Co-simulation of transfer alignment and CAN bus based on CANoe-MATLAB

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Abstract. The research on rapid transfer alignment for INS on moving base is very important in the field of the inertia technology. In order to build the real-time CAN bus network simulation system with the velocity matching model of the transfer alignment algorithm, CANoe(CAN open environment)-MATLAB interface is applied. The CANoe-MATLAB interface is connected with MATLAB/Simulink which has powerful modeling functions and CANoe which has perfect function of bus simulation. Modeling the transfer alignment algorithm by MATLAB/Simulink and providing the real-time CAN bus network communications in HIL(hardware-in-loop) simulation by CANoe. The simulations tests show that co-simulation system built by the CANoe and the MATLAB/Simulink performs favorably with rapid convergence and validity.

1. Introduction
CANoe is a total network simulation tool designed to both model nodes on a network and the network that binds them[1]. Typically the functionality of these network nodes are modelled using CAPL(Communication Access Programming Language) which is a C style programming language provided with CANoe. However, due to the limited ability of this language, it is difficult to design nodes with complex control algorithms or control functions.

The Vector_AddOn_Matlab_Interface extends CANoe’s node modeling capability by adding the strength of MATLAB/Simulink environment. This interface provides data exchange with CANoe for simulations running inside Simulink and assures time synchronization between both tools[2].

The transfer alignment process is made to the non-aligned slave INS by use of information of the aligned master INS when the master carrier is moving[3]. When the system is built in the real-time CAN bus network communications, the The CANoe-MATLAB interface is used necessarily.

2. Transfer alignment modelling
The process of transfer alignment is based on the system error model, establishing system equation and observation equation, and estimating the misalignment angle by means of various estimation methods of the stochastic system. The most commonly used estimation method in transfer alignment is the Kalman filtering; meanwhile the velocity matching error model is used as the observability analysis[3][4][5].

2.1. Kalman filter initialization
The following matrix need to be initialized: the identity matrix $I_k$, the state transition matrix $A_k$, the mean square error matrix $P_k$, the process noise covariance matrix $Q_k$, the measurements noise covariance matrix $R_k$, the relation matrix $H_k$ and the filter state matrix $X_k$.

### Table 1. Initial value.

| Symbol | Dimensionality | Initial Value |
|--------|----------------|---------------|
| $I_k$  | $5 \times 5$   | The elements on the diagonal line are 1.0 and the remaining elements are 0 |
| $A_k$  | $5 \times 5$   | The value is the same as $I_k$ |
| $P_k$  | $5 \times 5$   | The diagonal elements are $3.0 \times 10^{-4}$, $1.0 \times 10^{-4}$, $3.0 \times 10^{-4}$, $0.25$, $0.25$ successively and the remaining elements are 0 |
| $Q_k$  | $5 \times 5$   | The diagonal elements are $8.350 \times 10^{-13}$, $8.350 \times 10^{-13}$, $1.0 \times 10^{-6}$, $1.0 \times 6$ successively and the remaining elements are 0 |
| $R_k$  | $2 \times 2$   | $R_k = \begin{bmatrix} 0.01 & 0 \\ 0 & 0.01 \end{bmatrix}$ |
| $H_k$  | $2 \times 5$   | $H_k = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$ |
| $X_k$  | $5 \times 1$   | $X_k = [0 \ 0 \ 0.5 \ 0.5]$ |

### 2.2. Attitude matrix of slave INS and master INS calculation

Calculate the slave INS attitude matrix $C_{b}^{s}$ and the master INS attitude matrix $C_{b}^{m}$ as follows.

$$C_{b}^{s} = \begin{bmatrix} \cos \theta_{s} \cos \varphi_{s} - \sin \theta_{s} \cos \varphi_{s} \cos \gamma_{s} + \sin \varphi_{s} \sin \gamma_{s} & \sin \theta_{s} \cos \varphi_{s} \sin \gamma_{s} + \sin \varphi_{s} \cos \gamma_{s} \\ - \cos \theta_{s} \sin \varphi_{s} \sin \gamma_{s} + \sin \varphi_{s} \cos \gamma_{s} & \cos \theta_{s} \sin \gamma_{s} + \cos \varphi_{s} \cos \gamma_{s} \end{bmatrix}$$

$$C_{b}^{m} = \begin{bmatrix} \cos \theta_{m} \cos \varphi_{m} - \sin \theta_{m} \cos \varphi_{m} \cos \gamma_{m} + \sin \varphi_{m} \sin \gamma_{m} & \sin \theta_{m} \cos \varphi_{m} \sin \gamma_{m} + \sin \varphi_{m} \cos \gamma_{m} \\ - \cos \theta_{m} \sin \varphi_{m} \sin \gamma_{m} + \sin \varphi_{m} \cos \gamma_{m} & \cos \theta_{m} \sin \gamma_{m} + \cos \varphi_{m} \cos \gamma_{m} \end{bmatrix}$$

### 2.3. State transition matrix updating

After the traditional transfer alignment model has been initialized, improve the robustness of the system by updating the state transition matrix as follows.

$$A_{k}(4,2) = \Delta V_{E}^{o} A_{k}(5,2) = - \Delta V_{E}^{o}$$

### 2.4. Observation vector updating

The observation vector $Z_{k}$ is the velocity difference between master INS and slave INS.

$$Z_{k}(1) = V_{E}^{s} - V_{E}^{m}Z_{k}(2) = V_{N}^{s} - V_{N}^{m}$$

### 2.5. Kalman filter calculating

The Kalman filter state vector $X_{k}$ contains the attitude misalignment angle in 3 directions and the velocity error in northern and eastern directions.

$$X = [\varphi_{x}, \varphi_{y}, \varphi_{z}, \delta V_{E}, \delta V_{E}]^{T}$$

The recursive formula of Kalman filter is generalized as follows. Update the filter state matrix $X_{k}$ and the mean square error matrix $P_{k}$, and the result of transfer alignment is $X[0]$ $X[1]$ $X[2]$ in 3 directions.

$$X_{k,k+1} = A_{k}X_{k}$$

$$P_{k,k+1} = A_{k}P_{k}A_{k}^{T} + Q_{k}$$
\[ K_k = P_{k,k+1}H_k^T(H_kP_{k,k+1}H_k^T + R_k)^{-1} \]  
\[ P_{k+1} = (I_k - K_kH_k)P_{k,k+1} \]  
\[ X_{k+1} = X_{k,k+1} + K_k(Z_k - H_kX_{k,k+1}) \]  
\[ X_k = X_{k+1} \]  
\[ P_k = P_{k+1} \]  

3. CAN bus co-simulation

There are three different approaches of time synchronization [1]: (1) The Simulinktime base is used for the CANoe simulation. CANoe is operated in Slave mode whereas MATLAB Simulink is the simulation Master. This will be referred to as the Offline Mode. (2) In contrast to the Offline Mode the CANoe time base is used in MATLAB Simulink. Therefore the simulation is run in almost real-time, which is called the Synchronized Mode. (3) In the HIL Mode, a Windows DLL is produced with the Simulink which can be loaded in CANoe’s simulation environment.

Create a new database with CANdb++ in the CANoe environment, which contains environment variables, network nodes, messages and signals. In the CAN database, the following objects need to be linked: signals with messages, messages with network nodes and message signals with network nodes.

Open the model in Simulink. The model contains 3 CANoe specific blocks: Simulation step, Signal Input and Signal Output. The first block-Simulation step is only relevant to the simulation in Offline and Synchronized Mode. The others are signal input and output blocks respectively which are linked to the CAN database. Design the transfer alignment filter model by Chapter 2, which is shown as figure 1.

![Figure 1. Simulink model.](image)

Open the simulink setup and import the database into CANoe. The signals can be displayed in data and graphics windows. The whole system simulation process is based on the offline mode of the CANoe-MATLAB interface, which is used as a slave mode. When the simulink mode is started, the CANoe automatically opens the bus messages and signals, which can be used to feed back the Simulink model accuracy and real-time.

4. Analysis of simulation results
The purpose of the simulation consists of two parts. On one hand, verify the correctness of the transfer alignment model. On the other hand, verify the accuracy and real-time between CANoe and MATLAB. Figure 2 shows the velocity in northern and eastern directions of master INS and slave INS. Figure 3 shows the attitude of slave INS. What is clear from the data is that the master INS and slave INS are both on the moving base which is rolling, as shown in the figure 4. Through simulation the attitude misalignment angles in 3 directions are convergent using Kalman filter, which indicate the precision of model is good and is agree with actual stages, as shown in the figure 5.

![Figure 2. The velocity of master INS and slave INS.](image1)

![Figure 3. The attitude of slave INS.](image2)
5. Conclusion
The CANoe addon MATLAB co-simulation has a wide range of application, with this approach it is possible to test and verify the transfer alignment model designs with real CAN hardware in a real-time networked environment. The method covers the shortage of MATLAB’s capability to the CAN bus, meanwhile improves the ability to check out the defects of the model. The result of co-simulation based on CANoe and MATLAB/Simulink performs favorably with rapid convergence and validity. The simulation method will have more extensive applications.

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