

A simplified concept for recovering a UUV to a submarine

Martin Renilson*

Higher Colleges of Technology, Abu Dhabi, UAE

Australian Maritime College, University of Tasmania, Newnham, Tasmania 7248, Australia

Received 29 June 2014; Accepted 31 August 2014

Abstract

The use of unmanned underwater vehicles (UUVs) to enhance the military capabilities of submarines and to reduce their operational risk is being considered by navies around the world. However, a major difficulty with the operations of UUVs is their recovery back to the submarine at the end of the mission. Various schemes have been proposed by a number of organisations working in this field; however, they all have major drawbacks.

A simple concept is proposed based on a warp from the submarine to a low aspect ratio wing, similar to an otter board used by fishing trawlers. This approach allows the submarine to recover the UUV by slowly overtaking it. This is done at a sufficiently large transverse distance between the vessels where hydrodynamic interaction between the two is minimal, with the submarine travelling at a speed at which it can be safely controlled.

Keywords: unmanned underwater vehicle, recovery of UUV, submarine operations

1. Introduction

The use of unmanned underwater vehicles (UUVs) for naval operations is being considered by many navies around the world. The operation of UUVs from manned submarines reduces the risk to the submarine and potentially enables tasks to be undertaken that would not be possible with a standard submarine, either conventional or nuclear powered (e.g. Currie et al., 2014; Hardy and Barlow, 2008; Purton and Andrews, 2014).

One or more UUVs operating in conjunction with a standard submarine has the potential to considerably increase its military capability at a low cost, while reducing the risk to the valuable asset and/or its personnel. Possible uses for UUVs to support or conduct a mission have been identified by Evangelio et al. (2012) as:

- intelligence, surveillance and reconnaissance;
- mine countermeasures;
- anti-submarine warfare;
- inspection/identification;
- oceanography/hydrography;
- communication/navigation network nodes;
- payload delivery;
- influence activities; and
- time critical strike.

There is a diversity of UUVs available for military tasks, and many of these can be launched easily from existing torpedo tubes. They can be configured to undertake a wide range of tasks, many of which would be difficult, if not impossible otherwise. Good summaries of a number of different UUVs available for military use are given by Hardy and Barlow (2008) and Button et al. (2009). However, a major obstacle to the widespread use of UUVs from submarines is the ability to recover them after they have completed their task(s) (Button et al., 2009).

2. Background

A number of different approaches have been suggested to recover a UUV after it has completed its mission. Some of these are discussed in Currie et al. (2014), Hardy and Barlow (2008), Irani et al. (2014) and Watt et al. (2011). The solutions broadly fall into three different categories:

- a) recovering the UUV on a slowly moving submarine through the torpedo tube;
- b) recovering the UUV on a slowly moving submarine into a specially designed location; and
- c) recovering the UUV to a stationary bottomed submarine.

The first solution can tie up two torpedo tubes, which may interfere with the ‘normal’ operations of the submarine. It requires considerable infrastructure

* E-mail address: mrenilson@amc.edu.au

to be operated from a torpedo tube and places a limit on the number of UUVs that can be operated at any one time. The first two solutions require the submarine to be travelling very slowly, and hydrodynamic interactions can make it difficult to control the UUV when it is close to the submarine (Leong et al., 2014). In addition, controlling the submarine at low speeds is difficult and potentially dangerous (Burcher and Rydill, 1998). This risk will be increased considerably if operating close to the surface, with the waves having an effect on the dynamics of both vehicles (Crossland, 2013). It should be noted that the second solution includes the possible use of dry or wet ‘hangers’ as discussed by Hardy and Barlow (2008). The third solution requires the submarine to be bottomed, and hence is really only practical for a conventional submarine in shallow water.

Solutions where the UUV overtakes the submarine to enable it to dock into a specially designed arm, such as described by Currie et al. (2014) and Irani et al. (2014), require the UUV to be able to travel faster than the submarine which is receiving it. This can pose serious problems, as it is difficult to operate a submarine safely at low speeds, and even the top speed of a UUV is slow by comparison to that of a submarine. For example, if a UUV were travelling at 4 knots (close to the top speed of many typical UUVs), the speed of the submarine to enable it to be overtaken by the UUV would need to be substantially lower. Although the minimum safe operating speed of a particular submarine is classified, the difficulties of operating a boat at speeds lower than this are well known (Burcher and Rydill, 1998).

In addition, the UUV may be low on power at the end of the mission, meaning that it cannot even achieve 4 knots. This would make such a manoeuvre, and therefore recovery of the UUV, impossible. Solutions that require considerable dedicated infrastructure on the UUV mean that it will be heavier and may also have more hydrodynamic drag. These are likely to compromise the UUV operating envelope and hence should be avoided wherever possible.

3. Proposed solution

The proposed concept is to make use of a taught wire (warp) operated from the submarine, to pick up a weighted wire dangling from the nose of the UUV (dropper), using a connection fitting and a catching device as shown schematically in Fig 1. The design of the catching device is similar to that used for catching a moored mine and will be tailored to the diameter of the dropper.

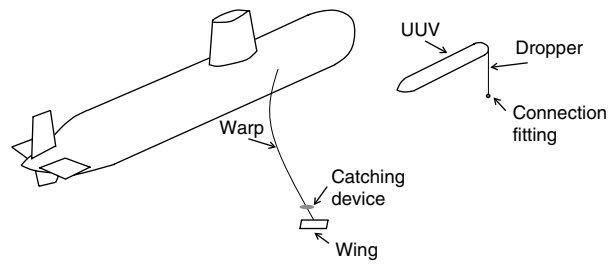


Fig 1: Schematic view

At the end of the mission, when the UUV is ready to be recovered, it will release a small mass at its nose attached to a bespoke connection fitting, as shown in Fig 2. This will dangle below the UUV at the end of the dropper. As the small mass and connection fitting are already on board the UUV, located at the bow of the UUV, the total mass and longitudinal centre of gravity (LCG) of the UUV will remain unchanged. The other end of the dropper is firmly attached to a point at the nose of the UUV.

The submarine will then release the warp, which is attached to a specially designed hydrodynamic low aspect ratio wing, similar to the otter board used by a fishing trawler, as shown in Fig 3. The wing has a fixed angle of attack to the flow in the horizontal plane, so its distance from the submarine will be determined by the length of the warp paid out from the submarine. Being a low aspect shape, it is stable in operation, as with the otter board on a pelagic fishing trawler. The vertical position of the wing can be controlled by a small trim tab on the wing, operated by remote control from within the submarine, using a signal transmitted through a cable within the warp. This means that the location of the wing can be controlled in both the horizontal and vertical planes from within the submarine as the submarine overtakes the UUV, as shown in Fig 4.

The submarine will then approach the UUV from astern, travelling slightly faster than the UUV. If the

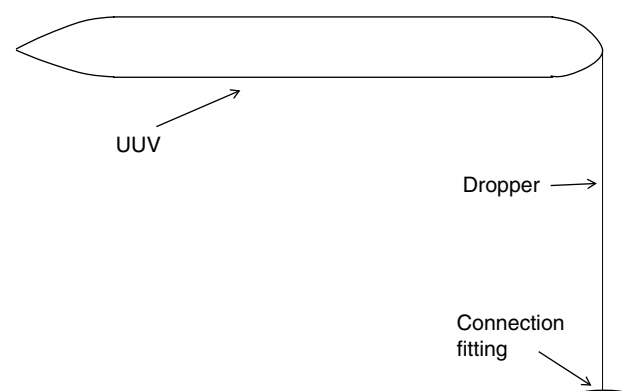


Fig 2: Profile view of UUV awaiting recovery

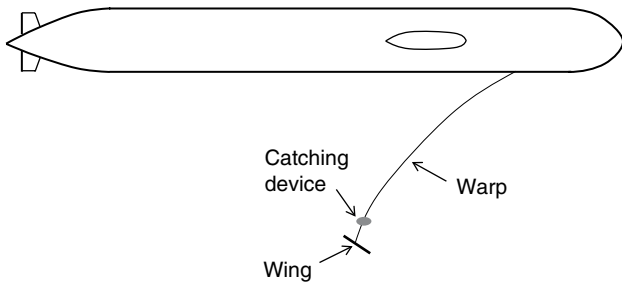


Fig 3: Plan view of submarine with catching rig deployed

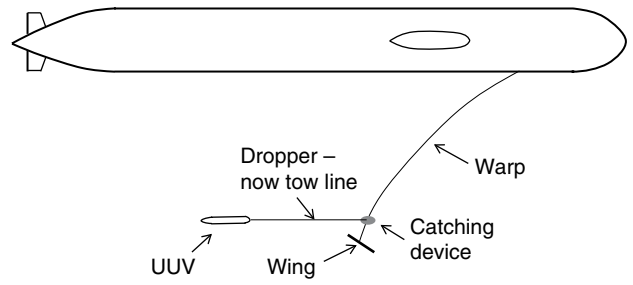


Fig 5: Plan view of submarine with UUV 'hooked up'

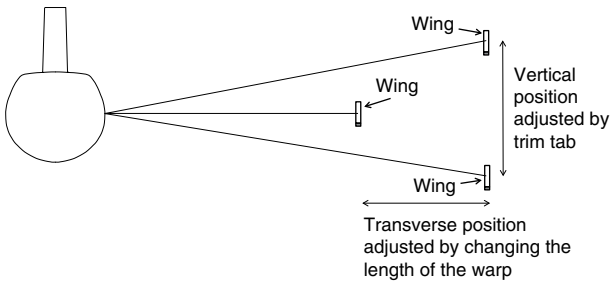


Fig 4: End view of submarine with catching rig deployed

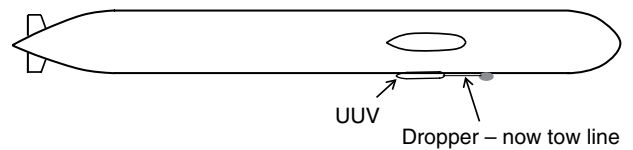


Fig 6: Plan view of submarine with UUV being docked

UUV were travelling at about 4 knots, then the submarine could approach at, say, 6 knots, which is above the safe minimum speed for the submarine. Note that if the UUV is low on energy and cannot achieve 4 knots, then it may be possible to undertake this manoeuvre with the UUV at a lower speed. In extreme conditions, if the UUV has already expended all its power, it could surface at zero forward speed and be picked up by the submarine (which would still be submerged) using this procedure.

The vertical location of the wing can be adjusted by an operator in the submarine such that the warp intersects the dropper. The location of the wing in the horizontal plane can be adjusted by the operator, such that the warp encounters the UUV's dropper close to the wing, but inboard of the catching device on the warp. The relative location of the UUV and the wing can be determined electronically using signals from the UUV and/or using a camera on the wing, if the visibility is adequate. Signals can be transmitted from the wing to the submarine and vice versa using a cable within the warp.

When the UUV dropper encounters the warp, it will slide up it until the connection fitting meets the warp. At this point, the connection fitting will clip around the warp. The connection fitting will then slide along the warp to the catching device. Once the connection fitting enters the catching device, the catching device will close and a positive linkage will be made between the dropper and the warp. This process is similar to the mooring line of a mine being picked up by the sweep wire in a specialised mine hunting rig. It has the advantage that

the exact diameter of the dropper is known, and there is a bespoke connection device at the end of the dropper.

As the submarine continues to overtake the UUV, it will start to tow the UUV using the dropper (which would now become a towing line) as shown in Fig 5, and the UUV motor can be shut down. The warp can then be winched into the submarine, with the UUV firmly attached. When the UUV is close to the submarine, it can easily be inserted into its docking mechanism since its longitudinal position will be known, as shown in Fig 6. Once the UUV is secured, the catching device can release the dropper, and the dropper can be drawn back into the nose of the UUV.

4. Further work

To develop the concept, a number of different factors need to be further developed. These include the following.

4.1. The influence of the dropper on the dynamics of the UUV

The deployment of the dropper may affect the dynamics of the UUV. Although the UUV mass and LCG will not be changed, assuming that the dropper is located at the bow of the UUV prior to being deployed, its dynamic behaviour may be influenced by the presence of the dropper. This aspect is probably best investigated using either a model or full-scale UUV in a controlled environment, such as a model basin or sheltered waterway.

4.2. The dynamics of the warp and low aspect wing

The low aspect ratio wing will be deployed from the submarine, and the dynamics of its behaviour during

this process will need to be investigated. In addition, once deployed the ability to control the location of the wing using the hydrodynamic trim tab and the winching in and out of the warp should be investigated. The design of the low aspect wing, its attachment to the warp and the design of the trim tab all need to be developed.

Much of the initial component of this work is probably best done experimentally using a circulating water channel facility. If a suitable circulating water channel is not available, then a towing tank facility could be used for this. However, the facility will need to be long enough to allow the rig to stabilise after the initial acceleration and to permit a range of manoeuvres at the desired scale speeds to be carried out.

The movement of the low aspect wing, and hence the catching device, in both the horizontal and vertical planes should be investigated. The design of the low aspect wing and its trim tab would be refined during this phase of the work. In addition, captive tests should be conducted on the low aspect ratio wing and the trim tab. A mathematical model permitting the simulation of the behaviour of the wing can then be developed and validated using results obtained experimentally. Finally, this should be done at large scale using a strut below a surface vessel. The horizontal and vertical movement of the low aspect wing, and hence the catching device, would be studied, as well as the ease by which this can be done at full scale determined.

4.3. The interaction between the warp and the dropper

This element is probably one of the most important aspects of the concept. It will be based on similar technologies used for mine sweeping. The dynamics of the warp engaging the dropper, with the subsequent effect on the motion of both the rest of the warp and the UUV, will be crucial. Although a detailed mathematical model could be developed to simulate this, it is probably easiest done at 'part scale' in a controlled environment. Initially a shortened scale warp attached to a strut could be used in a towing tank, together with a scale model of a UUV. The effect of the relative speed between the UUV and the overtaking 'submarine' could be assessed, along with the dynamics of both the warp and the UUV when contact is made.

4.4. The catching device

The catching device will then need to be developed, again based on existing mine sweeping technology. This is probably best done at full scale, using a much shortened warp, and a full-scale UUV. A large towing tank could be used for this, or alternatively

such tests could be done in a sheltered waterway, with the warp towed from a strut below a surface vessel. Visualisation of the process will be necessary to improve the design of the catching device, such that a positive linkage can be made with the dropper.

4.5. The dynamics of the UUV when being winched back to the submarine

Once the UUV has been 'captured' by the catching device on the warp, winching it back to alongside the submarine should be fairly straightforward. However, it is recommended that this be investigated experimentally to identify any potential problems. For example, care needs to be taken to ensure that there is no possibility that the rig would end up striking the propeller. Such tests could be conducted in a circulating water channel or a towing tank, using a model-scale UUV already connected to the model-scale warp with low aspect lifting surface.

Initially such tests could be undertaken with the warp deployed from a simple strut; however, subsequent tests should be carried out with a simulated wake similar to that generated by the submarine when the lifting surface and UUV approach it. Computational fluid dynamics (CFD) could be used to determine the structure of this wake and that simulated experimentally using wake screens. The mathematical model developed as part of the element discussed in section 4.2 could also be used to assess the dynamics of the complete rig in this condition.

4.6. The housing/docking procedure for the UUV

Once the UUV is alongside the submarine, it will need to be inserted into its docking mechanism. This aspect should be investigated, along with the design of the submarine, to enable realistic docking arrangements to be considered. It may be that a wet/dry hanger mounted on the submarine, as discussed by Hardy and Barlow (2008), would be the best solution, particularly for existing submarines.

4.7. Complete procedure

Once the various elements have been refined and shown to work, the complete procedure should be undertaken. Initially, this could be done using a mathematical simulation, based on experimental results obtained when investigating the various elements. Then, full-scale experiments could be conducted using a strut arrangement from a surface vessel with part of the submarine/dock represented. A full-scale UUV would be used and the whole process undertaken. Finally, the system could be installed in a full-scale submarine (possibly using a hanger)

and trials undertaken to demonstrate and validate the procedure.

5. Concluding comments

The recovery of a UUV by a submarine at the end of its mission is a major difficulty in the operation of UUVs for military purposes. A number of schemes have been proposed by various organisations working in this field. Each has major drawbacks.

A simplified concept has been proposed based on a warp from the submarine to a low aspect wing, similar to the otter board used by trawlers. This approach allows the submarine to recover the UUV by slowly overtaking it while it is at a transverse distance where hydrodynamic interaction between the two vessels is minimal, travelling at a speed at which the submarine can be safely controlled. Thus, the UUV is not required to overtake the submarine, which may not be possible with its remaining power at the end of a mission. In extreme conditions, if the UUV has already expended all its power, it could surface at zero forward speed and be picked up by the submarine (which would still be submerged) using this procedure.

The concept of a warp picking up a vertical mooring line using a catching mechanism has already been developed for use in mine sweeping. However, this needs to be better understood in the context of this application. The next stage in the progress of this concept is to develop details of the dropper, the connection fitting and the catching mechanism. Semi-scale trials are therefore recommended in either a towing tank or a circulating water channel to fine-tune this aspect of the concept. Once this has been refined, trials of the complete rig are recommended at sea, using a surface vessel rather than a submarine, such that the procedure can be observed more clearly.

References

- Burcher R and Rydill L. (1998). *Concepts in Submarine Design*. Cambridge: Cambridge University Press, 303pp.
- Button RW, Kamp J, Curtin TB and Dryden J. (2009). A survey of missions for unmanned undersea vehicles. RAND report, sponsored by the US Navy.
- Crossland P. (2013). Profiles of excess mass for a generic submarine operating under waves. In: Proceedings of the Pacific 2013 International Maritime Conference, 7–9 October, Sydney, Australia.
- Currie J, Gillis CB, Carretero JA, Dubay R, Jeans T and Watt GD. (2014). Dynamics of two active autonomous dock mechanisms for AUV recovery. *Transactions of the Canadian Society for Mechanical Engineering* **38**: 213–226.
- Evangelio A, Nyaas O, Yuzichuck G, Sweeney S, Karagoz M, Coffman M and Fox J. (2012). Guidance for developing maritime unmanned systems (MUS) capability. Combined Joint Operations from the Sea Centre of Excellence Report 12/029-02, 9 July 2012.
- Hardy T and Barlow G. (2008). Unmanned underwater vehicle (UUV) deployment and retrieval considerations for submarines. In: Proceedings of the 9th International Naval Engineering Conference (INEC) 2008, 1–3 April, Hamburg, Germany.
- Irani RA, Kehoe D, Spencer WW, Watt GD, Gillis C, Carretero JA and Dubay R. (2014). Towards a UUV launch and recovery system on a slowly moving submarine. In: Proceedings of Warship 2014: Naval Submarines & UUVs, Royal Institution of Naval Architects, 18–19 June, Bath, UK, 93–103.
- Leong ZQ, Ranmuthugala D, Penesis I and Nguyen H. (2014). Scaling and relative size effects on the hydrodynamic interaction on a UUV operating close to a submarine. In: Proceedings of Warship 2014: Naval Submarines & UUVs, Royal Institution of Naval Architects, 18–19 June, Bath, UK, 105–113.
- Purton IM and Andrews DJ. (2014). Computer simulated trends in designing a future unmanned underwater vehicle ‘mothership’ submarine. In: Proceedings of Warship 2014: Naval Submarines & UUVs, Royal Institution of Naval Architects, 18–19 June, Bath, UK, 75–91.
- Watt GD, Carretero JA, Dubay R and Mackenzie MR. (2011). Towards an automated active UUV dock on a slowly moving submarine. In: Proceedings of Warship 2011: Naval Submarines & UUVs, Royal Institution of Naval Architects, 29–30 June, Bath, UK.