Design of the Multi-Role *Springer* Unmanned Surface Vehicle

Robert Sutton
School of Engineering, The University of Plymouth,
Drake Circus, Plymouth PL4 8AA, UK

Abstract: An unmanned surface vehicle named Springer is being developed at the University of Plymouth to conduct environmental and geographical surveys in shallow waters. An equally important secondary role envisaged for Springer is as a platform for other marine research groups to test their own systems onboard the vehicle. This paper highlights Springer hardware and software architecture including various navigational sensors, speed controller and an environmental monitoring unit. Details regarding the development of a fault tolerant multi-sensor data fusion technique are also outlined. Moreover, a control strategy based on a linear quadratic Gaussian with loop transfer recovery theory is presented which is to be implemented in Springer for track keeping.

Keywords: Unmanned surface vehicle, navigation, guidance and control, linear quadratic Gaussian, multi-sensor data fusion, pollutant tracking

1. INTRODUCTION

The potential of the use of unmanned surface vehicles (USVs) for tasks such as shallow water surveying, weapon delivery, environmental data gathering, coordinating with autonomous underwater vehicles (AUVs) and surveillance is quite lucrative. Functionally, they are much simpler than AUVs yet quite versatile for the kind of missions they are able to perform. In fact, the accuracy of USVs is far better than that of the AUVs due to the availability of GPS fixes at all time in open waters. Whilst, AUVs regularly need to surface in order to correct for the error incurred by the dead reckoning navigation.

Some well known USV projects around the globe are detailed in [1]. The UK research interest in this key area has mainly been confined to that being undertaken by Corfield [2] who developed variants of *Mimir* EV1 for naval and surveying missions, and Young and Phillips [3] who developed a semi-submersible for deploying sensors for ocean surveys. More recently, Reed *et al.* [4] from the United States Naval Academy have published the design of a small monohull autonomous surface vehicle whilst Hook enlisted his findings in [5] on the existing USV types that are known to have recently been or being developed.

Also mentioned in the list is the *Springer* USV which has been designed and is being developed by the Marine and Industrial Dynamic Analysis (MIDAS) Research Group at the University of Plymouth, UK. *Springer* is intended to be a cost effective and environmentally friendly USV which is designed primarily for undertaking pollutant tracking, and environmental and hydrographic surveys in rivers, reservoirs, inland waterways and coastal waters, particularly where shallow waters prevail. An equally important secondary role is also envisaged for *Springer* as a test bed platform for other academic and scientific institutions involved in environmental data gathering, sensor and instrumentation technology, control systems engineering and power systems based on alternative energy sources.

In order for the vehicle to be capable of undertaking the kinds of mission that are contemplated, *Springer* requires a robust, reliable, accurate and adaptable navigation, guidance and control (NGC) system which allows seamless switching between automatic and manual control modes. Whilst AUVs are now in service in the offshore industry, such craft cannot be deployed in shallow or inland waters to perform the kind of

Sutton, R. (2007) Design of the Multi-Role *Springer* Unmanned Surface Vehicle. In *Platform Innovations and System Integration for Unmanned Air, Land and Sea Vehicles (AVT-SCI Joint Symposium)* (pp. 6-1 – 6-8). Meeting Proceedings RTO-MP-AVT-146, Paper 6. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

tasks outlined above. As a result, operational costs are currently high as SCUBA divers or special vessels containing a number of personnel have to be employed. It is foreseen that *Springer* will be portable and capable of operating in water from 1m to 60m in depth.

Several articles have already been published by the Plymouth team regarding the development of *Springer* USV, see for example [1, 6, 7]. This paper covers some of the previously published material and amalgamates it with up to date developments that have been carried out on the vessel. This mainly includes the trial results from experiments conducted at Roadford Reservoir, Devon, UK. A model of the catamaran is deduced from the trials data using system identification (SI) techniques and presented in Section 3. Section 4 details the *Springer* NGC architecture. This includes the formulation and simulation of a control algorithm based on linear quadratic Gaussian (LQG) theory for the identified model. In addition, a fault tolerant navigation subsystem based on a fuzzy multi-sensor data fusion methodology is also elaborated.

2. SPRINGER HARDWARE/SOFTWARE ARCHITECTURE

The *Springer* USV was designed as a medium waterplane twin hull (MWATH) vessel which is versatile in terms of mission profile and payload. It is approximately 4m long and 2.3m wide with a displacement of 0.6 tonnes. A schematic diagram is shown in Figure 1 showing the layout of the components within the hulls where each hull is divided into three watertight compartments.

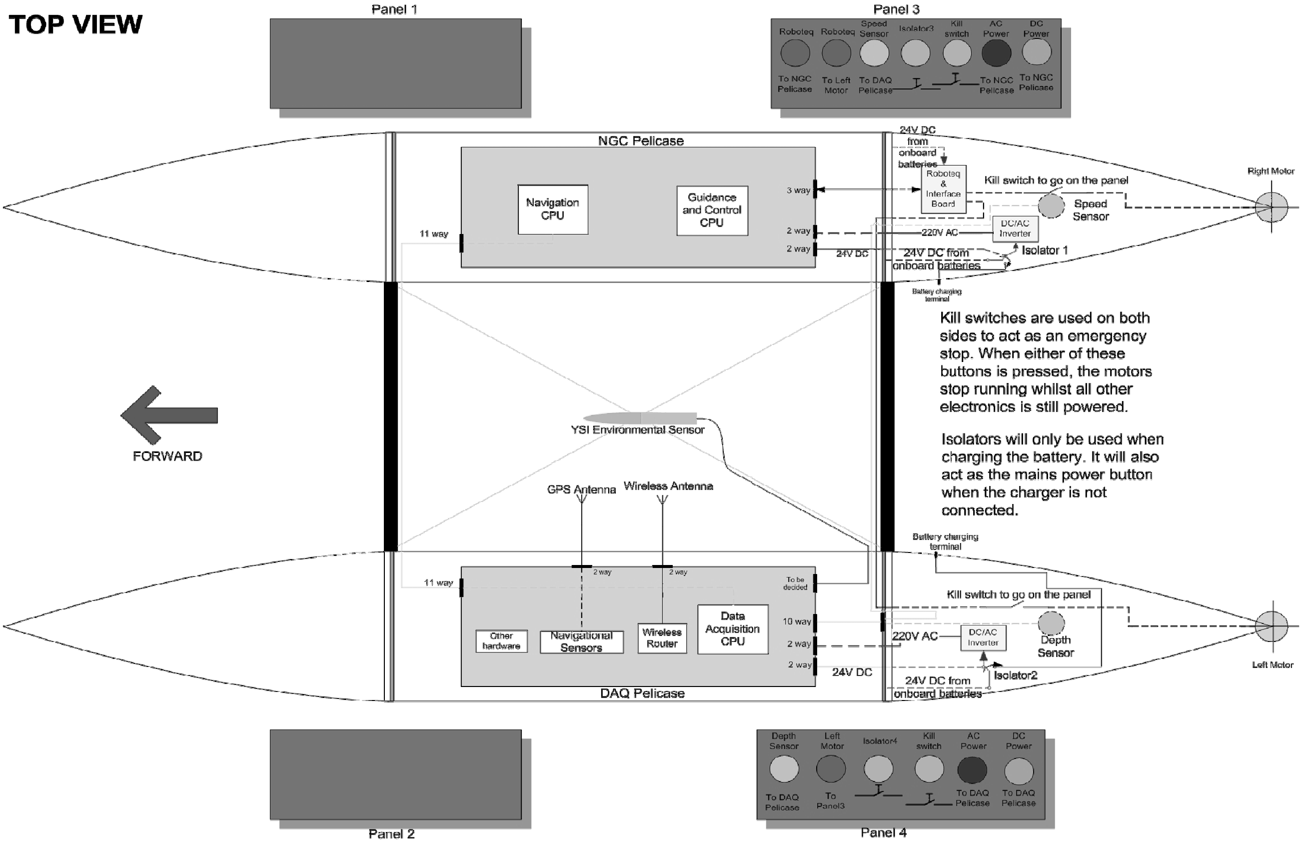


Figure 1: A schematic layout of *Springer* vehicle showing all onboard components

The data acquisition (DAQ) and NGC systems are carried within watertight pelicases, that are placed in a bay area between the cross beams. This facilitates the quick substitution of systems on shore or at water. This is illustrated in Figure 2a showing both pelicases. In order to maintain the temperature inside the pelicases, an economical but effective cooling system based on heat sinks is installed. This is vital for the onboard sensors otherwise the heat generated by the onboard computers could gradually build up to a level well outside the operating temperature of the sensors. An experiment was carried out with and without the heat sinks in the pelicases and it was found that the heat sinks facilitated the regulation of temperature within the pelicases.

Figure 2a: *Springer's* USV showing clearly the pelicases in the bay area between the cross beams

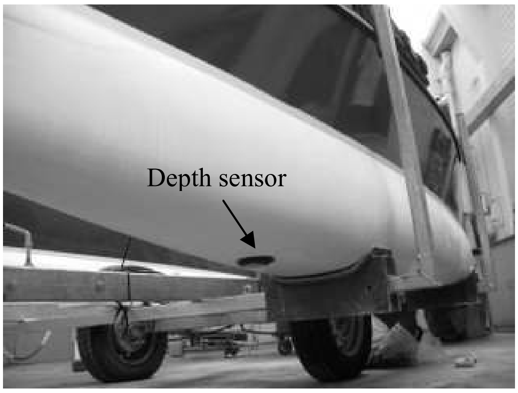


Figure 2b: Speed sensor installed at the bottom of the vehicle in the rear section

With the exception of the depth and speed sensors that are located at the bottom of the hulls, all other sensors are placed within the pelicases. The depth sensor is shown in Figure 2b whilst the speed sensor is located at the bottom of rear section of the other hull. Within the rear section of the hulls present the motor controller, radio control systems and AC power source for the onboard computers. These are mounted on custom made plates which are simple to install and replace.

The link from onboard electronics to the pelicases is created through front panels, shown in Figure 3a which are especially designed to accommodate various connectors, cable glands, isolators and emergency kill switches. The purpose of the isolators is to separate the batteries terminals from the electronics circuitry whilst being recharged whereas the emergency kill switches are installed on both panels and are manually operated from either side in case of an emergency. Another wired link is established between the DAQ and NGC PCs through a serial/ethernet cable laid across the hulls through the cross beam.

Figure 3a: One of the front panels showing the connectors, cable gland, isolator and an emergency switch

Figure 3b: Layout of components including batteries, hatch and front panel are shown on one of the hulls

The electronics and the propulsion system are powered by four 12V gel technology batteries that are placed in each hull accessed by a watertight hatch as shown in Figure 3b. These are paired together to supply 24V where each battery is capable of sourcing 135Ah of current.

In order to prevent any catastrophe resulting from a water leakage, leak sensors are utilised within the motor housing. If a breach is detected the onboard computer immediately issues warning to the user and/or take appropriate action in order to minimize damage to the onboard electronics.

A sensor that plays the vital role in carrying out *Springer* missions is the YSI environmental monitoring unit [8]. This will be installed in the centre of the vehicle as illustrated in Figure 1 on a purpose built platform that could be lowered or raised depending upon the situation. This unit is capable of measuring several important parameters such as pH, dissolved oxygen and turbidity to name a few and is vital in determining the water pollution level.

Furthermore, a mast has been installed to carry the GPS and wireless antennas. The wireless antenna is used as a means of communication between the vessel and its user and is intended to be utilised for remote monitoring purpose, intervention in the case of erratic behaviour and to alter the mission parameters.

In order to minimize the noise pollution and eradicate diesel fuel, *Springer* propulsion system consists of two propellers powered by a set of 24 V 74 lbs Minn Kota Riptide transom mount saltwater trolling motors which are placed in the rear of each hull. Steering of the vessel is based on differential propeller revolution rates. The steering aspects of the vehicle will be expanded upon in the guidance and control section. Details are now provided regarding the navigation suite, speed controller and the software architecture of the vessel.

2.1 Navigation sensor suite

In *Springer*, the integrated sensor suite combines a global positioning system (GPS), three different types of compasses, speed log and depth sensor. All of these sensors are interfaced to a PC via an NI-PCI 8430/8 (RS232) serial connector. The navigation sensor suite is shown in a block diagram form in Figure 4.

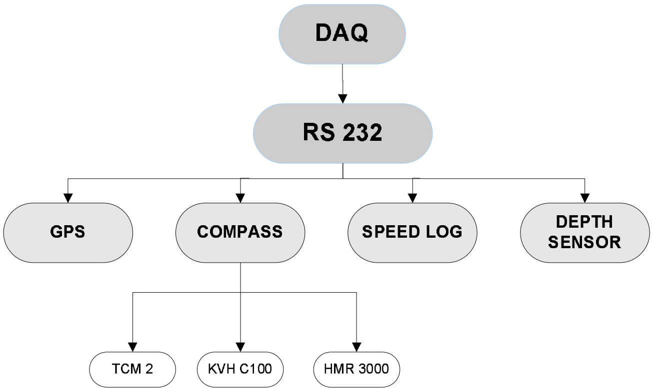


Figure 4: *Springer* sensor suite

The redundancy in the compasses is a requirement of the navigation system which combines all data readings and provides the best estimate using a novel form of multisensor data fusion (MSDF) algorithm taking advantage of soft computing methodology to adapt to always present sensors' noise. This will be further elaborated in Section 4.

2.2 RoboteQ controller

To control the speed of the propulsion motors and hence the speed of the vessel, a two channel RoboteQ's AX2850 is installed in the vehicle. The AX2850 is a highly configurable, microcomputer-based, dual channel digital speed controller which can accept speed commands in a variety of ways such as pulse-width based control from a standard radio control receiver, analogue voltage commands, or RS-232 commands from a microcontroller or wireless modem. For *Springer*, the commands to the controller are sent using the serial port communication from the onboard guidance and control PC.

The controller's two channels can be operated independently or can be combined to set the forward/reverse direction and steering of the vehicle by coordinating the motion on each side of the vehicle. This can be operated in either open loop or closed loop mode. In closed loop operation, actual speed measurements from tachometers or optical encoders are used to verify that the motor is rotating at the desired speed and to adjust the power to the motors accordingly [9].

2.3 Software architecture

Besides all the measurement sensors, the *Springer* is equipped with three onboard PCs running Windows XP. They are contained in the two Pelicases with a serial/ethernet link connecting them together. These machines are termed as DAQ PC, navigation PC and the control PC. The DAQ PC acquires all the sensors data and transmits them over the serial/ethernet cable to the navigation and control PCs by concatenating the desired data in one string. The transmit rate from the DAQ PC is the actual sampling rate to be used in the software to tune the navigation and controller parameters that can be specified by the user. The navigation PC provides estimates of the states of the vehicle by combining data using a fault tolerant MSDF technique described in Section 4.1. The controller PC issues commands directly to the speed controller which produces a differential thrust (if needed) and to steer the vehicle on the desired course.

The DAQ PC runs Labview where a user interface is created to monitor sensor readings and to alter the mission parameters if required. This user interface is accessible on a remote laptop through the wireless connection. The navigation and control PCs are running Matlab software and are interfaced together using a serial link. As mentioned earlier that another role envisaged for the *Springer* is to be utilised by other marine research groups as an easy to use platform to test their own NGC algorithms. The use of Matlab is an example of the ease of developing the NGC software to be directly implemented on *Springer* which offers an attractive feature to the marine research groups where Matlab is generally used for system design and simulation.

The next section details the SI procedure and its application to the *Springer* vehicle.

3. SYSTEM IDENTIFICATION AND MODELLING

SI techniques have been applied to obtain the *Springer* model and hence controllers are developed subsequently. For this, several sea trials were carried out where the vessel was driven for some calculated manoeuvres and data recorded. A similar approach has been adopted in [10] to extract the model of an AUV and was proved to be quite successful. A LQG controller will then be designed for the extracted model and tested in real time.

A block diagram of the complete SI procedure is depicted in Figure 5 below.

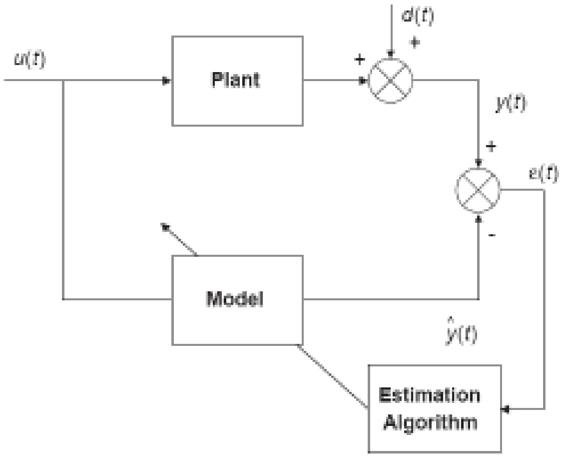


Figure 5: The overall system identification procedure

where u is the input, y is the output or response, d is the disturbance, $\hat{y}$ is the response of the model to the same input u and ε is the error between the model output and plant output also called the residuals. The objective of identification is to minimise the sum-squared errors or residuals ε. The interested reader is referred to [11] for a comprehensive treatment on this subject.

The next subsection applies SI to the *Springer* USV data obtained from recent trials.

3.1 Application to the Springer USV

In this section, the SI procedure is applied to data acquired from the *Springer* vehicle during recent experiments at Roadford Reservoir. The vehicle has a differential steering mechanism and thus require two inputs to adjust its course. This can be simply modelled as a two input, single output system in the form depicted in Figure 6.

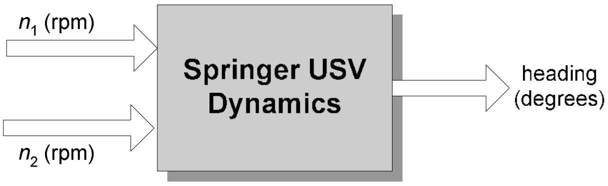


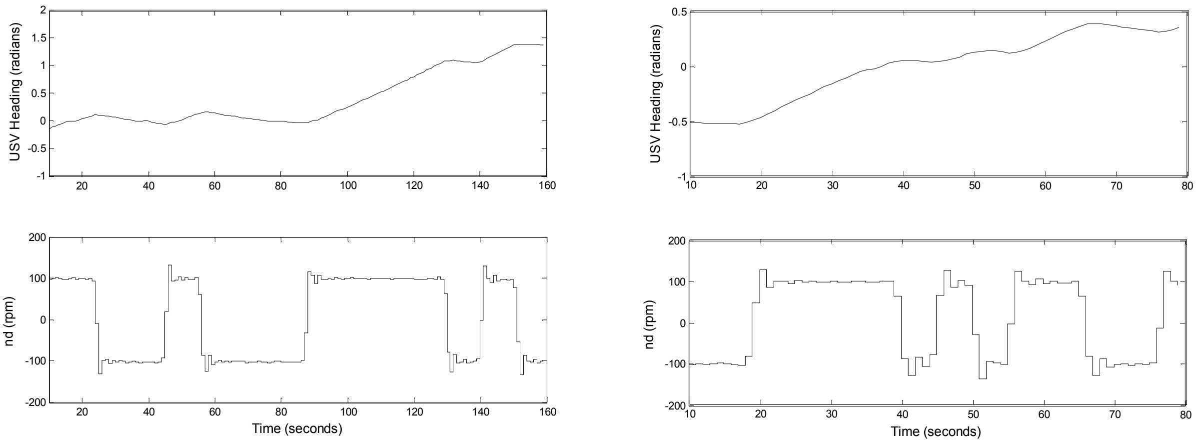
Figure 6: Block diagram representation of a two-input USV

where n_1 and n_2 being the two propeller thrusts in revolutions per minute (rpm). Clearly, straight line manoeuvres require both the thrusters running at the same speed whereas the differential thrust is zero in this case. In order to linearise the model at an operating point, it is assumed that the vehicle is running at a constant speed of 3 knots. This corresponds to both thrusters running at 900 rpm. To clarify this further, let n_c and n_d represents the common mode and differential mode thruster velocities defined to be

$$n_c = \frac{n_1 + n_2}{2} \qquad (1)$$

$$n_d = \frac{n_1 - n_2}{2} \qquad (2)$$

In order to maintain the velocity of the vessel, n_c must remain constant at all times. The differential mode input, however, oscillates about zero depending on the direction of the manoeuvre. For data acquisition, several inputs including a pseudo random binary sequence (prbs) was applied to the thrusters and the heading response was recorded. Figures 7a and 7b depict two data sets obtained fro those trials. The input shown is the differential rpm, n_d, which cause the vehicle to manoeuvre as required. The acquired data was processed and downsampled to 1 Hz since this frequency was deemed to be adequate for controller design.



(a) (b)

Figure 7: Experimental data sets from trials conducted at Roadford Reservoir in Devon, UK

SI was then applied to the acquired data set and a dynamic model of the vehicle is obtained in the following form.

$$y(z) = G_1(z)u_1 + G_2(z)u_2 \tag{3}$$

where G_1 and G_2 denotes the discrete transfer functions from inputs u_1 and u_2 respectively and y being the output of the system. In this case, only n_d has been manipulated and therefore act as the sole input to the system. This alters both n_1 and n_2 whereas n_c is maintained to conserve the operating regime. Two models of second and fourth order were identified from the data, however, subsequent simulation study revealed that there was no significant advantage of using a more complex fourth order model. Hence, the second order model shown in Equations 4 and 5 in state space form is selected for further analysis and controller design.

$$(k+1) = \mathbf{A}\quad (k) + \mathbf{B}u(k)$$
$$y(k) = \mathbf{C}\quad (k) + \mathbf{D}u(k)$$