Development of Autonomous recovery systems for USV/UUV

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Abstract — These

1 Objective

With increasing interest in the use of USV/UUVs within naval operations, one of the blockers for the introduction into naval service has been the challenges of launch and recovery from the mother platform.

This paper will discuss the development of the system from concept to its current development stage of TRL 7-9. Understanding the problem and the requirements is a key part of any product design process, and anyone familiar with the deployment and recovery of daughter craft from a vessel at sea will be familiar with this potentially hazardous process.

This challenge has driven commercial and governmental entities to invest in R&D to create viable solutions. Some have reached sea trials, while others remained as ideas in patent applications.

2 Introduction

Sealartec has been developing autonomous recovery systems for unmanned marine vehicles for over 7 years and has demonstrated its capability in Sea State 6 within hydrodynamic test facilities and at full scale we have demonstrated autonomous recovery of unmanned vehicles in sea state 4.

In this paper, we shall discuss the process of developing both USV and UUV recovery systems. The main content of this article deals with the USV recovery R&D process followed by reference to special considerations and adaptations created for the development of a recovery system for UUVs.

3 Approach

Setting the correct requirements is the first step of solving the problem. Thousands of years of seamanship teaches us basic principles that should be followed in order to create safe and stable processes. The problem of recovery of one small vessel to a ship, is a of 12 degrees of freedom (12 DOF). 6 degrees of motion freedom for each vessel: roll, pitch, yaw, heave, surge, and sway.

The approach of solution is to create a method and system which restrains these 12 DOF, step by step, in the optimal sequence, till the vessel to be recovered and the recovering platform are unified all in a manner that covers the stated requirements.

The first step is to create a small scale, fully functional, remotely operated prototype to be tested in flume test facility to validate the method.

After small scall has been proven functional and lessons learned, a full-scale sea trial in harsh sea conditions must be performed giving emphasis on real system design.

3.1 Setting the requirements.

Requirements were divided into groups.

3.1.1 Performance requirements

- Operational to sea state 6
- Recovery speed 5-15 knots
- Recovery time less than 1 min
- Be fully autonomous

3.1.2 Operational requirements

- Shall depend on minimal skills or capabilities from the operator of the USV/UUV
- Safe for crew & equipment
- Interoperability
- Compatible with:
    - Any boats (regardless of top deck installations)
    - Any ship or Rig
    - Any type of cane or davit
- Adjustable lift trim longitudinal position

3.2 Definition of the optimal process

3.2.1 Choice of cradle as lead solution

One specific requirement from the list above, to be compatible with any boat, any ship and any crane, has led us to choose the cradle-based solution to lead. From analysing the existing market of USVs and manned boats, it was clear that the most common feature of all boats is that monohull boats have generally very similar characteristics while any thing above deck height is dramatically different from one boat to another. It is also noted that the deck of most boats is the main asset for critical payloads installation.

A cradle supports the weight of the boat from the bottom, leaving the deck untouched. Also, most of the seagoing

boats form LOA of 3m-20m would generally have a deadrise angle of between 18°-24°, which allows the creation of very similar systems to a very wide range of boats.
Another significant advantage of a cradle solution is that the cradle and the vehicle to be recovered are riding essentially the same wave which means that the frequency and amplitude of motion in each 6 degrease of freedom of both are not so far apart. This makes the process of closing/restraining degrees of freedom simpler.

3.2.2 Painter line first

The immediate thought is that since the recovered vehicle has driving force, it can be easily manoeuvred into the cradle and force its way in. That would be the case in very calm sea conditions or inside the harbour. However, when attempting to drive a vehicle by force into a towed cradle in harsh sea conditions (sea state 2 and above), the boat needs to use great thrust which creates destabilizing forces on the towed cradle. Painter line of the towed cradle loses tension which is considered to be one of the most dangerous events while recovering in motion.

Driving a vehicle by force onto a cradle also creates high impact loads due to the required relative velocities and requires very high skills from the operator of the vehicle and its manoeuvring capabilities.

Using this analysis alongside some experience gained at see of Sealartec team of engineers, it was clear that the right order of actions to get the boat in the cradle should be:

- Recovered vehicle should position itself at the stern of the cradle and match velocities
- The cradle should be able to capture the bow of the boat autonomously
- Once the boat has been captured it should reduce thrust to zero and become towed by the cradle
- The cradle should now tow the boat in while restarting the bow motions to minimum
- While hauling the boat to the cradle, it should be designed in a way that the process of hauling will gradually restrain the relative motion between the two.
- Once boat and cradle are fully 'mated' it can be recovered safely using the ship/rig crane/davit

Concluding the above leads to the understanding that the main challenge of this process is creating a bow capture solution as the key element for the success of any recovery process in motion.

Sealartec has designed a few bow capture methods alongside 2 different type of cradles and tested it in numerous flume test and sea trials.

3.3 Description of process

3.3.1 Position cradle

Cradle is lowered to the water by the ships crane, towed using an extension boom to create a safe distance from the ship hull. Local positioning system is activated to locate to boat approaching.

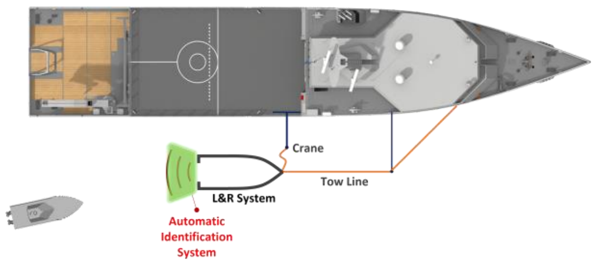

Fig. 1. Approach for recovery

3.3.2 Capture zone

Boat approaches capture zone, matches speed to the cradle and maintain its general position at stern of cradle. The cradle initiates an automatic capture device (the capture device is not described in this acticel) while it recognize the boat is in the capture zone. The green area in the image below represents the capture zone.

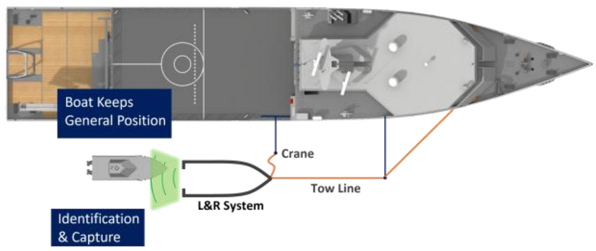

Fig. 2. Boat inified in capture zone

3.3.3 Boat captured and hauled in

Once captured, the boat reduces throttle to zero and being towed into the cradle. At the end of this process boat and cradle are mated and all 12 DOF are restrained. Boat and cradle are ready to be lifted to ship deck.

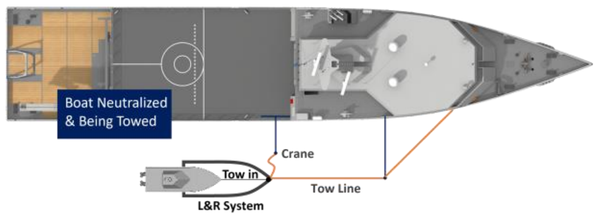

Fig. 3. Boat passive and being hauled in

4 Results and Discussion

Sealartec has conducted the following validation testing:

- Prototype #1 flume test- up to simulated sea state 5
- Prototype #2 flume test- improved system tested up to simulated sea state 6
- Full scale prototype sea trials- up to sea state 4

Flume test was conducted in the Technion Institute of Technology in a 40m long towing tank facility with wave generator and a traveling cart. Boat scale 1:25.

The sea trials have been conducted in open sea conditions west of the port of Haifa, where a weather wave buoy is near by to validate sea state conditions.

4.1 Prototype #1 flume test- sea state 5

This first cradle base system incorporated a 'hull shaped' cradle and included the capture device on a moving stage guided by rails along the cradle structure.

The entire functional elements were designed in a miniature scale using 3D printing methods with Nylon12. 5v DC micro motors was installed to act as actuators for cradle subsystems and all was operated by a remote control from the team on the cart. Boat of choice for this experiment is a standard RC boat with a deep rudder for better manoeuvrability and response to steering commands.

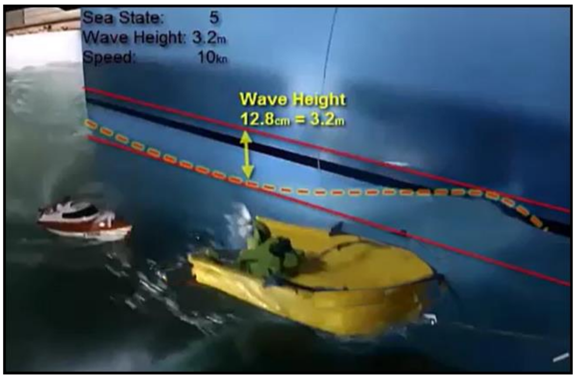

Fig. 4. Prototype #1.

Ovr 40 recoveries have been conducted in various conditions simulating sea state 0-5 and velocity of 5-10 knots.

Results has shown over 95% of success of bow capture in 1st attempt and 100% success including second attempt.

It has been demonstrated that after capture of the boat at the stern of the cradle, and reducing the thrust of the boat to zero, the towed cradle is towing the boat and the entire tow line chain creates stabilizing forces that always strive to find its position along the theoretical straight centre line of towing.

4.2 Prototype #2 flume test- sea state 6

This second cradle base system incorporated an 'open hull' cradle to allow recovery of USVs that have deployed sonar system from a moon pull that protrudes beneath the hull of the USV. Lessons learned from prototype #1 lead to installing the capture device on the cradle aft rather than on a moving stage.

Fig. 5. Prototype #2.

Over 32 recoveries have been conducted in various conditions simulating sea state 0-6 and velocity of 5-10 knots.

Results has shown that the method is working exactly the same in sea state 6 as it did in sea sate 5 (prototype #1). The new hull structure led to a more stable cradle in the water since the open hull shape had more drag and grip in the water, which made the manoeuvring to the capture zone at the aft of the cradle easier for the boat operator.

It has been decided to create this type of cradle and capture system for the next phase of full-scale sea trials.

4.3 Full scale sea trials- sea state 4

The sea trail demonstration unit is essentially an enlarged version of prototype #2. It was fabricated with 5083Al H321, and equipped with a combination of hydraulic, pneumatic, and electric actuators, all governed by a PLC by Unitronix.

Fig. 6. USV towed onto cradle, one sconed after bow capture.

USV characteristics:

- LOA- 5m
- Beam- 1.8m
- Deadrise- 20°
- Weight- 580 kg

Over 50 trials have been deployed. The testing method included initial testing of the capture robotic system installed at the aft of the cradle.

The first trials included a tugboat that towed the cradle and this testing intended to test only the critical process of capture and hauling without the last part of lifting the boat and cradle by the crane. First testing done in the harbour at low speed and last tests in sea state 4 in towing at 5 knots.

This initial testing included a few modifications to some technical parts of the system, but no changes were made to the general concept of operation.

Last testes included a 40m ship (Bat Galim) while using its standard MOB davit as the lifting system. This last trial has been made to prove the entire process as a hole but also to prove compliance to a main requirement which is to allow a fully autonomous recovery with a standard ship, a standard crane/davit and a standard monohull boat.

5 Lessons learned

5.1 "Painter line first" makes the difference

It has been demonstrated throughout the entire set of testing, that the capture system designed comply with the requirements. It has also been demonstrated that the fact that the boat was captured outside the cradle instead of driving by force, made the process highly stable.

5.2 Autonomous Identification of USV by recovery system

Though the capture zone behind the cradle is wide enough for any boat operator to drive in and maintain its general speed and position within, it has been learned the to time the initiation of the capture system requires timing response of about 1 sec. Therefore an automatic initiation system will increase dramatically the capture process throughout the lifetime use of the system. LPS (local positioning system) is under development in Sealartec with positioning accuracy of 10cm and latency of less than 0.1 sec. The information of the relative position between the cradle and the recovered vehicle will be used by the PLC to initiate the capture autonomously. Initial test in this field has been conducted as well and proven effective with the margins stated.

5.3 Shock mitigation

In order to reduce loads at the entire process of recovery a few methods have been applied. Towing and capture lines are carried out using servo winches. The servo winches are configurable by the user to set maximum load values and speed of line handling hence preventing snap loads.

6 Current and future work

Some aspects identified for future work includes:

- Further development of sensing methods to increase accuracy and performance of the systems
- Studies of method for weight reduction of cradle systems
- Incorporation of sensors for measuring loads of recovery process from impact, towing and lifting loads in harsh see conditions based on data collection system
- Development of international standard for autonomous recovery

7 UUV recovery considerations and adaptations

Whilst most of the process and principals of recovery of a USV remain the basis for the recovery of a UUV, some new requirements were created specifically for the UUV recovery.

Once again, a floating robotic recovery system shall be deployed by the crane of the ship to recover the. The sequence for restraining the 12 DOF remains the same as well:

- Printer line first. Connecting the bow of the UUV to the recovery system remains the critical part of the process.
- Hauling the UUV to be encapsulated withing the structure of the recovery system shall be designed in a manner that at the end of the hauling, all 12 degrees of freedom will be restrained and UUV will be unified with the recovery system, and ready for lifting to the ship.

One new requirement however, brought new challenges:

- UUV shall be recovered not only in motion but also while it is out of power, floating about the surface of the sea, and not capable of maneuvering.

7.1 Setting the additional requirements for UUV recovery

7.1.1 Performance requirements

- Recovery speed 0-5 knots
- Recovery time less than 15 min

7.1.2 Operational requirements

- Ability to recover non-manoeuvring UUV

7.2 Definition of the optimal process for UUV

7.2.1 The ship captain point of view

While recovering a UUV, visibility is a significant challenge. The UUV is mostly submerged under water and hard to spot. Moreover, the floating ship is affected mainly by wind and wave while the UUV is mainly affected by the currents, hence keeping constant distance becomes a significant challenge for the captain of the ship.

The way to overcome these challenges is to develop a self-manoeuvring launch and recovery platform, which is able to manoeuvre away from ship side to a safe distance but also to have the manoeuvring capabilities to accurately approach the UUV, connect at the bow an complete the process. Once the UUV is captured by the self-manoeuvring recovery system away from the ship, it is being manoeuvred back to be positioned under the craned and hoisted together with the UUV.

Due to IP reserved rights, specific technical information about the UUV recovery system can only be shared to this level of details.

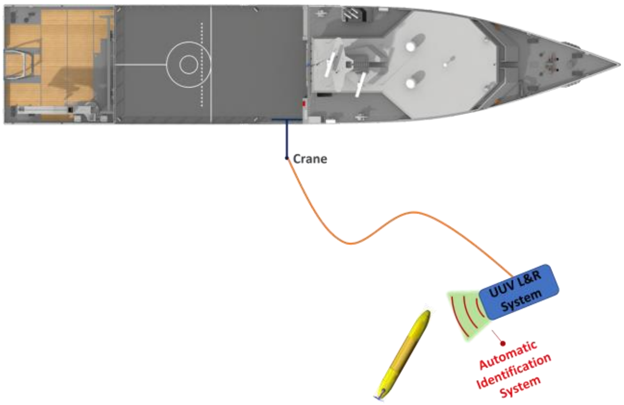

Fig. 7. UUV robotic recovery system manoeuvres towards recovery

7 Conclusions

Cradle based solution base on 'painter line' capture method has been proven to be highly effective. Some improvements required in the field of sensing, data collection and weight reduction are yet to be done to create a robust and viable solution.

Author/Speaker Biographies

Amitai Peleg is Co-Founder & CEO of Sealartec Ltd. a company specializing in autonomous launch and recovery of crewed or uncrewed marine vehicles. He has been involved in the autonomous marine vehicles industry since 2004 and has been operating, designing, manufacturing, testing, and supplying USVs to customers worldwide. With vast experience gained in his navy service, the idea of creating a fully autonomous launch and recovery capability sprang into existence as it is clearly one of the main challenges of the marine industry. Amitai holds a BSc. of mechanical engineering from the Technion Institute of Technology, Israel.