Design of a Deployable Cargo Vessel Based on Autonomous Surface Vehicle to Aid Offshore Maritime Shipping

A Robotic Solution for Insufficient Manpower in Maritime Shipping Industry Under Singapore's Context

Hou Linxin*
College of Design and Engineering, National University of Singapore, 4 Engineering Drive 3, Singapore 117583, E-mail: hou.linxin@u.nus.edu.

Chen Sirui*
College of Design and Engineering, National University of Singapore, 4 Engineering Drive 3, Singapore 117583, E-mail: siruichen@u.nus.edu

Png Qun Shen*
College of Design and Engineering, National University of Singapore, 4 Engineering Drive 3, Singapore 117583, E-mail: png.qunshen@u.nus.edu

ABSTRACT

As a major port in the world, Singapore's waters are constantly full of docked ships. For these ships to have enough resources, such as food and oil, smaller boats are used to transport resources from shore to the ships. The current resupply operation is manually handled, expensive and inconvenient. The Deployable Cargo Vessel (DCV) has been developed to address these problems through automation, saving precious labor costs. The DCV is a small-size speed boat equipped with an electrical system and a hook catcher system specially designed for unmanned transportation between ships. The main system utilizes ArduPilot's Pixhawk 4 as its control unit and adopts vectored four-thruster configuration. The DCV can work continuously for 4 hours on the calm sea while being remotely monitored by a camera. The mechanical design is focused on the hook catcher which can catch and secure the payload from the DCV to the ships. This paper will explain the overall system design including the mechanical structure and embedded systems of the DCV.

CCS CONCEPTS

• **Applied computing** → Physical sciences and engineering; Engineering; Computer-aided design.

KEYWORDS

Autonomous surface vehicle, Maritime shipping efficiency, Marine robotic system, Offshore supply vessel

ACM Reference Format:

Hou Linxin, Chen Sirui, and Png Qun Shen. 2022. Design of a Deployable Cargo Vessel Based on Autonomous Surface Vehicle to Aid Offshore Maritime Shipping: A Robotic Solution for Insufficient Manpower in Maritime Shipping Industry Under Singapore's Context. In *2022 8th International Conference on Robotics and Artificial Intelligence (ICRAI 2022), November 18–20, 2022, Singapore, Singapore.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3573910.3573918

*These authors contributed equally

ICRAI 2022, November 18–20, 2022, Singapore, Singapore

ACM ISBN 978-1-4503-9754-4/22/11…$15.00
https://doi.org/10.1145/3573910.3573918

1 INTRODUCTION

Singapore' geographical and political climate has always been friendly towards the maritime industry, attracting large volumes of bulk carriers, container ships, general cargo, oil tanker, and other ships [1]. The discharging and loading operations within limited space and tight schedule is a determining factor for shipping companies in achieving high efficiency and an economic edge over competitors [2]. Offshore resupplying provides fundamental services for ships during operations. However, the current offshore resupply operation in Singapore suffers from high cost due to tight labor market [3]. One existing solution to address the problem is the usage of commercial drones for shore-to-ship deliveries, which can deliver up to 100kg of goods for over 100km out at sea [4]. However, this solution can only support transportation of limited weight [5] and has specific requirements from the receiving ship, which not every shipping company is willing or able to adapt to. The DCV aims to address this gap, to provide unmanned resupply of heavier cargos from shore to docked ships, that can potentially fully replace resupply boats in future.

2 SERVICE DESIGN

After analyzing the challenges, the proposed service solution is as such:

- When customers (docked ships) need a resupply, they can place their order for supplies online, and choose their desired time of delivery.
- The service provider will pack and load up the requested supplies onto a pallet on the DCV.
- The DCV will navigate to the customer's ship.
- The customer's ship will lower a crane hook to the DCV to pick up the supplies on the DCV and bring it up to the ship.

The figure 1 below illustrates the above steps in a clearer way.

3 DEPLOYABLE CARGO VESSEL DESIGN

The 3D model of DCV is shown in figure 2 below:

The DCV consists of a dinghy boat and a few subassemblies which will be discussed separately in the following sections.

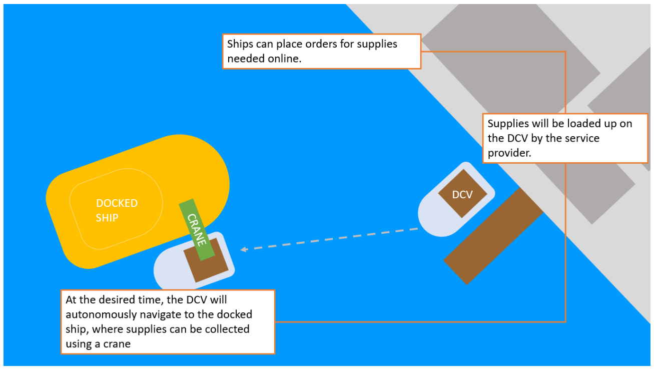

Figure 1: Illustration of DCV in operation

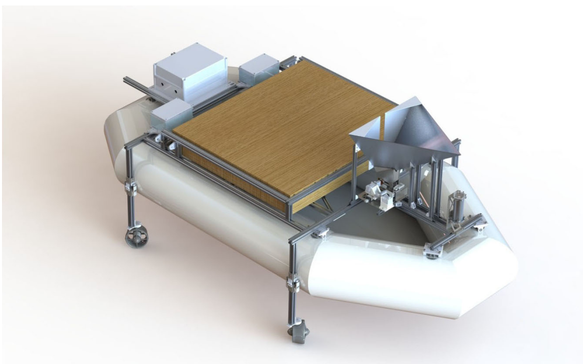

Figure 2: 3D model of DCV, made using SOLIDWORKS

Figure 3: Frame and hull of DCV mounted on the dinghy

3.1 Mechanical System

3.1.1 Hull and Frame. An off-the-shelf inflatable dinghy is used as the base of the DCV. The dinghy is approximately 2.9m long, 1.4m wide, and has a capacity of 315kg. A metal extrusion frame is fitted onto the DCV, serving as the base structure for all other components to be mounted, including the pallet which contains the shipping cargo. 3030 aluminum extrusion bars are chosen for their high strength to weight ratio, as well as their modularity and affordability. The frame is attached to the dinghy by mounting to the plastic handles of the dinghy. The 3D model of the frame and hull of DCV is shown in figure 3 below.

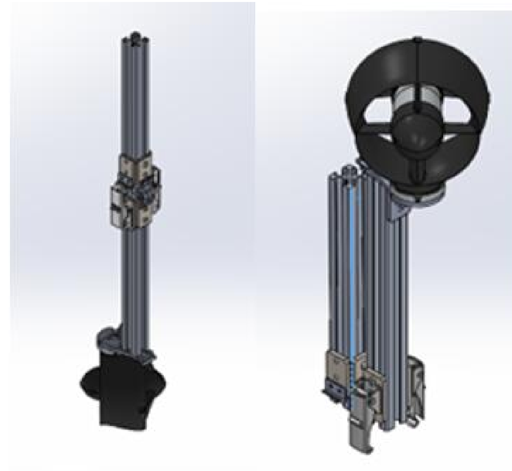

Figure 4: Thruster with hinge, extended (left) and stowed (right)

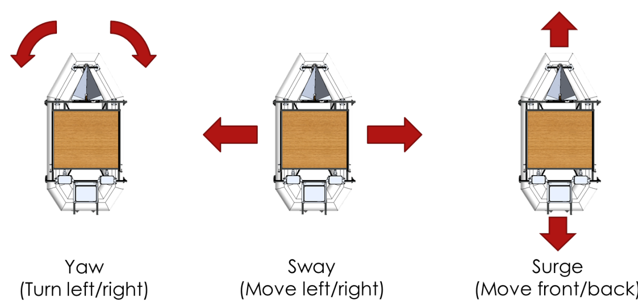

Figure 5: 3 degrees of freedom of the DCV

3.1.2 Thrusters. Four BeeX proprietary thrusters [6] are mounted at the four corners of the DCV. To achieve vectored-thrust [7], they are each mounted at a 45-degree angle about the estimated center of gravity. Controls of the thrusters were done using a FrSky Taranis controller. For the thrusters to be stowed for storage or transportation purposes, a hinge and locking mechanism is added to each thruster. The diagram is shown in figure 4 below.

With this vectored-thrust configuration, the DCV is able to achieve 3 degrees of freedom (Yaw, Sway and Surge), giving the ability to achieve more nimble movements compared to traditional vessels. This allows the DCV to be able to effectively position itself under the shipping crane for smooth transfer of the payload. Detailed diagram is shown in figure 5 below.

3.1.3 Hook Catcher Mechanism. During the cargo transfer, the crane hook will be lowered from a height of approximately 20m to the DCV, during which the hook will be exposed to strong winds condition, which could induce some oscillation of the crane hook as shown in the diagram below. The biggest challenge for the DCV is in getting the hook from the docked ship's crane to line up with the cargo under such conditions, and autonomously latch onto the

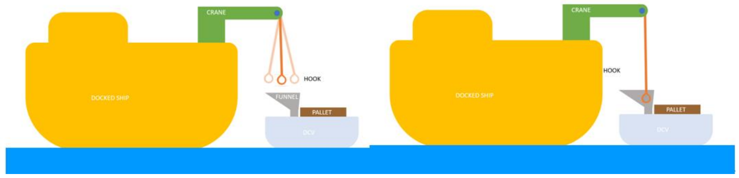

Figure 6: Illustration of hook catcher system resolving issue of oscillation of crane hook

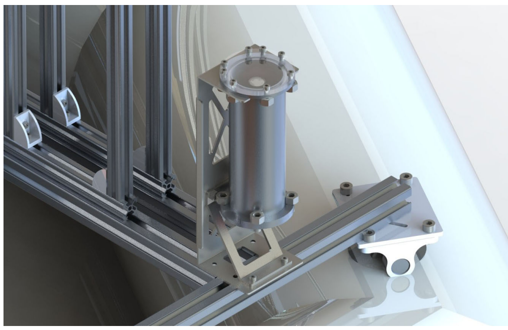

Figure 7: SOLIDWORKS model of upwards facing camera on the hook catcher

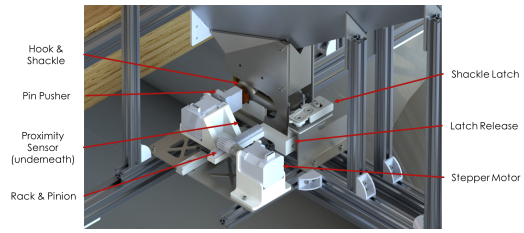

Figure 8: SOLIDWORKS model of the hook catcher mechanism

cargo successfully. A hook catcher system is designed to guide the hook and lock it at the desired location as shown in figure 6 below.

The hook catcher consists of a funnel that covers a larger surface area, which would capture the hook and guides it into position. Additionally, the hook catcher has an upward-facing camera to spot the hook as it is descending from the crane. An inductive proximity sensor is mounted underneath the hook catcher to detect the presence of the hook once it is in the correct position and orientation. Subsequently, a series of action will be activated to latch the hook onto the cargo securely. The SOLIDWORKS model of upwards facing camera is shown in figure 7.

Once the hook is in the desired location at the bottom of the funnel, it would be situated in between a shackle connected to the pallet of cargo. This hook securing subsystem involves using 2 stepper motors working in tandem to tighten a pin onto a shackle, effectively latching the shackle onto the hook.

The first motor is mounted onto a linear rail system together with the shackle pin and is used to rotate the shackle pin about its own axis. The second motor is used to move the first motor and the shackle pin along the linear rail using a rack and pinion mechanism. When both motor works in sync (figure 9), it achieves the effect of threading the shackle pin onto the shackle, analogous to a person turning a screw into a threaded hole. The

SOLIDWORKS model of the hook catcher mechanism is shown in figure 8 below.

Once the pin is in place, the latch release is activated, and the shackle will be released. The hook is now connected to the shackle and can lift the shackle along with the pallet. Detailed diagram is shown in figure 9.

Overall, the steps taken are as follows:

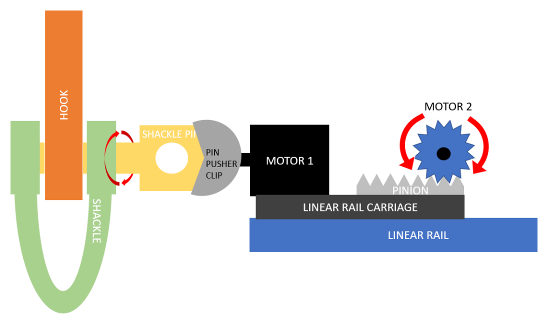

Figure 9: Illustration of the hook securing mechanism

- Proximity sensor detects hook in the correct location and orientation between the shackle
- Motor 1 turns the shackle pin about its axis and motor 2 drives pin pusher in via the rack and pinion mechanism, tightening the shackle pin onto the shackle
- The shackle pin tightens on the shackle and presses on the latch release
- Latch releases and pin pusher retracts, allowing the shackle and hook to leave the hook catcher
- Shackle is tightly secured on the hook, along with the pallet of cargo

The mechanism is mounted on the frame at the front of the DCV. All other components are mounted using aluminum or stainless-steel sheet metal parts. 3D-printed parts are also used for mounts with more complex geometries, such as the carriage on the linear rail.

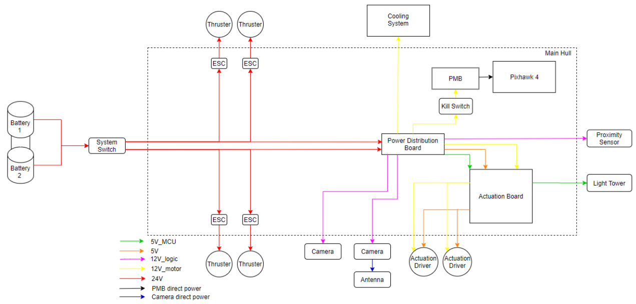

Figure 10: Power architecture of DCV

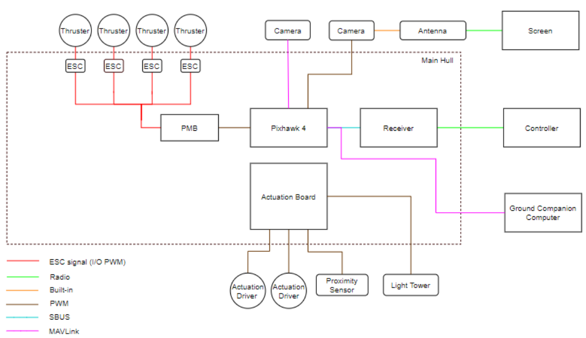

Figure 11: Communication architecture of DCV

3.2 Electrical System

3.2.1 Power Management. The power architecture of the DCV is shown in figure 10 below.

The overall electrical system is powered by two 6-cell 24V LiPo Batteries. Each battery is connected to 2 Electronic Speed Control (ESC) to provide the 24V needed for the thrusters. Both batteries are also connected to the power distribution board, which transfers power to the main controller (Pixhawk), upwards facing camera, inductive proximity sensor, the cooling system, and the actuation board.

The power distribution board balances the load of both batteries and provides isolated voltage to isolate the sensitive components, like the proximity sensor, from motors and thrusters. The voltage is also stepped down to 12V and 5V for the various components as required. The actuation board further distributes power to the actuation drivers and the light tower.

3.2.2 Communication Subsystems. The communication architecture of DCV is shown in figure 11 below.

The Pixhawk is the main controller of the DCV as shown in figure 11. It receives user controls via radio signal to perform various tasks. It can also accomplish missions through the MAVLink camera and ground companion computer. For vehicle control, it connects to a Pixhawk Power Management Board and sends Pulse Width Modulation (PWM) signals. This Pixhawk Power Management Board then sends the I/O PWM signal to each ESC to individually control each thruster.

Figure 12: Demonstration of DCV at Bee Sin Shipyard

The hook catching mechanism is triggered by the proximity sensor. When the actuation board receives a signal from the proximity sensor, indicating detection of the hook, it sends a signal to the ATmega 328P microcontroller on the actuation board to trigger the hook securing mechanism. The ATmega 328P is programmed to control the steps and timing precisely for each stepper motor, to effectively achieve latching.

4 SEA TRIALS AND OPERATION

Testing of the DCV is conducted at Bee Sin Shipyard. Bee Sin Shipyard contains multiple vessels and is an ideal location for testing the DCV as it simulates the actual environment where the DCV is meant to be operated in. Demonstration pictures are shown in figure 12 below.

Various sea trials have achieved two main objectives:

- Test the controls systems of the DCV to achieve the desired degree of freedom and movement
- Ensure reliability and consistency of the hook catcher system's ability to latch a pallet of goods onto the crane

During operation, the DCV is launched from the shipyard after being loaded. The DCV can be controlled either manually by the FrSky controller or automatically by MAVLink which is supported by Pixhawk 4. Manual control is preferred at the current stage due to unstable and changing sea conditions. For automated control, the DCV uses MAVLink protocol through telemetry radio to control and navigate towards the targeting position by a ground companion computer. The real-time video from the front-facing camera is transmitted back to the companion computer for manual adjustment if necessary. When the up-facing camera captures the crane in its field of view, the DCV will station-keep at its location and wait for the hook to be lowered.

At the final stage, the receiving ship will lower the crane until the hook catching and securing mechanism is triggered. The light tower on DCV will notify the receiver on the ship once the cargo is secured and can be lifted to the ship. The entire cargo transfer operation will subsequently be completed and the DCV will return to shore for the next mission.

5 CONCLUSION

In conclusion, the DCV has been designed toward a resupply service that reduces the need for intense manpower as well as the need for coordination among the different boats whilst still making it cost-effective for service providers. Sea trial testing has shown initial success of the vehicle in delivering and lifting cargos by the hook catcher system. However, the current stage of DCV takes a long time in reaching and identifying cranes and may not yet be operationally feasible. Therefore, further research is needed in order to increase the efficiency in identifying moving ships and navigating through fluctuant sea water. Further development could also include a user interface for easier use of the DCV by untrained shipyard workers.

ACKNOWLEDGMENTS

The research work described in this paper was supported by the National University of Singapore, Bumblebee Autonomous Systems and Eng Hup Shipping Pte. Ltd.

The BeeX thruster used in this paper was sponsored by BeeX Pte. Ltd.

REFERENCES

[1] D. C. Vu, K. Lee and H. L. Vu, "An Empirical Analysis of the Prominent Roles of Taxations in the Synchronicity on Boost of Maritime Industry in Singapore," International Journal of Economics and Financial Issues, vol. 6, (1), 2016.
[2] X. Cao, S. Wang, C. Zhou, and N. Wu, "Offshore platform for containerized cargo redistribution: A new concept and simulation-based Performance Study," Maritime Policy & Management, vol. 48, no. 7, pp. 1032–1052, 2020.
[3] Vinh V. Thai , Linkesh Balasubramanyam, Karen Kai Lin Yeoh & Sofian Norsofiana, "Revisiting the seafarer shortage problem: the case of Singapore, Maritime Policy & Management," 40:1, 80-94, 2016.
[4] F-drones, "How it works", 2022, [Online]. Available: https://www.f-drones.com/
[5] H. Y. Jeong, B. D. Song, and S. Lee, "Truck-drone hybrid delivery routing: Payload-energy dependency and no-fly zones," International Journal of Production Economics, vol. 214, pp. 220–233, 2019.
[6] BeeX, "A.IKANBILIS HAUV", 2022, [online] Available: https://beex.sg/
[7] C. R. Sonnenburg and C. A. Woolsey, "Modeling, identification, and control of an unmanned surface vehicle," Journal of Field Robotics, vol. 30, no. 3, pp. 371–398, 2013.