Unmotorize ROV gripper to catch profiling floats

Christophe Viel*

* CNRS, Lab-STICC, F-29806, Brest, France (e-mail: firstname.lastname@ensta-bretagne.fr).

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ABSTRACT

This paper proposes an ROV (Remotely Operated underwater Vehicle) gripper for retrieving cylindrical profiling floats. In order to fit several types of ROVs and to be easily installed, the gripper is not motorized, using only the robot's movements to catch the floats by simply moving forward on them. Then, the gripper uses the turnstile and freewheel concept to grasp and hold the float, with a safety release system to free an unwanted catch. The effectiveness of the clamp was tested in the pool and in the lake, with two actual rescues of lost floats. The limits of the methods are discussed.

1. Introduction

Profiling floats are a specific kind of Autonomous Underwater Vehicle (AUV) which can only regulate their depth. They are widely used in oceanography to measure data inside the water column like pressure, temperature, conductivity or biochemical. In the past two decades, the profiling float has allowed to collect and process over two million vertical profiles of temperature and salinity from the global ocean [13, 12]: the Argo project [10, 13, 1] has deployed 4000 profiling float gathering data continuously all over the world. With the success of these missions, the data collection needs of oceanographers are increasing, leading to the development of new inexpensive floats [6, 2].

However, the floats can stop operating for several reason [4]: the float becomes heavier than it was planned and can not reach the surface, software bug, sensors return wrong information, or float is captured by a fishery boat... During the development phase, software bugs are particularly common, increasing the risk of lost during the first immersion. In these cases, it can be complex to catch and bring the float to the surface, requiring the use of an ROV to rescue it.

Underwater robotic manipulation is an inherently difficult task and a slow process [9, 3]. Indeed, ROV pilots face problems such as lack of 3D information on arm position, a poor visibility in murky waters, or significant delay in the information transmission [7]. Moreover, obtaining a stable position to operate the arm can be difficult due to the umbilical, water currents, and fluid resistance, especially if the ROV cannot be landed on the sea floor [3].

The shape of the gripper changes according to the object to be gripped and its needs (size, weight, fragility...). [9] describe an overview of a large variety of grippers and tools commonly used in underwater sampling for scientific purposes. Gripper with two or three-finger pliers can be sufficient to catch a tube [11], provided they are large enough. However, these tools can be complex to build, and always requires an electrical or pneumatic connection to operate, and therefore cannot always be easily disassembled once the mission is finished. Other works like [8, 5] proposes an universal soft membrane gripper to grasp irregularly shaped objects. A membrane allows to conform to the shape of the object and a hydraulic circuits is used to compress the object with a desire force. If this system is simpler than those used in classic hydraulic arm designs, it still requires to equip the ROV with a hydraulic system with pump and an incompressible fluid.

In this paper, we propose a gripper for ROV to recover the float in the water column or on the seabed as long as it remains globally vertical. In order to offer a low cost solution, simple to implement and adapted to a wide range of robot, the gripper is non-motorized to eliminate any electrical or pneumatic connections. In opposite with the gripper exposed below, our method uses the robot movement's to activate the clamp, and does not require an accurate positioning to catch the floats. The effectiveness of the clamp was tested at pool and in lake.

The concept of the proposed solution and its requirements are exposed in Section 2.1 and 2.2. The geometry of the gripper is described in Section 2.3 and the lock and unlock mechanism is detailed in Section 2.4. Section 3 presents experimental results of the gripper, and limits of the method are exposed in Section 4.

2. The gripper

2.1. Requirement

This paper design a gripper specific for profiling floats. We consider the following assumption on the floats:

- the floats can be roughly assimilated by vertical tubes with a stop on it, generally a stability disk or a support platform for sensors (see examples in Figure 1). Name it "float stop" in this paper.
- The floats maintain an approximate vertical orientation when submerged.
- The floats have a minimum weight, given them a minimum inertia underwater.

The second condition is not aberrant because the floats are balanced in this way and the majority of the failures are due to problems of exit of the float's piston, which modifies its overall buoyancy but not its balance: the floats sink until

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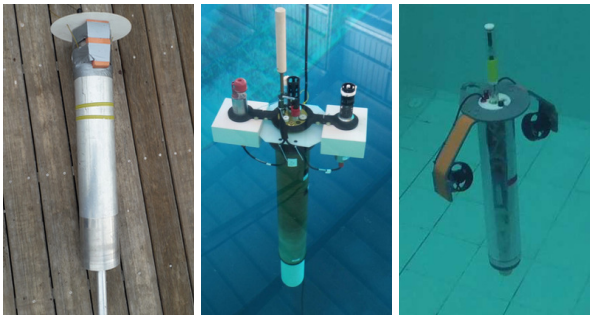


Figure 1: Example of profiling floats from Ifremer, the NAOS Project [1], or ENSTA Bretagne[6].

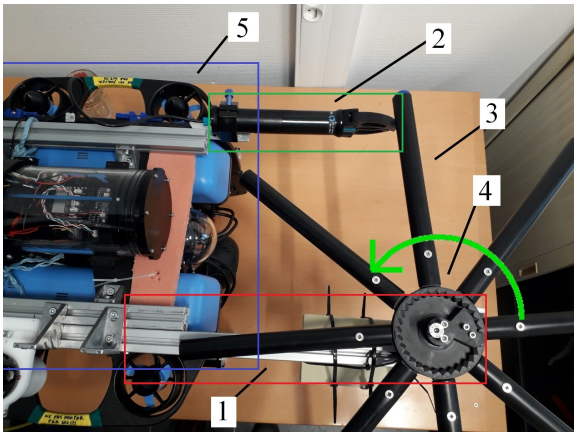


Figure 2: Turnstile gripper. 1: first arm with the freewheel. 2: second arm to close the space (here performed with a bluerov gripper already installed on the robot, but this gripper is not used in the strategy). 3 : branch of the turnside. 4: freewheel. 5: ROV.

they rest vertically on the sea floor. In following sections, the grippers are thus designed to grip vertical tubes with a stop in the middle or top.

2.2. The concept

In order to be adapted for several kind of ROV and be easily assembled and disassembled, we decide to develop an unmotorized grip to eliminate any electrical or pneumatic connections. The closing and opening of the gripper must therefore be activated by a movement of the ROV. Moreover, we desire that the gripper can catch easily the floats for the operator.

The method chosen is the turnstile method. The clamp is composed of two arms. The end of the first arms is equipped at its extremity by a freewheel with several branches in the horizontal plan (see Figure 2) turning freely towards the inside of the clamp, and blocking towards the outside. The second arm is a simple rod that creates a closed space with the first arm.

Catching the float is very simple: the ROV moves towards the float by aiming between the two arms. The float pushes the branches of the turnstile, and cannot turn around anymore. By security, an unlock system is proposed to turn in the other side if the torque becomes too important, see Section 2.4. When the ROV ascent, the branches of the gripper come in contact with the float stop. The distance between the arms is kept loose, so the system does not require a lot of accuracy to catch the float. Note however that the float it is just locked and not tightened, and downward movement requires descending at the same speed as the float sink.

2.3. Gripper geometry

In the horizontal plan, the float can be assimilate to a circle C_1 of radius R. Let L be is the gripper's branches length from the center of rotation C, e be the thickness of the branches, D be the distance between the two arms of the gripper, as illustrate in Figure 3. The angle between the branches is defined as $\gamma = \frac{2\pi}{N}$, where N is the number of branches.

To guarantee the freewheel will trap easily the float no matter what the initial position of the wheel, a gripper with eight branches has been chosen. With less branches, the turnstile will be less easily dragged along by the float. With more branches, a more cumbersome clamp will have to be made, as it will be shown by the relation (3). L and D must also be chosen such that 1) the float can enter between two branches, 2) the float cannot slides between the branches and the second arm when it is inside the gripper.

As detailed in the Appendix A, the float is lock by the gripper if the circle C_1 is inscribed inside the triangle performed by two branches and the second arms. The following relations can be obtained

$$L \geq l_1 \tag{1}$$

$$l_1 \leq D < l_2 \tag{2}$$

where

$$l_1 = \frac{\left(1 + \frac{1}{\cos(\gamma)} + \tan(\gamma)\right)}{\tan(\gamma)} \left(R + \frac{e}{2}\right) \tag{3}$$

$$l_2 = \frac{2R}{(1 - \cos(\gamma))}. \tag{4}$$

where $\gamma = \frac{\pi}{4}$ in the case of eight branches. Since $\gamma = \frac{2\pi}{N}$, remark that the more branches there are, the longer L is, as so the clamp is cumbersome.

2.4. Lock and unlock security system

The gripper is locked with a freewheel mechanism. As illustrated in Figure 4, the freewheel is composed of three parts: a central fixed part with the axis of rotation (in green), a rotating gear where the branches are attached (in gray), and a pawl to allows the rotary motion in only one direction while preventing motion in the opposite direction (in red).

In a classic freewheel, the system can turn only in one direction. It can however be dangerous to not be able to release an undesirable item, mostly if this one is a fixed underwater item (example: submarine pillar, a tree in a submerged lake, etc...). Thus, an unlock security system is proposed here. Since the gripper is unmotorized, the release mechanical uses only the movement of the robot.

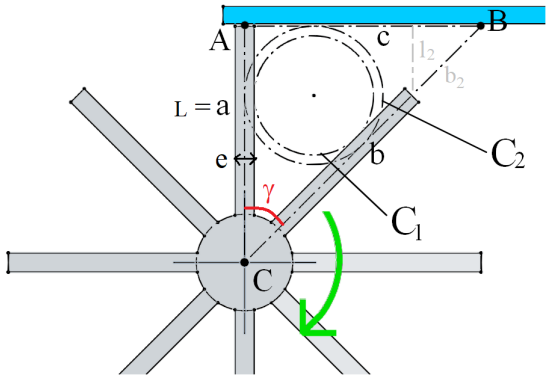


Figure 3: General shape of the gripper with 8 branches. In gray, first arm with the freewheel. In blue, second arm. C_1 correspond to the diameter of the float. Green arrow: rotation side.

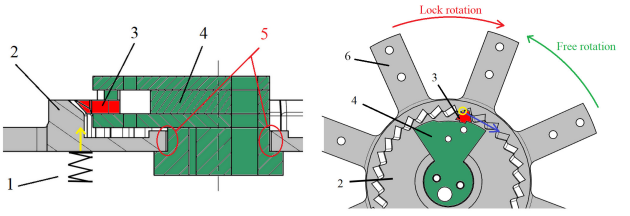


Figure 4: Freewheel system with unlock security. 1: spring. 2: rotating part (grey). 3: pawl to lock the freewheel (red). 4: Fixed part (green). 5: mechanical slack. 6: branches of the gripper. A second spring not illustrated here allows to keep the pawl 3 in contact with the rotating part 2. Blue arrow: horizontal force applied on the pawl made by the torque. Yellow arrow: vertical torque applied by the spring

First, a mechanical slack is added around the rotational axis to allow the rotation part to tilt and therefore disengage the system (see Figure 6). In classic operation, the rotation part is maintains at the horizontal in contact with the pawl by a spring (name it "lock spring"), see Figures 6 and 4. Secondly, in opposite with a classic freewheel where the teeth are vertically right, vertically inclined teeth are used here, see Figure 5. The angle teeth divide the torque received from the rotating part into a vertical and a horizontal forces. When the vertical force becomes stronger that the force applied by the lock spring, the pawl slides on the teeth, the freewheel is disengage and can turn in the both directions. Thus, when too much torque is applied to the clamp, it unlocks to release its grip. The gripper can thus be opened by a strong backward push if the object is fixed, or by a strong backward acceleration performed by the robot.

A simple estimation of the unlocking torque C_{open} can be performed:

$$C_{\text{open}} = \frac{L F_{\text{spring}}}{\tan(\alpha)} \tag{5}$$

where L is the branches length, F_{spring} is the force of the unlock spring, α is the vertical inclination performed by the teeth such that $\alpha = 0$ corresponds to vertical teeth and $\alpha = \frac{\pi}{2}$ corresponds to "horizontal" teeth (no teeth). One observe that the more the teeth are inclined, the easier the freewheel will open.

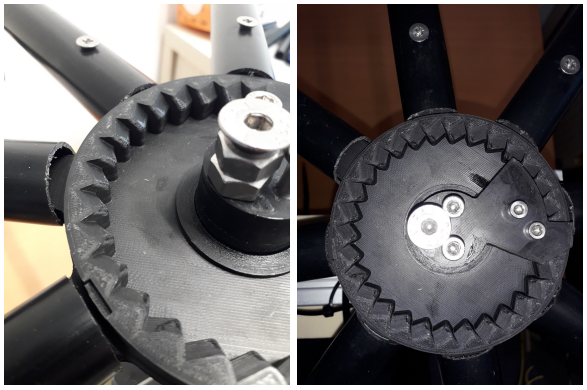


Figure 5: Freewheel with angled teeth



Figure 6: Left: lock gripper. Right: unlock gripper when the torque becomes too high. 1: spring (inside a guide tube) to maintain the rotating part at the horizontal in contact with the pawl when the gripper is lock.

Note that 5 does not consider friction on the rotation axis or the teeth. In practice, the friction on the rotation axis induces a minimum torques is require to turn the freewheel in classic operation, so the floats have a minimum inertia to create a torque when the ROV moves to the float, as said in Section 2.1. Moreover, the contact between the lock spring and the rotating part adds friction, and so increase the minimal torque to turn the freewheel.

Since the inclined teeth can be difficult to machine, we perform it with a 3D printer. To limit the friction, the rotational axis has been greased and the contact of the lock spring has been made by a ball to obtain a point-contact junction.

3. Experiments and floats rescues

3.1. Material

A BlueROV2[1] was used for the experiments, initially equipped with a frontal camera, two lights, a barometer and an IMU. The ROV has however been modified to add other instruments, like an sonar Blueview[2] to locate the float and a second camera facing downwards. The ROV was controlled in depth and heading to keep them constant when the operator does not control them.

[1] https://bluerobotics.com/store/rov/bluerov2/
[2] http://www.teledynemarine.com/blueview/



Figure 7: turnstile gripper

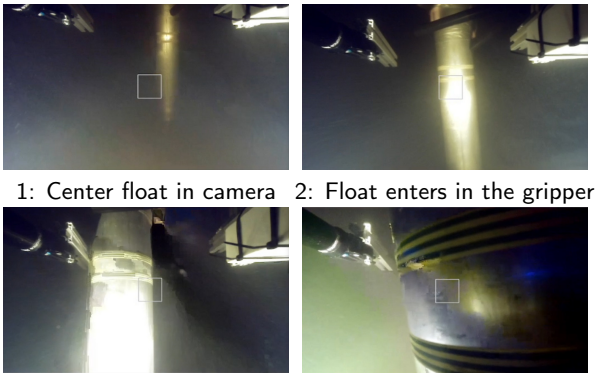


Figure 8: Capture of a float with the gripper. First, the float is center with ROV camera. Then, the ROV moves forward to enter the float in the gripper. The gripper turns and the float is trapped in the gripper.

The gripper has been built using a 3D printer for the gear part and plastic pipes for the branches of the turnstile. An angle $\alpha = \frac{\pi}{4}$ has been chosen. It has been installed on the ROV so that the center of the clamp coincides with the center of the camera, so that the float hides the camera when it is grabbed, see Figure 7.

3.2. Results

The gripper was tested in pool of size 3m×4m×3m and at the lake of Guerlédan in France, a former valley flooded by a dam that still has some immersed trees. A large number of tests were performed in pool, two training tests were performed in the lake, and two true float rescues were performed in the lake at a depth of 39m (first float in Figure 1).

The most difficult part was to find the float inside the lake with the sonar and an approximate GPS location of the lost float. Then, since the ROV was controlled in depth and heading, the operator just needed to center the float in the camera, then moved forward to enter the float in the gripper. The gripper turned and the float was trapped in the gripper, see Figure 8. The ROV ascended then to come in contact with the float stop and bring the float to the surface. Note that an automation of the positioning of the robot to center the float with the camera was realized in the pool by using the tracking of a sticker on the float, but the water of the lake was too cloudy to make it effective in real condition.

During the two rescues, the floats were grabbed on the first try with the gripper. In the first case, the float was placed vertically on the sea floor without obstacles around it. In the second case, the float was trap at the top of a tree, creating a most complex environment but still free of direct lateral obstacles. Paradoxically, most complex case were performed in pool were the small environment dimension makes sometime the seizure of the float impossible when this one is to close of a wall, and so the turnside cannot turn enough to catch the float. A solution tested was to use a longer second arm with an hook to move the float away from the walls first, then move forward to catch it, but this method requires a much more cumbersome equipment and makes the maneuver much more complex.

A video of the rescue can be found at https://youtu.be/-IElz9GbFic.

4. Limits of the gripper

If the propose gripper has many advantage by its simplicity and the absence of motorization, the method has several limitation. First, it is adapted only to catch a vertical cylinder with a stop: it cannot catch a perfect cylinder or an horizontal cylinder. The float also requires to have a minimal inertia to overcome the freewheel friction. It is also complex or impossible to catch a float against a wall: the use of a hook on a pole to move the float away from the wall is a possible solution. Finally, the geometry of the gripper makes it bulky.

5. Conclusion

This paper proposes a gripper for cylindrical floats with a vertical stop. The gripper is unmotorize, cheap, and simple to built and set up. The method uses the concept of turnstile and freewheel to trap the float without release it. The ROV displacements allow to catch the floats by simply advancing on them, without an important accuracy. An unlock system is proposed to release an undesirable underwater obstacle that could keep the robot stuck underwater. The effectiveness of the clamp has been tested in pool and in lake, with two real rescues of lost floats. The method has however some limits, for example it can only catch vertical cylindrical item, and this one require a minimum inertia to turn the turnstile.

Future work will attempt to catch inclined or horizontal floats. We are also focusing on an automatic long-range float detection system, the most difficult part of the rescue being finding the float.

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author declares that there is no conflict of interest.

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A. Calculation of the branch's length

Let define the rectangular triangle ABC with $\widehat{BAC} = \frac{\pi}{2}$ as defined in Figure 3. Let define $a = \text{AC}$, $b = \text{CB}$, $c = \text{A}\hat{\text{B}}$ and the angle $\gamma = \widehat{ACB}$. The length a can be considered as a branch's length, γ the angle between two branches and c a part of the second arm. Let define the circle C_1 of radius R as the section of the float, and consider the circle C_2 of radius $R_2 = R + \frac{e}{2}$ to assimilate the arms to straight lines. The float is lock by the gripper only if the circle C_2 is inscribed inside the triangle ABC: let's find the adapted value of a.

The radius of the inscribed circle can be expressed as

$$R_2 = \frac{2S}{a+b+c} \tag{6}$$

where S is the area of the triangle, which can be expressed from the law of sinus as

$$S = \frac{1}{2}ab\sin(\gamma) \tag{7}$$

Since ABC is a rectangular triangle, one also has $b = \frac{a}{\cos(\gamma)}$ and $c = a\tan(\gamma)$. From these property, and (6)-(7), one gets

$$\begin{aligned} R_2 &= \frac{a\frac{a}{\cos(\gamma)}\sin(\gamma)}{a + \frac{a}{\cos(\gamma)} + a\tan(\gamma)} \\ R_2 &= \frac{a\tan(\gamma)}{1 + \frac{1}{\cos(\gamma)} + \tan(\gamma)} \\ a &= \frac{1 + \frac{1}{\cos(\gamma)} + \tan(\gamma)}{\tan(\gamma)} R_2. \end{aligned} \tag{8}$$

In our case, $D = a$ and $L \geq a$, thus (8) provides the minimum length of the branches.

Notice that since $a < b$, there is a gap between the branch of CB and the second arm when $L = a$. The projection of this gap on the axis AC, noted l_2, can be evaluated as

$$\begin{aligned} l_2 &= \cos(\gamma)(b-a) \\ &= a\cos(\gamma)\left(\frac{1}{\cos(\gamma)} - 1\right) \\ &= D(1-\cos(\gamma)). \end{aligned} \tag{9}$$

To guarantee the float cannot pass by this gap, the distance D must also respect the following condition:

$$\begin{aligned} l_2 &< 2R \\ D(1-\cos(\gamma)) &< 2R \\ D &< \frac{2R}{(1-\cos(\gamma))}. \end{aligned} \tag{10}$$