An Introduction to the Use of Complementary Filters for Fusion of Sensor Data

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Abstract

Complementary filters are defined in mathematical terms and in the context of Weiner and Kalman filters. The derivation of common forms is explored, and it is shown why a Kalman filter is often used within a complementary filter structure. An example of the design of a complementary filter for a practical application is presented in detail.

Introduction

The term "complementary filter" is often casually used in the literature to refer to any digital algorithm that serves to "blend" or "fuse" similar or redundant data from different sensors to achieve a robust estimate of a single state variable.

For example, in aerospace navigation systems, a complementary filter is often utilized to estimate the position in space of an airframe by combining the high resolution position information obtained from integrating acceleration and velocity data with the low resolution position information obtained directly from the GPS satellite network. The data available from an inertial navigation systems is very good information for a short period of time. However, as integration errors grow in an unbounded fashion, they can no longer be tolerated. On the other hand, the position errors associated with GPS data, though quite large, are bounded and well characterized. A complementary filter combines the excellent high frequency position information derived from the integration of inertial sensor data with the good low frequency position information from GPS data, while rejecting the errors peculiar to each method.

The reader should note that complementary filters are in a class by themselves. While filters in general act on a signal, the complementary filter does not. It acts only on the different kinds of noise associated with different kinds of measurements of the same signal. It is a solution waiting for a very special problem - that of estimating a state variable from data from multiple sources, which exhibit noise with different frequency content.

Mathematical definition

The complementary filter is a frequency domain filter. In its strictest sense, the definition of a complementary filter refers to the use of two or more transfer functions, which are mathematical complements of one another. Thus, if the data from one sensor is operated on by G(s), then the data from the other sensor is operated on by I-G(s), and the sum of the transfer functions is I, the identity matrix. In the case of a one-dimensional filter as will be described in this paper, the identity matrix reduces to the scalar number one.

In a typical two-input system, one input will provide information with high frequency noise, and is thus low-pass filtered. The other input provides information with low frequency noise, and is high-pass filtered. If the low-pass and high-pass filters are mathematical complements, then the output of the filter is the complete reconstruction of the variable being sensed, minus the noise associated with the sensors.

A block diagram illustrating this process with "perfect" 1st-order low-pass and high-pass filters is shown below: