An Adaptable Navigation System for an Underwater ROV

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ABSTRACT

This paper presents a multi-sensor adaptable navigation system for an underwater remotely operated vehicle (ROV). A new multiple Kalman filter strategy is proposed, in which sensors can easily be added and removed from the navigation system without users having to modify the navigation algorithm. Sensors are assigned confidence levels, modifiable by the operator and the algorithm. The results of two sensor failure detection and recovery strategies are also given.

Keywords: Sensor fusion; Kalman filter; Remotely operated vehicle (ROV); Underwater navigation; Neural network; Fuzzy logic; Sensor failure.

INTRODUCTION

An underwater remotely operated vehicle (ROV) is currently under development at the Institut de recherche d'Hydro-Québec (IREQ). The underwater vehicle is to be used in various tasks such as the inspection of concrete dam surfaces and other hard to access underwater areas. As the ROV inspects the dam, each default on the surface must be identified using the on-board camera, precisely located and reproduced in a virtual environment, consisting of a complete scaled model of the dam. Later on, maintenance crews will want to return to the identified defaults to follow their evolution in time or to perform restoration work. A precise navigation system is therefore a crucial part of the ROV. The navigation system is composed of a variety of sensors giving information about position and movement. Sensor fusion techniques are used to obtain an optimal estimate of the vehicle position using data from all the sensors.

To meet the needs of the ROV operators and designers, the navigation system must be easy to use and adaptable. Two important requirements for the navigation system are: 1) Users of the ROV must be able to add and remove sensors from the vehicle without having to alter the information fusion algorithm; 2) With each sensor must be associated a confidence level, accounting for the noise level, modifiable by the user and giving a measure of the validity of the information from the sensor.

Assignment of confidence levels to sensors has been suggested [1], but they were solely based on the noise level of each sensor. It is suggested here to add a user modifiable factor to the confidence level of each sensor, and to use this new confidence level in a multiple Kalman filter algorithm. This multiple Kalman filter algorithm is able to accommodate different types and combinations of sensors. To obtain a more robust navigation system, a sensor failure detection and recovery scheme is added to the system. In case of sensor failure, action will be taken in order to alter confidence levels or the choice of sensors so that the global position estimate is not corrupted.

A MULTIPLE KALMAN FILTER STRATEGY

The Kalman filter is the most widely used estimator in sensor fusion systems. The purpose of this filter is to give the optimal estimation of the position of a vehicle, given the model of the system and measures from various complementary sensors.

Once the navigation equations and the statistics of the noise on each sensor are given, the Kalman filter will give the optimal estimation as long as the sensors and noise distributions do not change. In order to accommodate requirement 1), the solution proposed is to design a series of generic Kalman filters, reflecting all the different sensor combinations that can occur. For this purpose, sensors are classified according to the physical quantity they measure. The choice of the Kalman filter(s) to use will depend on the sensors that are currently active on the ROV. These active sensors are specified by the operator. The choice of active sensors may also be modified by the navigation algorithm in case of sensor failure (see the following section).

The Kalman filter is designed in its basic form to fuse information from complementary sensors. For example, it will be used to find a better position estimate by fusing data from accelerometers with data from an acoustic positioning system, giving absolute position. But what if there are two redundant measures of absolute position coming from two different positioning systems?

The answer is to use two identical Kalman filters, to fuse each of the two position measurements with the data from the accelerometers. The outputs of both Kalman filters are then fused to obtain an optimal global estimate that combines a maximum of information. An interesting mathematical model for fusing information from multiple Kalman filters, called *decentralized Kalman filtering*, is suggested in [2]. This fusion process is based, as is usually the case in Kalman filters, only on noise statistics. The algorithm used in the ROV navigation is inspired from this model and adds information from the user-defined confidence levels.

SENSOR FAILURE DETECTION AND RECOVERY

During the operation of the ROV, sensor failure must be accounted for. At any time, any of the sensors can break down or stop sending information, temporarily or permanently. In these cases, the navigation system must immediately identify the failed sensor and act in such a way that data from the failed sensor will not corrupt the global estimates. This action can be to remove the sensor from the list of active sensors and therefore change the selection of Kalman filter(s), or simply to change the confidence level of the sensor. Two means of accommodating for failed sensors have been implemented and tested in the development of the IREQ ROV project.

The first one is inspired by work in [3]. The idea is to use neural networks to approximate each sensors output behavior under normal operating conditions. Inputs to the networks are data from the other sensors and actuators of the ROV. During operation, a significant difference between the measured value of a sensor output and the value predicted by the corresponding network would signal a sensor failure for that sensor. The sensor can then be cut off or replaced by the output of the neural network. This algorithm works well for the case of an aircraft, which has numerous control signals, sensors and actuators, some of which give redundant information. However, in the case of the ROV, tests have shown that there is not enough redundant information in normal operation to allow the neural networks to learn the output of a sensor using data from other sensors. Therefore, this strategy would not be robust enough for the ROV project.

A second more promising sensor failure detection and accommodation scheme has also been simulated and tested. Inspired from work in [4], it involves the use of fuzzy logic to detect and accommodate for sensor failures. The input to the fuzzy system are coefficients that quantify the difference between the measured values and the values estimated by the Kalman filter, for a particular sensor (the absolute positioning system). If this difference relative to the error noise covariance is large, then the value measured by the sensor may be corrupted. In this case, the fuzzy system will determine a coefficient that will alter the Kalman gain, lessening the influence of the corrupted sensor proportionally to the importance of the corruption. Simulations have shown that this method can significantly reduce the influence of sensor failure.

Figure 1 shows the result of the simulation of the fuzzy failure detection algorithm on some corrupted data. The output of a Kalman filter that fuses a functional accelerometer with a corrupted positioning system is shown. The light, noisy plot is the output of the Kalman filter without the fuzzy detection scheme, while the darker plot shows the fuzzy-filtered data. It can be seen that the failure detection and recovery scheme brings significant benefit to the system.

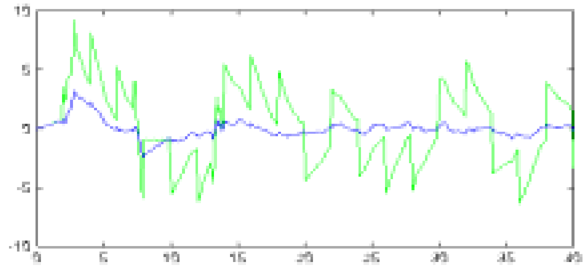

Figure 1: Results of fuzzy failure detection

CONCLUSION

An adaptable navigation system for an underwater ROV has been presented. The algorithm is based on a multiple Kalman filter approach to allow different sensor combinations and the use of redundant sensors. Further improvement of the Kalman filtering algorithm could be obtained with the use of adaptive Kalman filtering techniques, ensuring that the position estimate is always optimal. An effective way to detect and accommodate for sensor failure was also presented.

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