CyberShip Arctic Drillship

User Manual

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Preface

The purpose of this document is to provide a manual that ease the process of using CyberShip Arctic Drillship(CSAD), and concerns only software and hardware of CSAD specifically. For information about the Marine Cybernetics Laboratory(MCLab) and its systems, the reader is referred to the MCLab Handbook, which can be found on GitHub.

Structure of document

This User Manual is divided in two parts:

- Technical description(hardware, software, mathematical models etc.)

- Operation manual(software deployment, launching/demolition instructions etc.)

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Part I

Technical description

Chapter 1

Hardware

1.1 Introduction to CSAD

The CS Arctic Drillship was built and instrumented in 2016, with the intention of facilitating more research on Thruster-Assisted Position Mooring. For an in-depth description of the design and construction process, the reader is referred to Bjørnø (2016).

The vessel is a 1:90 scale model of the Statoil Cat I Arctic Drillship. It is equipped with 6 azimuth thruster (3 fore and 3 aft), in addition to a moon-pool for turret and mooring lines. The main dimensions of the vessel are:

Table 1.1: Main dimensions of CSE1

LOA	2.578[m]
B	0.440 [m]
D	0.211[m]
T	0.133[m]
Δ	127.92 [kg][1]

1.1.1 Literature

The development of CSAD and its systems is a product of research from several theses, which contain complementary information on the theory applied to the system.

Journals and conferences

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Specialization projects and master theses

- Thruster-Assisted Position Mooring of C/S Inocean Cat I Drillship (Bjørnø, 2016)

- Constrained Optimal Thrust Allocation for C/S Inocean Cat I Drillship (Frederich, 2016)

- Force Field Identification and Positioning Control of an Autonomous Vessel using Inertial Measurement Units (Udjus, 2017)

1.2 Actuators

The installed azimuth thrusters are of the type Aero-naut Precision Schottel, with 30 millimeter diameter propellers. They are positioned according to the design of the full-scale ship, as given in Figure 1.1 and Table 1.2.
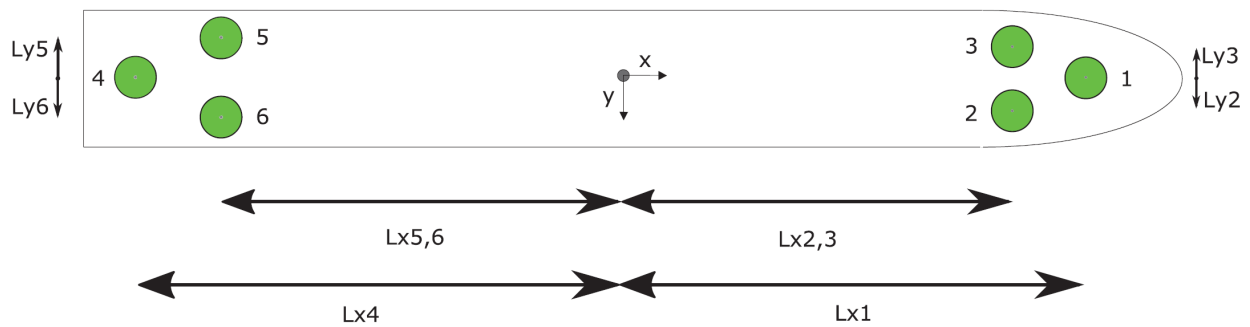

Figure 1.1: Illustration of thruster positions. Adapted from Frederich (2016)

In Frederich (2016), the thrust coefficients were estimated based on bollard pull tests. The values given in Table 1.3 are mean values from the tests, due to discrepancies in the bollard pull test at low thrust commands.

Table 1.2: Thruster positions

Thruster	Position X[m]	Position Y[m]
Thruster 1	1.0678	0.0
Thruster 2	0.9344	0.11
Thruster 3	0.9344	-0.11
Thruster 4	-1.1644	0.0
Thruster 5	-0.9911	-0.1644
Thruster 6	-0.9911	0.1644

Table 1.3: Thruster coefficients

	Thruster 1	Thruster 2	Thruster 3	Thruster 4	Thruster 5	Thruster 6
K_T	0.3763	0.3901	0.3776	0.5641	0.4799	0.5588
K_Q	0.0113	0.0117	0.0113	0.0169	0.0144	0.0168

1.3 Power system

The vessel is powered through six 12V 12Ah batteries, connected in parallel. Figure 1.2a show a schematic drawing of the power system.

1.4 IMU

CSAD is equipped with one Inertial Measurement Unit (IMU) from Analog Devices. The sensor mounted on-board is the ADIS16364 and includes a triaxis gyroscope and triaxis accelerometer. The sensor has built-in compensation for bias, alignment and sensitivity, and provides accurate measurements over a temperature range of -10 to +70 degrees Celsius. The most relevant data is presented in Table 1.4, and for supplementary information the reader is referred to the data sheet Analog Devices (2017). The reference frame of the sensor is illustrated in Figure 1.3, with positive directions illustrated by arrows. As seen, the standard reference frame for linear accelerations uses left-hand orientation, while the angular rates uses right-hand orientation. It is advised to change the reference frame of accelerations to right-hand, which is achieved by multiplying the accelerations with -1. Note that this also changes the positive direction, defined as the direction of acceleration that produces a positive output.
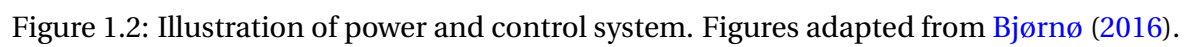
(a) Power system   (b) Control system

Figure 1.2: Illustration of power and control system. Figures adapted from Bjørnø (2016).

Table 1.4: IMU specifications

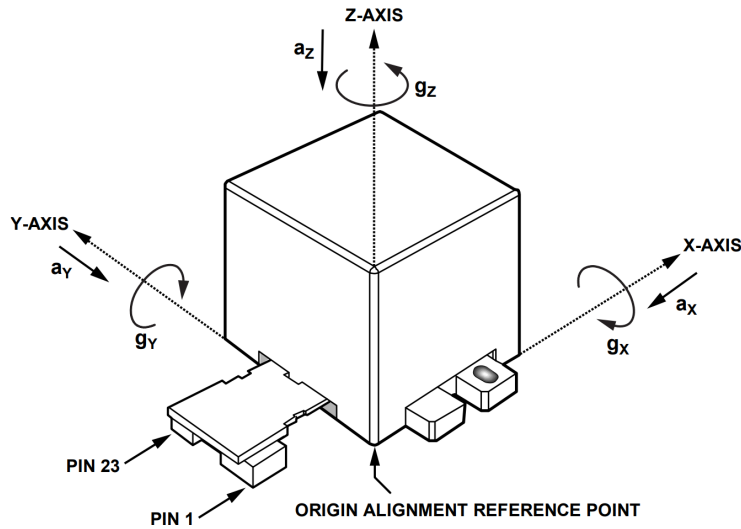|	Parameter	Typical value	Unit
Gyroscopes	Dynamic range	±350	^{o}/sec
	Sensitivity	0.0125	^{o}/sec/LSB
	Bias stability, σ	0.007	^{o}/sec
	Angular random walk	2.0	$^o/\sqrt{hr}$
	Output noise	0.8	^{o}/sec rms
Accelerometers	Dynamic range	±5.25	g
	Sensitivity	1.00	mg/LSB
	Bias stability, σ	0.1	mg
	Velocity random walk	0.12	m/sec/$\sqrt{hr}$
	Output noise	5	mg rms
Power supply	Operating voltage	5.0 ± 0.25	V

Figure 1.3: IMU reference frame from manufacturer

1.5 Control system

The on-board control system is illustrated in Figure 1.2b, and consists of the following parts:

- one National Instruments compact reconfigurable input/output (cRIO) embedded controller

- one Raspberry Pi (RPi) single-board computer

- six electronic speed controllers (ESC) connected to six motors controlling thruster speed

- six servos controlling thruster angle

For complementary information on the ESC, motors, servos and PWM signals, see Bjørnø (2016).

1.5.1   cRIO

The model on-board is the cRIO-9024, and it is connected to 4 FPGA modules for analog and digital I/O:

- One NI-9215, Analog input

- Two NI-0237, Analog bridge

- Two NI-9401, Bidirectional digital input

- One NI-9411, Digital input

- One NI-9474, Digital output

- One NI-9871, Serial interface

1.5.2   RPi

The Raspberry Pi provides communication with the Siaxaxis controller, as described in Section 1.6. It works as an embedded system, and once powered it will start connecting to the wireless controller. When connection is established, it continuously sends the Sixaxis controller output to the cRIO over Ethernet.

If there are problems establishing connection between Sixaxis and RPi, try restarting the RPi. If this doesn't work, contact Torgeir Wahl or see the MCLab Handbook on Github for description on how to reconfigure the RPi.

1.5.3   ESC and DC-motor

The ESC's are of the type O.S. OCA-150 50 A BL, connected to brushless UMA-2820-950 DC motors driving the thrusters. The ESC's are controlled with PWM signals. As the motors are much more powerful than desired for the model, the PWM signal is constrained. Table 1.5 gives the constraints on the PWM signal.

Verify
the
PWM
con-

Table 1.5: PWM constraints

Direction	Signal range PWM	Tick
Full reverse	6.25 [%]	50.000
Neutral	7.5 [%]	60.000
Full forward	8.75 [%]	70.000

1.5.4 Servo

The servos controlling the thruster angles are of the type Dynamixel MX-106R, and are geared 1:1 with the thrusters(1 degree turn on servo results in 1 degree on thruster). The servos are manually tuned to have a zero-angle offset in initial start. As of July 2017, the initial offsets are given in Table 1.6. Maximum and minimum angles for all servos are given in (1.1). If one thruster reaches maximum/minimum angle, it is reset to initial neutral position, as described in the software section. For complementary information.

$$\boldsymbol{\alpha} \in [-10240°, 10240°] \tag{1.1}$$

update min/max values on PWM in init file

Table 1.6: Servo angle offset

Thruster	Offset
α_1	-149°
α_2	50°
α_3	5°
α_4	-17°
α_5	127°
α_6	-36°

1.6 High-level communication

Following Figure 1.4 from left to right:

Sixaxis transmits its Joystick information to the RPi over Bluetooth communication.

RPi receives Sixaxis data through the USB dongle and forwards it using Ethernet connection (TCP).
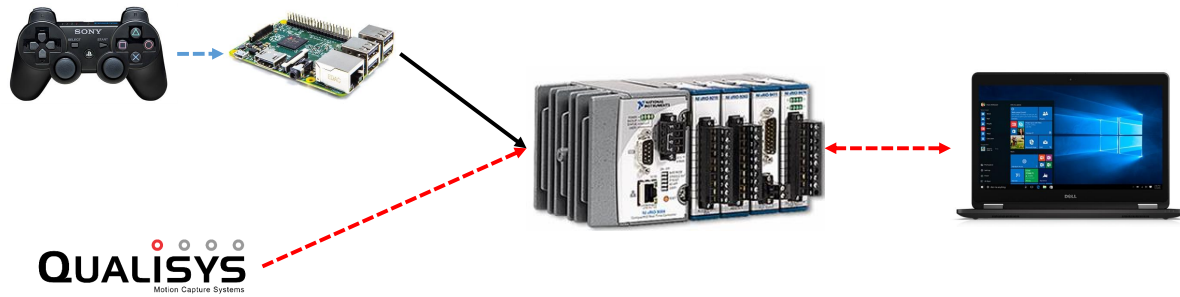
Figure 1.4: CSE1 communication diagram

cRIO reads QTM broadcast positioning data through the Wi-Fi bridge on Ethernet port 1, Six-axis data on Ethernet port 2. Online data and laptop input is transmitted and received on Ethernet port 1 by the VeriStand Engine.

Laptop reads simulation data and sends input to the cRIO over MC Lab Wi-Fi.

Hence, there are two possible methods for controlling the vessel:

- laptop connected to the MC Lab wireless network

- Sixaxis wireless gamepad(labeled *CSAD*)

Chapter 2

Software

2.1 Introduction

In order to control CSAD, there are several software parts that runs. This chapter gives a description of the software topology on CSAD. Note that the software is ready to use, and alterations in the software described here is not necessary(except modifying *ctrl_custom*, see Part II).

2.2 Control system

Figure 2.1 illustrate the software architecture, and gives an overview on how the different modules and I/O from the Simulink models are connected in VeriStand. In general, the software can be divided into 2 groups:

MATLAB generated parts: ctrl_custom, ctrl_TAPM, ctrl_sixaxis2thruster, STOP and u2pwm

LabVIEW generated parts: IMU, Oqus, WL_Joystick and FPGA

All of these modules are described in the latter.

2.2.1 ctrl_custom

This is the only reconfigurable software, and does not consist of any control system. In Part II a description on how to configure and upload the code to CSAD is given.
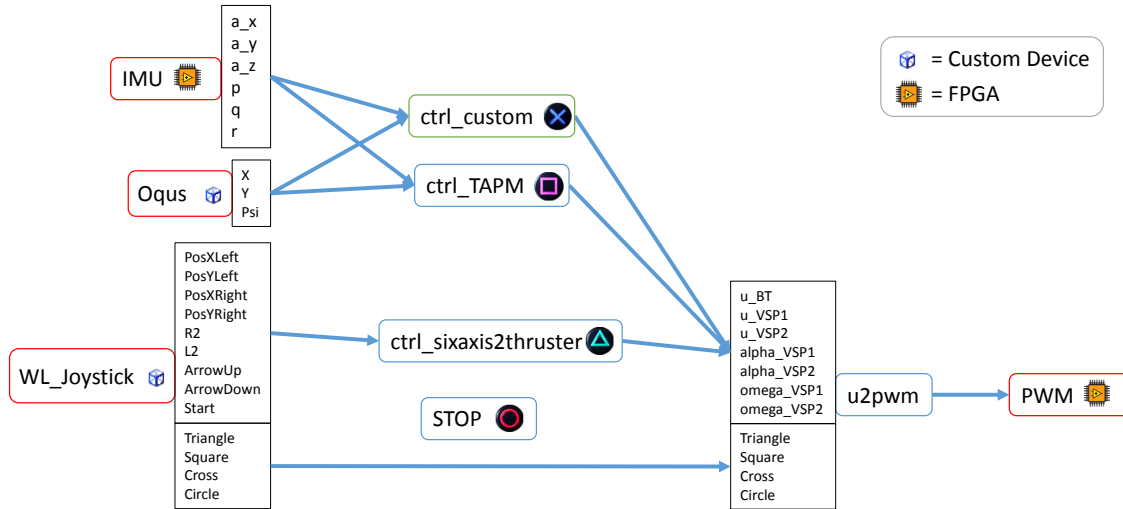
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Figure 2.1: CSE1 control software

2.2.2 ctrl_TAPM

This code is a basic TAPM control system, intended for demonstrations of the vessel. The desired position of the vessel is modified in VeriStand.

2.2.3 ctrl_sixaxis2thruster

All 6 thruster can be controlled manually using the Sixaxis controller. The right joystick controls the direction of the three thrusters aft, while the left joystick controls the front thrusters. ArrowUp and ArrowDown sets the thrust limits, and Start resets the limitation to 0.

2.2.4 STOP

This system simply stops the vessel, by setting the thrust of all thrusters to 0.

2.2.5 u2pwm

This code transforms the control input to PWM signals, which are sent to the FPGA module. There are 2 groups of inputs, namely the control signal and a switch signal. The switch signal is used to switch between the 4 control systems described previously. Switching is simply achieved by pressing either one of the four symbols, and the mapping between the buttons and models is shown in Figure 2.1. The code is not supposed to be altered, and should work as it is.

Switch

The switch simply forward the input from the desired model, as given by the switch signal:

- ctrl_sixaxis2thruster when △ is pushed

- ctrl_sixaxis2direction when ▢ is pushed

- ctrl_DP when ○ is pushed

- ctrl_student when ✕ is pushed

Saturation

Low-pass

Mapping

2.2.6   Oqus

The Qualisys Track Manager software broadcast the position data of the vessel over MC Lab Wifi. Reading these data is done on the cRIO through a Custom Device module named Oqus. The Oqus software simply listen to the network for data from QTM, and once it receives data it forward the position and orientation to the models as given in Figure 2.1. The Custom Device is programmed by Torgeir Wahl, and can be found on GitHub.

2.2.7   WL_Joystick

This is the second Custom Device that runs on the cRIO, which listen to the Ethernet 2 port for input from the RPi. It forwards this data to the respective models as given in Figure 2.1. The software is designed by Torgeir Wahl, and can be found on GitHub.

2.2.8   FPGA

For the CSE1, 3 FPGA modules are in use(1 for analog signals, 1 for digital signals and 1 for reading IMU data). The FPGA software is described in the MC Lab Software Handbook, and

provides a guide on how to create an FPGA module. The modules can be found on GitHub, but are as standard. The PWM signal is mapped as described in Table

2.3   Connecting software

All the different software parts described in the previous Section are connected together in Veri-Stand. On CSAD, VeriStand 2017 is used. In the system definition file *CSE1.nivssddf*, all necessary mappings of variables are done. In addition, here the different Custom Devices, FPGA code and Simulink Models can be included. However, the standard setup should not be altered, as all necessary code and mappings is already taken care of. For description on how to implement the modified ctrl_student Simulink model, the reader is referred to Part II.

Chapter 3

Modeling

The mathematical model of CSE1 is given here, based on system identification done in previous Master's Theses. The model is valid for low-speed. The proposed control design model is

Part II

User Manual

It is assumed that the reader has studied the MCLab Handbook before using CSE1, and has knowledge about Lab procedures and Safety precautions.

Chapter 4

Launching

Describe hardware preparations, establishing connection, building and including simulink model, uploading code to vessel The following list is important to keep in mind when operating CSE1:

Water damage: CSE1 is not waterproof and has excessive thrust capability which can inflict large roll angles. The risk of water on deck is reduced through thrust limitation and HIL testing before application of new control algorithms.

Propeller dry running: BT must only be run in water. Before removing the vessel from the water, the control system must be stopped and the VeriStand project undeployed.

Loss of laptop control: Wireless network instability may result in loss of connection between the laptop user interface and the cRIO. In this event, fall back to manual thruster control, by pushing △ on the Sixaxis.

Total loss of control: Pull CSE1 with a boat hook, and keep the vessel in water while disconnecting batteries.

Chapter 5

Controlling

Give some instructions on the control mode, user interface in VeriStand, etc

Chapter 6

Demolition

Deploying and shut-down procedure. Clean lab.

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