A VISUAL CONTROL SCHEME FOR AUV UNDERWATER PIPELINE TRACKING

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Aims and Motivations

- Inspection of submarine cables and pipelines is nowadays more and more carried out by Autonomous Underwater Vehicles (AUVs) because of their improvements and effectiveness both technological and methodological in the field.

- In this paper, we discuss the design of a visual control scheme aimed at solving a pipeline tracking control problem.

- The presented scheme consists of autonomously generating a reference path of an underwater pipeline deployed on the seabed from the images taken by a camera mounted on the AUV in order to allow the vehicle to move parallel to the longitudinal axis of the pipeline so as to inspect its status.

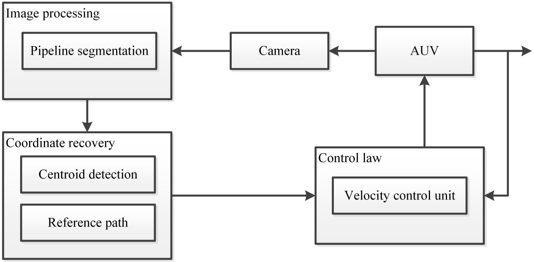
- Simulation study under robotic operating system and gazebo is presented

Introduction (1/2)

- Underwater pipelines are used as a means of transportation for oil, gas or other fluid in an underwater environment.
- The application of autonomous underwater vehicles (AUVs) has been found in both industry and research activities as sophisticated solutions for underwater pipeline inspection and tracking.
- The use of camera sensors and laser scanned LIDAR has allowed researchers to develop vision-based tracking systems.
- In this paper, a comprehensive approach is discussed to address a vision-based underwater pipeline tracking system for AUVs.

Introduction (2/2)

- The control law has been designed on the basis of a visual input taken from camera online integrated with reference path generator.



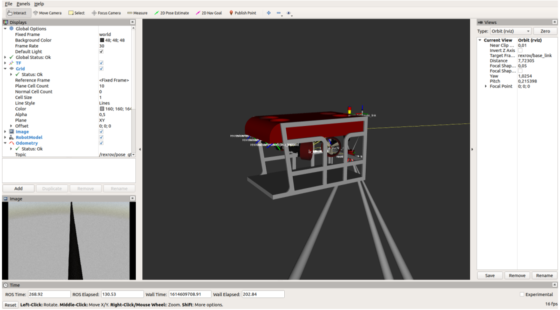
Simulation environment

- "Unmanned Underwater Vehicle Simulator" (UUV) simulator [1].
- The simulation environment consists of a seabed scene that comes along with the UUV simulator package, and an underwater vehicle used as a tracker.
- To simulate the underwater pipeline scenario, we have modified the seabed scene by adding a single pipeline using the blender tool.
- The simulation is performed on ROS melodic distribution installed on Ubuntu 18.04.4 LTS.

[1] Musa Morena Marcusso Manhaes, Sebastian A. Scherer, ˜ Martin Voss, Luiz Ricardo Douat, and Thomas Rauschenbach, "UUV simulator: A gazebo-based package for underwater intervention and multi-robot simulation," in OCEANS 2016 MTS/IEEE Monterey. sep 2016, IEEE.

Vehicle model

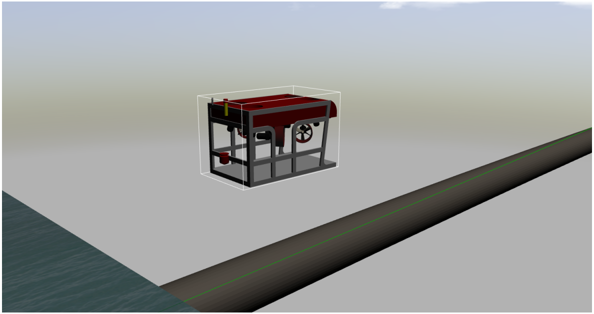
- The vehicle model consists of a mechanical base with a camera and additional sensing devices such as IMU (an inertial measurement unit) and LIDAR.
- The camera sensor is available with the vehicle model and installed at the bottom of the model that faces downward.
- The ROS camera easily generates image frames that have 640 pixels in width and 490 pixels in height.
- The “cv-bridge” plugin converts images from ROS to OpenCV and vice versa.



Initialization

Init:

Let us consider an underwater pipeline placed or suspended on the surface of the ocean floor. A rexrov vehicle model is spawned on the simulation world with default positions and the same for the pipeline.



Proposed scheme

The vision-based underwater pipeline tracking system is achieved by using an integrated three-module-based approach.

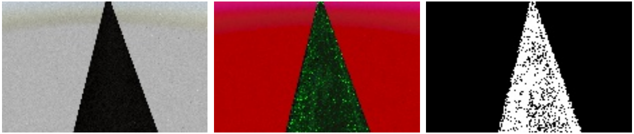
Image processing

Steps for pipe detection
Init:

1. lower and upper HSV of pipe in the image

For $t > 0$:

1. Import: image from ROS to OpenCV
2. Convert: image to HSV
3. Segment: the pipe pixels from the rest in the image
4. Save: segmented pipe information in the list



Coordinate recovery

Here the pipe object, that was previously segmented and masked in the image, is used as input for the “moment” method. The method returns the centroid cx and cy coordinates of the pipe in the image:

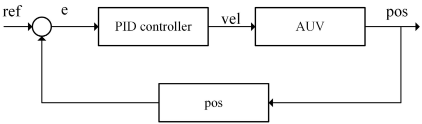
$$cx = \frac{1}{n}\sum_{1}^{n} x_i \quad , \quad cy = \frac{1}{n}\sum_{1}^{n} y_i \tag{1}$$

Next the target relative x and y positions with respect to vehicle are calculated:

$$\begin{aligned} x &= (cx - width/2) * sensitivity, \\ y &= (cy - height/2) * sensitivity \end{aligned} \tag{2}$$

Control law (1/2)

- A point-to-point reference path tracking control law is created by using the centroid information of the pipe in the image frame
- The basic idea here is that the vehicle should move in order to keep the pipe in the center position of the image frame.



$$vel(t) = k_p e(t) + k_i \int_0^t e(t)dt + k_d \frac{d}{dt} e(t) \quad (3)$$

Here, $k_p > 0, k_i > 0$ and $k_d > 0$ are the proportional, integral, and derivative gains respectively.

Control law (1/2)

- Next we discuss the robustness of the scheme to the image blur that causes noise in the estimation of the actual position of the pipeline in the image.
- This is done by adding a random error in the current vehicle position throughout the simulation.

$$cp(t) = cp(t) + N(t) \tag{4}$$

where *cp* shows the current position of the vehicle. Correspondingly, the updated error becomes

$$e(t) = tp(t) - cp(t) = tp(t) - cp(t) - N(t) \tag{5}$$

where $e(t)$ is the current error, *tp* target position, *cp* current position and N is the noise. The velocity command is updated as follows:

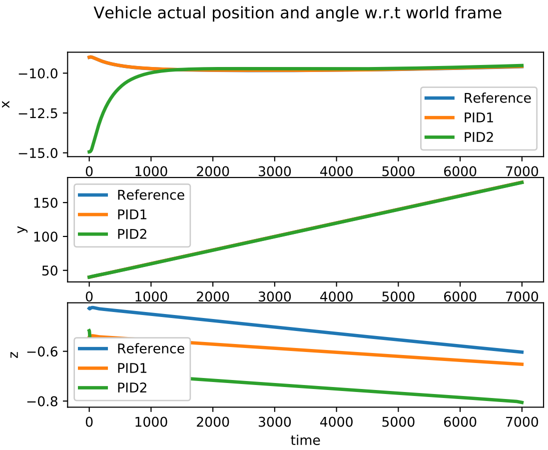
$$\begin{aligned} vel(t) = k_p e(t) + k_i \int_0^t e(t)dt + k_d \frac{d}{dt} e(t) + \\ k_p N + k_i \int_0^t N dt + k_d \frac{d}{dt} N \end{aligned} \tag{6}$$

Simulation setup

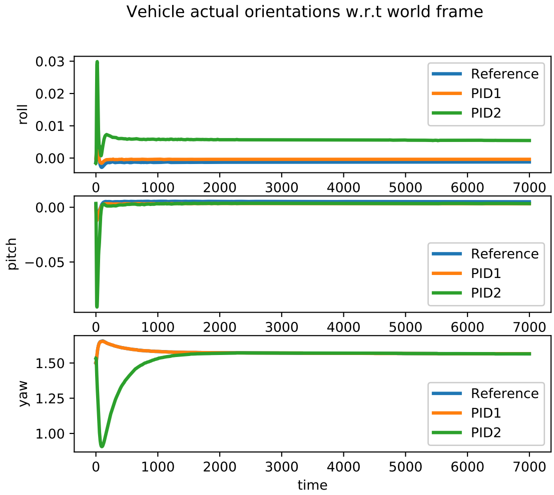
For simulation purposes, different case scenarios have been implemented as follows:

- No-disturbance: in this case, no external disturbances are considered and handled in the controller part. This scenario is used as baseline solution.
- PID1: in this case, $kp = 0.5$, $ki = 0.05$, and $kd = 0.1$ are set along with the external disturbance 0.1
- PID2: in this case, $kp = 0.1$, $ki = 0.05$, and $kd = 0.01$ are set along with the external disturbance 0.1

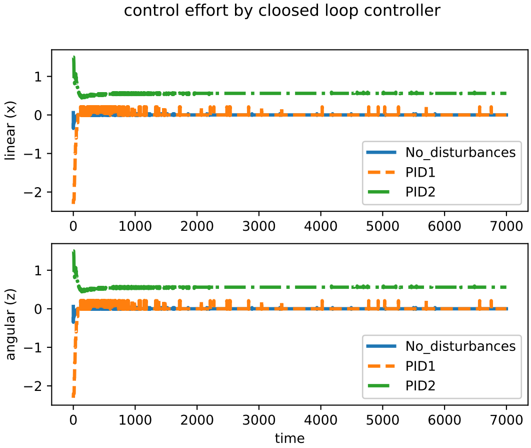
Vehicle positions



Vehicle orientations



Control efforts



Conclusions

- The visual-based control law for underwater pipeline tracking through simulation is considered in this work.
- A testing platform ROS and gazebo simulator is used.
- A UUV simulator is adopted and modified to perform the tracking of the underwater pipeline.
- The proposed solution consists of three modules: image processing, coordinate recovery and PID control law.
- The performance of the tracking system is shown by adding and handling the external disturbance in the controller part.
- Future works foresees the implementation of this class of control allocation strategies on real marine vehicles.

THANK YOU !