

# Rigid Tether Modeling for Underwater Environment Simulation

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**Abstract**—Simulation in the field of robotics is a powerful tool. Indeed, it allows to easily and quickly test the robot in different conditions and to have a reproducibility of the results. Then it let us be able to create situations that would be difficult to find in reality, in order to make sure of the robot's behavior. It should be noticed that the simulation of robots does not replace tests in real conditions, but it remains practical during the development phase. However, the simulation of robots in the maritime environment is a field that still has shortcomings, especially when we want to simulate the tethers of submarine robots. Indeed, it is not easy to find an analytical way to simulate a tether that does not require large resources, especially when simulation environments become complex. This is why we will try to suggest an approach of simulation by discretization of the tether by proposing a behavioral model of force between each tether element. The results seem satisfactory and with a correct initialization of the position of the tether elements, the behavior of the tether seems quite right. However, the tether stiffness phenomena are not taken into account in this modeling, the tether is of fixed length, and both ends have been fixed so the system has not been tested dynamically.

**Index Terms**—Modeling, Tether, Remotely Operated Underwater Vehicle, Simulation.

## I. INTRODUCTION

In the world of marine and underwater robotics we can identify two categories of elements: mobile marine objects (MMO) and flexible tethers (FT). Mobile marine objects include surface vessels, submarines and remotely operated vehicles. Flexible tethers can represent umbilical cables, traction cables and anchor chains in the marine environment. They constitute all the necessary elements to achieve a mission in this environment which is sometimes quite difficult to explore.

The simulation of moving marine objects is something well known. We are now able to know from state equations the behavior of robots in their environment, and these equations are known for ships, submarines, sailboats, etc...

On the other hand, determining the behavior of a flexible tether becomes more complicated. Indeed, the equation of motion of these objects involves non-linear partial differential equations and the motion between the different objects in the environment are dynamically dependent. It is well illustrated that if the boat moves, it will induce a motion in the flexible tether that will modify the trajectory of the remotely operated vehicle. This is why it is difficult to find a way to model flexible tethers in underwater environments.

## II. FORMALISM

The idea proposed in the scientific paper [1] is to solve this problem using finite element simulation. This implies that we

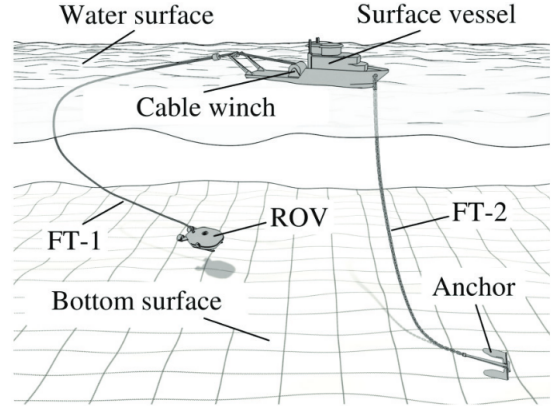


Fig. 1. Example of a complex underwater environment

need to discretize the tether in order to simulate its global behavior.

Suppose we want to simulate a tether of length  $L$ . We will then divide it into a finite number  $n$  of nodes connected by links. These links should be of length  $l = \frac{L}{n-1}$  as the two nodes at the ends of the tether will not be connected to any other links.

We will focus here on the case where the first node and the last node are immobile, because otherwise we would have to simulate a mobile marine object that would be attached at the end, which is not the goal of our study.

Next, it is necessary to make a balance of the forces that apply to each tether element. For this simulation, we will take into account the weight, noted  $F_g$ , the buoyancy, noted  $F_b$ , and the force exerted by the previous element on the considered element, noted  $F_{t,p}$ , as well as that of the next element, noted  $F_{t,n}$ .

These forces will allow us to simply describe the behavior of the tether in its environment. Moreover we could then improve the quality of the simulation by adding other forces such as drag forces.

### A. Weight $F_g$

Considering that each element has a mass  $m$ , we are able to express the weight that applies to this node :

$$\vec{F}_g = \begin{bmatrix} 0 \\ 0 \\ -m.g \end{bmatrix}$$

### B. Buoyancy $F_b$

If we note the volume of each element  $V$  and  $\rho$  the density of the fluid in which the tether is immersed, we can also express the buoyancy force of this node:

$$\vec{F}_b = \begin{bmatrix} 0 \\ 0 \\ \rho \cdot V \cdot g \end{bmatrix}$$

### C. Tether force $F_{t,p}$ and $F_{t,n}$

It is difficult to find an analytical form to describe these two forces. Therefore, we must find a way to describe them. This is why we will use a behavioral model here. We know that each node will have to be at a distance  $l$  from each of its neighbors. We can assume that the system behaves here as a three-dimensional damped mass-spring system and we will then consider that these forces are like elastic spring forces and viscous frictionnal forces.

By noting then  $p_p$  the position of the previous node and  $p_c$  the position of the current node, by introducing three coefficients  $K_p$ ,  $K_d$  and  $K_i$  allowing to express the stiffness with which a node will correct its position with respect to its neighbors, we are able to express the behavioral model of these two forces:

$$\vec{F}_t = - \left( K_p \cdot e + K_d \cdot \dot{e} + K_i \cdot \int_0^t e(\tau) \cdot d\tau \right) \cdot \vec{u}$$

In these expressions, it is assumed that  $\vec{u}$  is the unitary vector oriented from the current node to the neighboring node,  $e(t)$  is the error of position between two nodes,  $\dot{e}$  is the derivative of this error and  $\int_0^t e(\tau) \cdot d\tau$  is the integral of this error. Both derivative and integral part will be estimated numerically respectively using the Euler's method and the rectangles method. We have therefore :

$$\vec{u} = \frac{\overrightarrow{p_c - p_p}}{\|p_c - p_p\|} \quad e(t) = \frac{\|p_c - p_p\| - l}{\|p_c - p_p\|}$$

These two forces  $F_{t,p}$  and  $F_{t,n}$  can therefore be expressed using the expression of  $F_t$ , taking care to take the correct next and previous element for each case.

### III. IMPLEMENTATION

As for the implementation, it is available in the same GitHub repository and offers a simulator coded in Python3. The goal of this simulator is to study the viability of such a system, in particular to validate the performance of the tether with this behavioral model.

So we will create a class *TetherElement* which will represent a node. It will have to contain its mass, volume and distance information from its neighbors, but also its position, velocity and acceleration, as well as a pointer to each of its two neighbors.

This will allow us later on to implement a *Tether* class to be able to simulate a tether. This object must have a length, a number of elements and a list containing the different *TetherElement* that compose it. It must also know the mass,

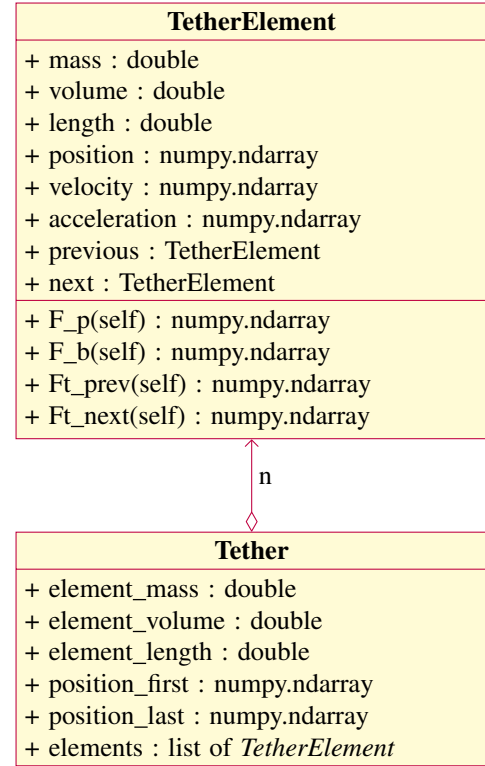


Fig. 2. UML diagram of the implementation

the volume of each node in order to correctly instantiate the *TetherElement*, but also the length of each link between nodes.

A diagram of these two classes is visible on the FIGURE 2. It respects the UML format and allows to see the different class variables and methods associated to each class.

### IV. CONCLUSION

The conclusion goes here.

### APPENDIX A

#### PROOF OF THE FIRST ZONKLAR EQUATION

Appendix one text goes here.

### APPENDIX B

Appendix two text goes here.

### ACKNOWLEDGMENT

The authors would like to thank...

### REFERENCES

- [1] H. Kopka and P. W. Daly, *A Guide to L<sup>A</sup>T<sub>E</sub>X*, 3rd ed. Harlow, England: Addison-Wesley, 1999.



**Michael Shell** Biography text here.

**John Doe** Biography text here.

**Jane Doe** Biography text here.