Chapter 1

Lever arm estimation for GNSS and MRU lever arms

This Chapter considers the topic of estimating the body frame position of the GNSS and MRU sensors. For the GNSS position an observer design and an adaptive scheme are proposed and analyzed. The estimation designs are tested using numerical simulations and experimental data from the Gunnerus sea trials. A similar observer is proposed for the MRU positions, and experimental data from the sea trials are used to test the observer.

1.1 Introduction

In automatic motion control of marine vessels we usually consider set-point stabilization. This means that the vessel is actuated such that a defined point P_0 in the vessel body frame converges to and tracks a predefined position or path in the NED frame. As it is often impractical or impossible to place motion sensing equipment in P_0, it is important to know accurately where the sensors are placed. This makes it possible to compensate for the motion difference between the sensor location and P_0. If this is inaccurate it may lead to degraded position tracking performance and increased fuel consumption. Today, these lever arms are measured at dock using a laser surveying technique. Although accurate, it is time consuming, expensive, and potentially subject to human errors as the laser equipment must be moved several times for each lever arm. Therefore, this Chapter proposes to estimate the lever arms of both GNSS antennas and MRUs numerically using the sensor measurements from a maneuver with sufficient rotation and movement of the vessel. This is attractive as it removes the human influence and does not requiring expensive time at dock.

For GPS and INS integration extensive research has been performed in **?**, **?**, **?**, and **?**. A single antenna GPS with accurate measurements is used in combination with a low-grade inertial measurement unit (IMU). In **?** the observability of the error states in the INS/GPS integrated system is studied, and in **?** experimental studies verify the lever arm estimation

of the GPS antenna using a setup on a car. In
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1.1.1 Scope

The scope of work is to analyze and test the two following methods for simultaneously estimating multiple lever arms:

- A Luenberger observer design
- An adaptive observer design

These methods will be analytically derived and their stability properties will be analyzed. As a part of this, observability and persistence of excitation investigations will be performed to investigate what level of motion and perturbation is required for the lever arm estimates to converge to the true values.

The observability of the problem is considered in Section **??**, and requirement for the problem to be observable is found. A design for a (Luenberger) observer is proposed, and stability is proven (Section **??**). In Section **??** an adaptive observer is proposed, and stability and convergence of the adaptive observer is shown in Section **??**. Further, the persistence of excitation criteria is investigated in Section **??**.

In Section **??** the problem setup for MRU lever arms are formulated, and in Section **??** the observability of the dynamics is considered. In Section **??** an observer is proposed.

For the GNSS lever arms two case studies with data from the sea trials with R/V Gunnerus are performed in Section **??**. In the first case study (Section **??**) data from a sea trial is used, but the GPS data is simulated, and in the second **??** real GPS data is used. A case study for the MRU lever arms is performed in Section **??**. Data from a sea trial with R/V Gunnerus is used.

In the following, the rotation matrix will be viewed as a signal, such that the system equations, instead of being nonlinear, can be treated as linear time varying (LTV). The GNSS and MRU problems are treated separately, and it is assumed that all needed measurements are available.