System on Chip based Design of a Prototype Unmanned Sea Surface Vehicle

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Abstract—This paper discusses regarding design and development of a simple, low cost, the prototype of an Unmanned Sea Surface Vehicle (USSV). Prototype USSV using System on Chip (SoC) can be developed which could be used for carrying out surveillance at sea and underwater survey operations. After implementing autonomous control system this vehicle can be used for more complex operation such as Intelligence Surveillance and Reconnaissance (ISR) operations. This vehicle is developed based on centralized architecture, System on Chip (SoC). Interfacing circuits using analog components are designed so that input-output devices can be reliably interfaced. Interfacing Software, Communication Protocols, and the Remote control panel is designed and developed for the prototype USSV. Selection of off the shelf navigation and Instrumentation sensors, Thrusters, Communication systems and Payloads with its interfacing is briefly explained in the paper. Finally tests and trial results are discussed along with conclusions and further scope for improvement.

Index Terms—Unmanned Sea Surface Vehicle, System on Chip, Hardware and software design, Development of algorithm formation, Remote control design, Interfacing of sensors and Input-output device, Tests and Trials, Conclusions and scope for improvements

I. INTRODUCTION

An Unmanned Sea Surface Vehicle (USSV) is a robotic vehicle which is driven through the water by a propulsion system and piloted by an onboard computer with remote control. A functional block diagram of basic USSV sub-systems is shown in Figure 1.

India has large coastal area and exclusive economic zone (EEZ) which needs to be constantly surveyed for sustainable exploitation and to be guarded and protected from infiltrators and unlawful activities. In the recent past, coastal security has become a subject of great concern. Increased awareness and demand for coastal surveillance coupled with advances in technology has brought in the possibility of deploying USSVs for maritime security and survey. USSV can relieve man out of areas of danger in the sea and accomplish repetitive surveillance of vast coastal area with ease. USSV can be used either independently or can be teamed up with Autonomous Underwater Vehicles (AUV), Unmanned Aerial Vehicles (UAV), manned aircrafts and ships, satellites or a combination of such platforms to serve as an effective force multiplier in a battle space. In this paper, an attempt has been made to design, develop and implement a Low-cost Prototype Vehicle Control System for a Remotely Operated Unmanned Sea Surface Vehicle based on System on Chip.

Fig. 1: USSV Block Diagram

II. DESIGN AND DEVELOPMENTS OF PROTOTYPE USSV

The development of USSV technology can be dated back to World War II. First attempts were primarily to develop torpedo type vehicles to clear mines or obstacles in the surface zone. [1]. In 1946 USSVs were used to collect water samples after atomic testing on Bikini Atoll. Another common use was (and still is) to use the USSV’s as target drone boats for target training. [1] These vessels were typically operated as radio controlled boats. But recently, the focus has shifted from using these vehicles for mere target practice to much more complex operations such as Intelligence Surveillance and Reconnaissance (ISR) missions. Attacks on Marine Assets such as USS Cole (2000), French oil Tanker Limburg (2002), Philippine Superferry 14 (2004), and Khor Al Amaya oil terminal (2004), [7] and recent attacks in Mumbai by terrorists have driven an increased interest in anti-terrorism and littoral
TABLE I: Vehicle Characteristics

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Length (overall)</td>
<td>1.6 m</td>
</tr>
<tr>
<td>02</td>
<td>Width (overall)</td>
<td>0.6 m</td>
</tr>
<tr>
<td>03</td>
<td>Depth</td>
<td>0.3 m Aft 0.4 m</td>
</tr>
<tr>
<td>04</td>
<td>Displacement</td>
<td>40 Kgs</td>
</tr>
<tr>
<td>05</td>
<td>Design Speed</td>
<td>2 to 4 knots</td>
</tr>
</tbody>
</table>

warfare. In the modern age, USSV was first developed in 1993 at MIT, Sea Grant College program, named ARTEMIS which was capable of testing the navigation and control systems. [2], thereafter many vehicles were developed around the world. In India there is not much research has taken place in this area. notably, National Institute of Oceanography, Goa, has developed a USSV named ROSS (remotely operable sea skimmer) which was an early prototype that could be operated remotely with a joystick. ROSS is a small craft having a length of 1.6 m, hull width of 35 cm, and a weight of 90 kg and it has two spaced out dc motor driven thrusters attached to its undercarriage [3].

- **Vehicle Systems**

The USSV comprises of a self-propelled the boat with different systems required for remote controlling along with power sources and other sensors as discussed in the subsequent paragraphs.

(i) **Vehicle Platform:** considering the facts that this vehicle will be at sea during its operation, carrying out some dedicated mission application, Catamaran hull [4], which is stable and has a low hydrodynamic drag with a high deck area is selected for the application. This vehicle is made up of Fiber reinforced plastic (FRP), which is lighter and maintenance free. The Vehicle Characteristics are indicated in Table 1.

(ii) **Propulsion:** To provide thrust for moving the vehicle in the forward and reverse directions, two 24 VDC, 300-watt propulsion thrusters along with PWM controller are selected. Thruster and controller are shown in figure 4.

(iii) **Navigational Aids:** GPS which gives latitude, longitude, course, and speed of the vehicle with 10 meters accuracy of M/s Furuno is selected for the vehicle. To obtain heading, roll, and pitch of the vehicle a magnetic compass of M/s Honeywell, the USA which is very light (92 grams) and provides accuracy of 0.5 with 0.1 Resolution is selected for the application. This Compass gives data output in serial full-duplex RS-232 format. Magnetic Compass is mounted in a watertight enclosure and antenna is mounted on a pole for getting a good signal. Figure 2 indicates Magnetic compass and GPS antenna mounting.

(iv) **Communication:** Ultra high frequency (UHF) radio frequency modem of M/s Elpro which has a range of 5-6 Km with a baud rate of 4.8 kbps is selected for the communication. Communication done by this modem is a half duplex. As original UHF modem is fragile and is not waterproof, an antenna is covered with FRP. Figure 3 shows communication modem mounted in a watertight enclosure and an antenna with FRP enclosure.

(v) **Power:** Four Lead-acid Batteries of 6 V 10 Ah capacity selected for the vehicle testing and trials. The higher capacity battery can be used for longer endurance.

(vi) **Instrumentation:** To monitor the health of the vehicle and systems, three kinds of sensors have been selected. Voltage sensor monitors battery status and current sensor monitors the power consumption by the systems and sub-systems. Leak sensor monitors any water leak in the vehicle. As this vehicle is designed to be operated at sea, water leak sensor is a very important tool for checking any leak in the vehicle. The Hall Effect based voltage and current sensor are used which gives a standard output of voltage of 0 to 4 Volt. Leak sensor is made up of two conductors separated by a small insulating material. Leak sensor based on Single clad PCB, which is developed by Naval Science Technological Lab is used in view of stable and accurate performance. Single clad PCB can
be easily mounted to the hull of USSV. When seawater is in contact with the two conductors a short circuit is created and the leak is sensed. Figure 5 indicates Integrated voltage sensor and leak sensor.

(vii) Payloads: ISR and underwater survey operation are the two functions which are considered to be performed by this vehicle. CCTV camera with real-time transmission capability is considered for the vehicle. CCTV camera to be mounted on the mast of the vehicle. This camera can capture continuous images and after capturing these images, are transmitted in real time to the command and control station with the help of a dedicated Radio transmitter and Receiver.

Altimeter with measuring a range of 100 meters with a range resolution of 2 mm is considered for carrying out underwater survey operation.

(viii) Control of the vehicle: USSV requires to be controlled to maintain course and to change course during any mission. To keep the control simpler and to reduce the sub-systems on board the vehicle, control using differential mode of propulsion thruster has been selected using PD controller. Vehicle Control using rudder will be added on in future.

(ix) Development of Vehicle Control system: The Vehicle control system (VCS) is the brain of the vehicle. SoC along with interfacing circuits, power supply unit and its connectors form the VCS. The Vehicle Control System will receive data from command and control station through UHF link. VCS which in-turn decode this data and control the vehicle operation based on the remote commands and its internal algorithm. VCS will also have the provision to record instrumentation data and transmit important data to command and control station. To reduce the software and hardware complexity a Centralized Architecture for the vehicle development has been selected. An Alarm will be initiated by the VCS which in-turn transmitted to the Command and Control Station over UHF link, whenever an emergency arises in the vehicle. System on Chip C8051F120 manufactured by Silicon Laboratories is considered for the development of VCS due to reasonably good speed, a sufficient number of I/O, ADC, DAC, UART devices is provided onboard. Specifications [12] are provided in Table II.

III. HARDWARE AND SOFTWARE DESIGN FOR VEHICLE CONTROL SYSTEM

A. Hardware Design:

The Hardware of the system on chip cannot drive high power systems [12], and it has limited serial ports. Hence, interfacing circuits are required to be designed to interface with the other systems of the vehicle.

(a) Analog to Digital Converter design: This device has 12-bit SAR ADC (ADC0) with a 9-channel input multiplexer and programmable gain amplifier. With a maximum throughput of 100 kbps, the 12-bit ADC offers true 12-bit linearity. There is a requirement of monitoring three sensors analog output data, one voltage and two current sensors. Hence, first three channels of SoC are allocated for each sensor. As the voltage and current sensors output voltage are 0 to 4 V and analog input channel can accept a maximum voltage of 2.4 V, sensor output voltage needs to be suitably reduced before supplying to SoC. Voltage divider network is designed using resistors as shown in figure 6.

(b) Digital to Analog converter Design: SoC include two on-chip 12-bit Digital-to-Analog converters (DAC’s). The Starboard (STBD) and Port propulsion thrusters controller need to be controlled via analog channels. Analog output channel can produce output voltage range from 0 V to 2.4 V. But both Motor controllers require control voltage from 0 to 15 V. Hence analog output voltage required to be suitably amplified. Amplifier circuit designed using a non-inverting operational amplifier. The Circuit is shown in figure 7.

Serial Ports Interface design: USSV has two sensors which are giving a serial output that is GPS and Magnetic.
compass. But SoC has limited UART port. So as to share the UART 1 port, multiplexing is carried out. [6]. Multiplexer is switched by MCU digital signal. Selection is based on the time. Magnetic compass data is supplied to UART 1 for 0.5 seconds and next 0.5 seconds GPS data is supplied to UART1. Block diagram is shown in figure 8.

(aa) Multiplexer design: IC 74 LS 158 is selected for 2-1 multiplexer. Select line is controlled by port 2.0. Tx line of magnetic compass and GPS is connected to 1 A and 1 B of multiplexer respectively. The output is taken from 1 Y. As the multiplexer output needs to be complemented, inverter IC 74 LS 04 is selected to be interfaced at the output of the multiplexer.

(ab) Serial RS 232 interface: As UART 1 is not configured for RS 232 communication protocol, MAX 232 IC is connected between SoC and inverter IC.

(d) Digital Input and output design: Alarm signals are interfaced with digital input. The digital input can tolerate maximum 5 Volt, hence alarms signals sent through deep relays and in-turn deep relays are interfaced with Digital Input. Digital output pins are interfaced with switching circuits. The digital output can not drive relays directly as SoC maximum output is 3.0 V 20 mA, hence Darlington pair IC 2803 used which can drive load up to 500 mA used to switch electronics systems and deep relays used for switching ON motor power.

B. Software design:

Software design requires allocation of particular channels to the device, configuring the channel of a system on chip and the data interpretation. Summary of Special Function Register configuration of SoC is given in figure 9 and 10.

IV. ALGORITHM FOR SOFTWARE DEVELOPMENT ON SYSTEM ON CHIP (SoC)

A. Remote control of USSV

(a) Initialize oscillator.
(b) Initialize crossbar and Group I/O.
(c) Initialize UART 0 and timer.
(d) Initialize DAC0 and DAC1.
(e) Receive data on UART0.
(f) If Byte = A, store byte in a CONTROL-CMDS(cnt) array.
(g) If Byte = D, assume data transmission is complete and carry out.
(aa) Switching of Output ports: Eight switching ON/OFF commands to be executed.
(ab) Send data to DAC: data is shifted to left by 4 bits and multiplied by 455 and written to DAC0 and DAC 1.
(h) Continue (f) and (g) till remote control command are being sent.

B. Data Acquisition of sensors which are giving analog o/p

(a) Initialize ADC.
(b) Initialize timer 3.
(c) Receive data on AIN0.1.
(d) 12-bit ADC value is averaged across measurements.

\[
\text{Measurement(mV)} = \frac{V_{ref}(mV)}{2^{12} - 1(\text{bits})} \times \text{Results(bits)} \quad (1)
\]

(e) The result is then stored as right-justified in an array.

\[
\text{samples[input]} \ [\text{num-samples}] = \text{measurement}
\]

(f) If Measurement \(\geq 4000\) mV set voltage-alarm Bit.
(g) Receive next analog input i.e. AIN0.2 and repeat paragraph (d) to (f).
(h) If Measurement \(\geq 4000\) mV set Current-alarm Bit.
(i) Receive next analog input i.e. AIN0.3 and repeat para (d) to (f).
(j) Update sample count.
(k) If a number of samples = 1024 samples then reset the sample count.
(l) Repeat (c) to (l).

C. Data acquisition of sensors which are giving serial o/p

(a) Initialize UART 1 and timer 1.
(b) Initialize timer 4.
(c) Start timer 4 and set timer 4 to 500 milliseconds delay.
(d) Receive data on UART1.
(aa) Store byte in a Compass- data(i) array.
(e) Carry out para (c) operation for 500 milliseconds. At the end of 0.5 seconds set the port 2.0 to high so that multiplexer changes the UART 1 input.
(f) Receive data on UART1.
(aa) Store byte in a GPS- data[i] array.
(g) Carry out para (f) operation for 500 milliseconds. At the end of 500 milliseconds. Set the Port 2.0 to low so that multiplexer changes the UART 1 input.
(h) Repeat para (c) to (g)

D. Transmission of data to remote:

(a) Initialize data-out (i) array: following data to be initialized
(aa) Leak Alarm
(ab) Motor Shutdown
(ac) Voltage alarm
(ad) Current alarm
(ae) GPS data
(b) Initialize UART0
(c) Send the data via UART 0

E. Communication Protocols Development:

(a) Communication Protocol from Remote control Panel PC to USSV: Data is required to be transmitted and received from remote control panel and USSV hence communication protocol is designed which is indicated in Table III

F. Communication Protocol from USSV to Remote Control Panel PC :

(a) Byte1- Header Byte A
(b) Byte 2 Leak-alarm
(c) Byte 3 Shutdown alarm
(d) Byte 4 Voltage-alarm
(e) Byte 5 Current- alarm
(f) Byte 6- GPS data
(g) Byte 7 - Carriage return byte

G. Remote Control Panel Programming:

Remote control panel programming is carried out using Labview software

(i) Following Commands are given from remote panel
(a) Header byte A
(b) Switch ON /OFF all system
(c) Switch On Motor supply
(d) Emergency shutdown
(e) Remote/Auto
(f) Direction of STBD thruster
(g) Direction of Port thruster
(h) Direction of Rudder
(i) Auto Override
(j) STBD Thruster Command
(k) PORT Thruster Command

Serial No (a) to (i) are On/Off commands and serial number (j) and (k) are analog commands. These all commands are combined as one string and this string is sent to COM port every after the set delay time.

(ii) Following Data is displayed on remote control Panel
(a) Leak -alarm
(b) Shutdown-bit alarm
(c) Voltage-alarm
(d) Current-alarm
(e) GPS data

This data is received in the serial channel, the data is
TABLE III: Communication Protocol from Remote to USSV

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Byte No</th>
<th>Command Description</th>
<th>Byte Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Byte 1</td>
<td>Header byte</td>
<td>A</td>
</tr>
<tr>
<td>02</td>
<td>Byte 2</td>
<td>Switch ON all system</td>
<td>01-ON 00-0FF</td>
</tr>
<tr>
<td>03</td>
<td>Byte 3</td>
<td>Switch On Motor Supply</td>
<td>01-ON 00-0FF</td>
</tr>
<tr>
<td>04</td>
<td>Byte 4</td>
<td>Emergency shut down</td>
<td>01- Shut down 00-NO Action</td>
</tr>
<tr>
<td>05</td>
<td>Byte 5</td>
<td>Remote/Auto</td>
<td>01- Auto 00 Remote</td>
</tr>
<tr>
<td>06</td>
<td>Byte 6</td>
<td>Direction of rotation of STBD thruster</td>
<td>01- Anti-clockwise 00 Clock wise</td>
</tr>
<tr>
<td>07</td>
<td>Byte 7</td>
<td>Direction of rotation of PORT thruster</td>
<td>01- Anti-clockwise 00 Clock wise</td>
</tr>
<tr>
<td>08</td>
<td>Byte 8</td>
<td>Direction of Rudder</td>
<td>01- Right 00 Left</td>
</tr>
<tr>
<td>09</td>
<td>Byte 9</td>
<td>Auto override</td>
<td>01- Override 00- NO Action</td>
</tr>
<tr>
<td>10</td>
<td>Byte 10</td>
<td>Switch on Lights and Camera</td>
<td>01-ON 00-0FF</td>
</tr>
<tr>
<td>11</td>
<td>Byte 11</td>
<td>STBD Propulsion Thruster Command</td>
<td>Analog Value</td>
</tr>
<tr>
<td>12</td>
<td>Byte 12</td>
<td>PORT Propulsion Thruster Command</td>
<td>Analog Value</td>
</tr>
<tr>
<td>13</td>
<td>Byte 13</td>
<td>Carriage return Byte</td>
<td>D</td>
</tr>
</tbody>
</table>

separated as per protocols and the particular alarm is initiated. GPS data is decoded for Latitude, Longitude, course, and speed of the vehicle.

The Graphical user interface front panel design is shown in figure 10.

V. RESULTS AND DISCUSSIONS

Conduct of Lab Test and trials were conducted at Naval Science and Technological lab of DRDO at Visakhapatnam. Few results are shown below.

- Test results

(i) Execution of remote commands test: Execution of remote commands test:- In this test remote commands Execution were tested. Figure 12 shows Remote Control of Command and Scale V/s DAC O/P Scale in the USSV, Figure 13 shows Amplification of DAC output. From this, it is found that amplification circuit, software, hardware design of vehicle control system is working as expected as per design

(ii) Data logging of ADC channels: Voltage and current sensor output checked for data logging operation. Figure 14 shows voltage sensor output graph and Figure 15 shows current sensor output graph during calibration.

A. Observations and modifications after bench tests:

Observations and modifications after bench tests (i) Thruster motor controller were designed to operate at control
Trials

After carrying out relevant bench tests all the systems and subsystems were installed in the vehicle as per layout plan. After installation, all the systems were connected to each other as per electrical wiring diagram. System checks were carried out again before taking the vehicle for trials. Once the system checks were satisfactory, the vehicle was taken to the High speed towing tank of NSTL. The vehicle was lowered in water and allowed to settle down. Then commands were given through the command and control panel. Figure 18 shows command and Control Station PC during trials and Figure 19 shows USSV in water during trials.

Trial result i) Data logging of ADC channels: After the trials, Data downloaded from the SoC and analyzed. Figure 6.16 shows Battery output voltage graph and figure 6.17 shows course followed by USSV during 2 minutes run. Course graph indicates vehicle traveled straight with minor deviations.

VI. CONCLUSION

This paper presents simple, low-cost approach towards implementation of prototype Unmanned Sea Surface Vehicle platform with remote control using off the shelf components. Following are the conclusions:

(i) Centralized architecture based on system on Chip is ideally suited for concept proving and to reduce the software complexity.

(ii) GPS and UHF antenna can be covered with Fiber Reinforced Plastics material so as to make it waterproof, without losing signal strength.

(iii) I/O devices can be interfaced using voltage divider network, amplifiers based on OPAMPs, multiplexers etc.

(iv) Data acquisition and control of USSV can be done using algorithm and communication protocols explained in the paper.

(v) Remote Control Panel programming can be done with user-friendly GUI software such as Labview.

(vi) This USSV can also be used as a standalone unit which can carry any mission payloads up to 5 Kg in weight.

(vii) Optical buffer IC need to be used instead of transistor based IC as this will give good isolation characteristics.

VII. SCOPE FOR IMPROVEMENT

There is a ample scope for improving and upgrading the system performance. Following improvements are suggested:

(i) System on Chip with more serial ports can be considered for future Development.

(ii) Higher capacity flash memory will be useful to store more data for a longer duration.

(iii) Vehicle Control System hardware to be ruggedized to sustain the shock, Vibration and it is to be made heat resistant.

(iv) UHF Modem with full duplex communication to be used for this kind of application so that data transmission and reception happen simultaneously.

(v) This vehicle can be made to work in autonomous mode.
Fig. 18: Remote Control Station during Trials

Fig. 19: USSV in water during trials

by using suitable algorithm and controller.
(vi) DGPS can be used in place of GPS for more accuracy.
(vii) Graphical User Interface Software can be made more user-friendly and imitate real driving wheels and speed control.

ACKNOWLEDGMENT

I express my sincere and heartfelt gratitude to Dr. V. Bhujiang Rao, the then Director, NSTL for giving me permission to do the project work at the Naval Sciences and Technological Laboratory (NSTL), Visakhapatnam. I express my profound sense of gratitude to Dr. Manu Korulla, Scientist ‘G’ and Sri. Bharatwaja Srinivasan, scientist ‘E’ of NSTL for the constant guidance in every stage of work. I express my deep sense of gratitude to Dr. PD Shendge, Associate Professor, Department of Instrumentation and Control Engineering, College Of Engineering, Pune for his valuable suggestions, benevolent guidance, support and encouragement during the paper writing.