{x}_k^- \in \mathbb{R}^n$ to be our *a priori* state estimate at step k given measurement z_k. P_k^- is the *a priori* estimate error covariance.
So we get these Discrete Filter time update equations:

$$\hat{x}_k^- = A\hat{x}_{k-1} + Bu_{k-1} \tag{1}$$

$$P_k^- = AP_{k-1}A^T + Q \tag{2}$$

The $n \times n$ matrix A relates the state at the previous time step $k-1$ to the state at the current step k, assumed to be constant. The $n \times l$ matrix B relates the optional control input $u \in \mathbb{R}^l$ to the state x. The *process noise covariance* Q is assumed to be constant as well.
The measurement update equations, the *gain* or *blending factor* K, the *a posteriori* state estimate $\hat{x}_k$ and the *a posteriori* estimate error covariance P_k are the following:

$$K_k = P_k^- H^T(HP_k^- H^T + R^{-1}) \tag{3}$$

$$\hat{x}_k = \hat{x}_k^- + K_k(z_k - H\hat{x}_k^-) \tag{4}$$

$$P_k = (I - K_kH)P_k^- \tag{5}$$

The $n \times m$ matrix K, the so-called *Kalman Gain* minimizes the *a posteriori* error covariance. R is the *measurement noise covariane*, assumed to be constant. The $m \times n$ matrix H, the predicted measurement, relates the state to the measurement z_k is assumed to be constant as well. (compare [5])

The federated Kalman Filter

In my work I will not only use one filter for each sensor but build a hierarchical System of filters for a better customization of the parameters. There will be two local filter versions filtering data from each tracking system. Those filters will create their model from the measurements. An additional *master* filter will make a fusion of the data of both sensors. This sensor gets its model from the application.

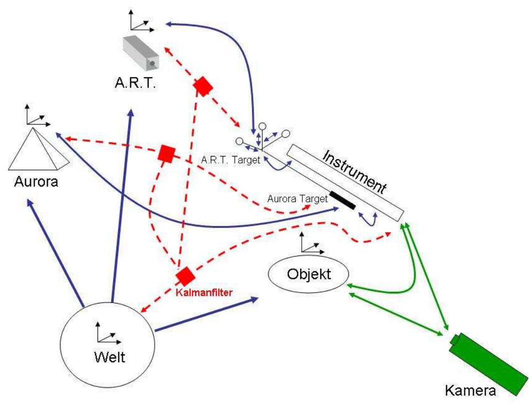

Figure 3: Combination of local device filters and one master filter

In comparation to classical filter implementations the hierarchical design "achieves a major improvement in throughput (speed), is well suited to real-time system Inplementation, and enhances fault detection, isolation and recovery capability" [3].

Realisation

The realisiation of my method for sensor fusion will be an augmentation of laparoscopic surgery at the institute for minimally invasive Therapy and Intervention (MITI) in Munich. The used optical tracking system is "dtrack" von Advanced Realtime Tracking GmbH (A.R.T.). The electromagnetic tracking system is "Aurora" von Northern Digital Inc. (NDI), for both systems are already drivers available. The implementation will be coded in c++ and will be part of an existing library for AR applications, the "CAMP"-lib at chair 16, TU-München.

Milestones

The first part of my work will be the study and comparation of existing realisations like the work from N. A. Carlson [3] and J. Côté et al. [6]. In about one month I start concentrating on the implementation part. The last part from march until middle of may I will address myself to write down the work. In the last month of this thesis there will be also the chance to implement the work in an experimental setup with the aid of other student projects for the purpose of demonstrating the results.

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