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APPROACHES TO IMPLEMENTATION OF THE 3D LASER SCANNING TO ENSURE THE SEARCH AND DOCKING OF AUTONOMOUS UNDERWATER ROBOTS WITH A WALKING BASE

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Abstract

Underwater operations, such as docking with the base module to get/adjust the instructions, as well as recharging the onboard power batteries, are increasingly being robotized in order to solve safety problems and reduce costs. Robotic systems typically rely on vision sensors to perform fundamental tasks such as navigation and object recognition. In particular, active optical 3D scanners are implemented to solve a number of specific tasks related to obtaining images underwater. However, their capabilities are limited by a range of several meters. The paper considers an approach, that allows increasing of an operational range for the seabed walking robot. The above, in turn, acts as the base for the autonomous floating robots, carrying sensor devices.

Keywords: intelligent 3D-sensing laser system; underwater walking robot with docking autonomous satellites.

1. Introduction, Problem statement

When using underwater vehicles, a significant part of the time is spent on the operations of lifting and lowering them to recharge and remove information. The paper considers a technology involving the use of an underwater walking base equipped with a docking station for receiving and servicing several smaller underwater robotic satellites carrying a sensor suspension. In such a scheme, an essential task is to automate the search by satellites for a docking station from sufficiently significant distances of about 50 meters.This significantly extends the operational time in such a robotic complex. An autonomous underwater vehicle should automatically (without communication with the main carrier) recognize a docking node having a pre-known geometric 3D shape with a dimensions of 1-2m. The shape for recognition is made of pipes (round or rectangular in cross-section, well reflecting both light and acoustic radiation. It is advisable to visualize and recognize this object from a distance of 20-30 meters and at about the same depth in possibly turbid water in automatic mode based on the received image and, in the future, to dock to it also automatically. It is highly desirable that the docking node remains in passive mode and does not emit anything continuously or in response to a request. The mooring process is controlled, respectively, by the same vehicle in automatic mode. The range of action of the sonar forming the image along the beam is 30-8 m. At a closer distance <8 m, it is planned to use optical means, on which we will focus below (Fig.1)

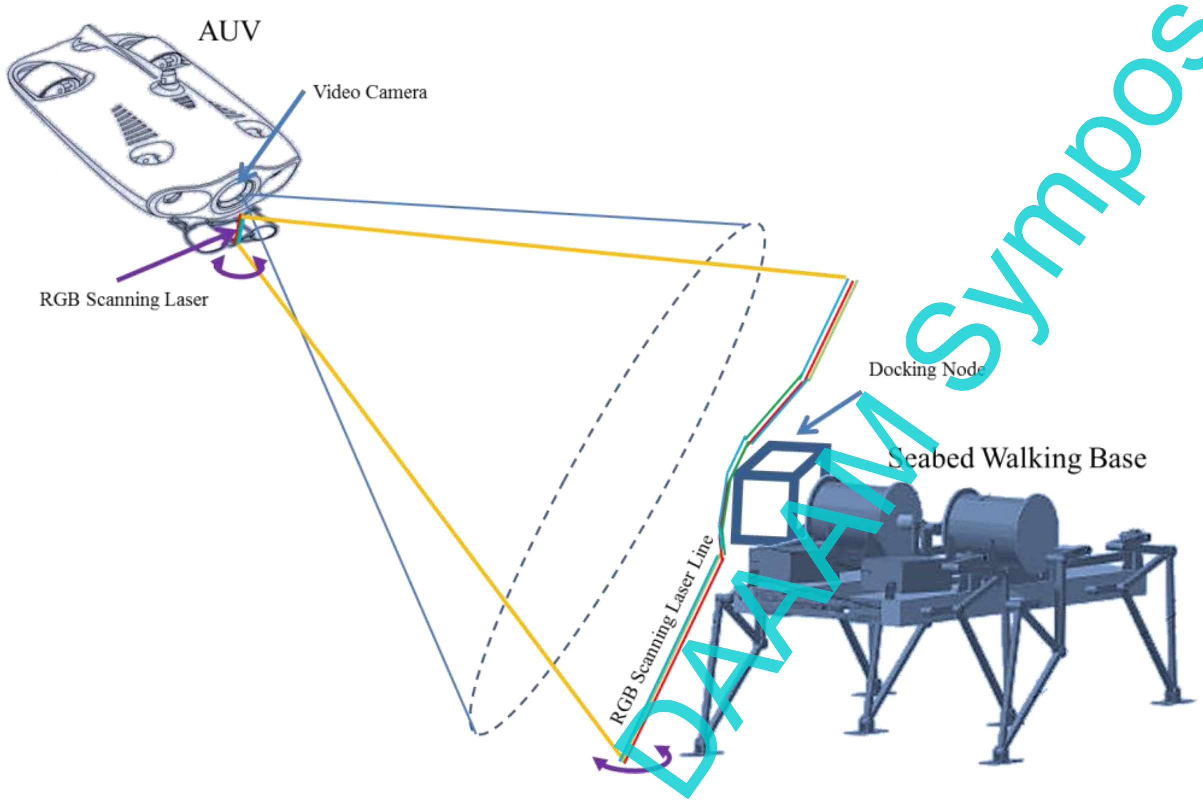

Fig. 1. AUV Docking by means of 3D RGB Underwater Laser Scanner

Optical 3D sensors – State of the Art

Optical 3D sensors can be categorized as active or passive. Active optical 3D scanners are more commonly used due to the domain-specific challenges of underwater imaging. An underwater sensor is said to use active (or structured) light when it projects light patterns onto the scene in a controlled way. These patterns can be a point, a line or more complex shapes. In active techniques, the information given by the structure of the pattern is key to reconstruct the scene in 3D. Active techniques determine the 3D position of the points in the environment either by time of flight ToF or by triangulation principles [1]. Passive lighting relies solely in ambient light to illuminate the scene, although artificial diffuse light may be used in dark environments. Passive techniques in underwater environments typically use stereo vision or structure from motion (SfM). Active light triangulation sensors find the 3D position of a point in the scene by combining geometrical information from the light emitter and the receiver. This way, the position in space of the scanned point coincides with the intersection of two light rays: the one sent by the projector and the one going from the camera focal point through the illuminated pixel. The main difference in performance between ToF and triangulation sensors concerns the scan range and depth resolution. The depth resolution of a ToF scanner depends on the resolution of the time or phase measurement but not on the scan distance, unlike for triangulation scanners.

Classification of 3D scanning techniques

The search for a solution led us to the most priority methods, which are:

- Active techniques that do not perform beam steering are of most priority: LLS - laser line scanner & DOE - diffractive optical element;
- Laser steering technologies are classified according to whether they involve mechanical elements or not;
- Scanning technologies can also be classified in raster and random-access scanning. Raster scanners (such as polygon mirrors or MEMS in resonant mode) need to steer the flying spot or line through the entire FoV (Field of View) before they can start to scan again.
- Random-access scanners can dynamically modify the scanned Field of View (FoV) in order to increase spatial resolution or decrease acquisition time, which makes them more flexible.
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Searching for an approachable to implement Active Light Projection technologies

Active optical 3D scanners project light in a known direction and/or at a known instant in time, which gives essential information for the 3D scene reconstruction. Their main advantage in underwater applications is that they help provide a more homogeneous, denser point cloud, less dependent on the scene's texture than passive methods such as stereo vision. Scanning technologies can also be classified in raster and random-access scanning. Raster scanners (such as polygon mirrors or MEMS in resonant mode) need to steer the flying spot or line through the entire FoV before they can start to scan again. Random-access scanners can dynamically modify the scanned FoV in order to increase spatial resolution or decrease acquisition time, which makes them more flexible. Usually, the main performance criteria of laser scanners are scanning speed, FoV, resolution, and accuracy. Let's consider the two light projection techniques that do not use any type of beam-steering mechanism.

1. The whole scene can be illuminated at once using a homogeneizer diffractive optical element (DOE) (see Figure). This technique needs a 2D ToF sensor [4] in order to resolve the 3D position of the scanned scene [1]. This is considered an active method because, even though the light direction is not actively controlled, its time structure provides information for the 3D reconstruction.

2. A variation of no beam steering could be a special diffractive optical element (DOE) to project a pattern of lines and resolve their 3D position by triangulation. Acquiring the whole scene at once has the advantage of being robust against the high dynamics of the scanned scene and against the sensor movement. However, it usually comes at the cost of reducing lateral resolution [2], [3].

3. A fixed laser line scanner (also called profiler) can be used. This setup usually consists of a laser line module and a camera. The relative position of the projected laser plane with respect to the camera is always the same. Even though the laser light is not swept across the scene, it is considered an active technique because the plane equation of the light is essential to reconstruct the 3D points. This 3D reconstruction is usually done by triangulation. This configuration makes these scanners simpler to build and calibrate, but they always need to be attached to a moving platform, usually either an UUV or a rotating tripod. Therefore, the accuracy of the final reconstruction depends greatly on the accuracy of the pose of the platform.

4. Mechanical beam steering is achieved by moving an object, usually a mirror, in a controlled way. A laser beam can also be steered by moving the whole sensor. However, the smaller the inertia of the moving part, the faster the scanning can take place. Also, if the moving element is surrounded by air, the friction forces are smaller than in water. Hence, the moving part of an underwater scanner is usually placed inside a sealed housing. In all mirror systems, the reflection angle is twice the mirror tilting angle. Consequently, mechanical scanners can achieve high deflection angles more easily. Moreover, mechanical systems are usually suitable for a wider range of laser wavelengths and since the mirror's surface generally has very broadband reflectance.

Search conclusion

From the point of quick prototyping and testing implementation, operability and efficiency, we came to the conclusion: mechanical laser scanners provide higher angular resolution and maximum deflection angle, while non-mechanical devices provide much higher speeds.

Experimental Setup for LLS - laser line scanner

Our experimental RGB laser module produces a bright white spot, which is then going through the diffraction laser line lens. The above converts the laser spot to a laser line polarization. Laser line lens is mounted inside the hollow shaft of the rotating gear motor, angular speed of the rotation is controlled remotely. Resulting laser line is directed to the round mirror attached to the shaft of the servomotor, controlled from the Arduino-UNO microprocessor Underwater video camera, mounted rigid at the same meridian as the mirror, is capturing the distortion of the scanning laser line reflection (or scattering) and the software (being developed) for reconstruction of the 3D image of the scanned object using triangulation algorithm. Depending on the water turbidity, few tests of laser line reflection are automatically conducted before the final scan. Test includes variation of laser color and intensity and angular speed of the scanning mirror (Fig.2).

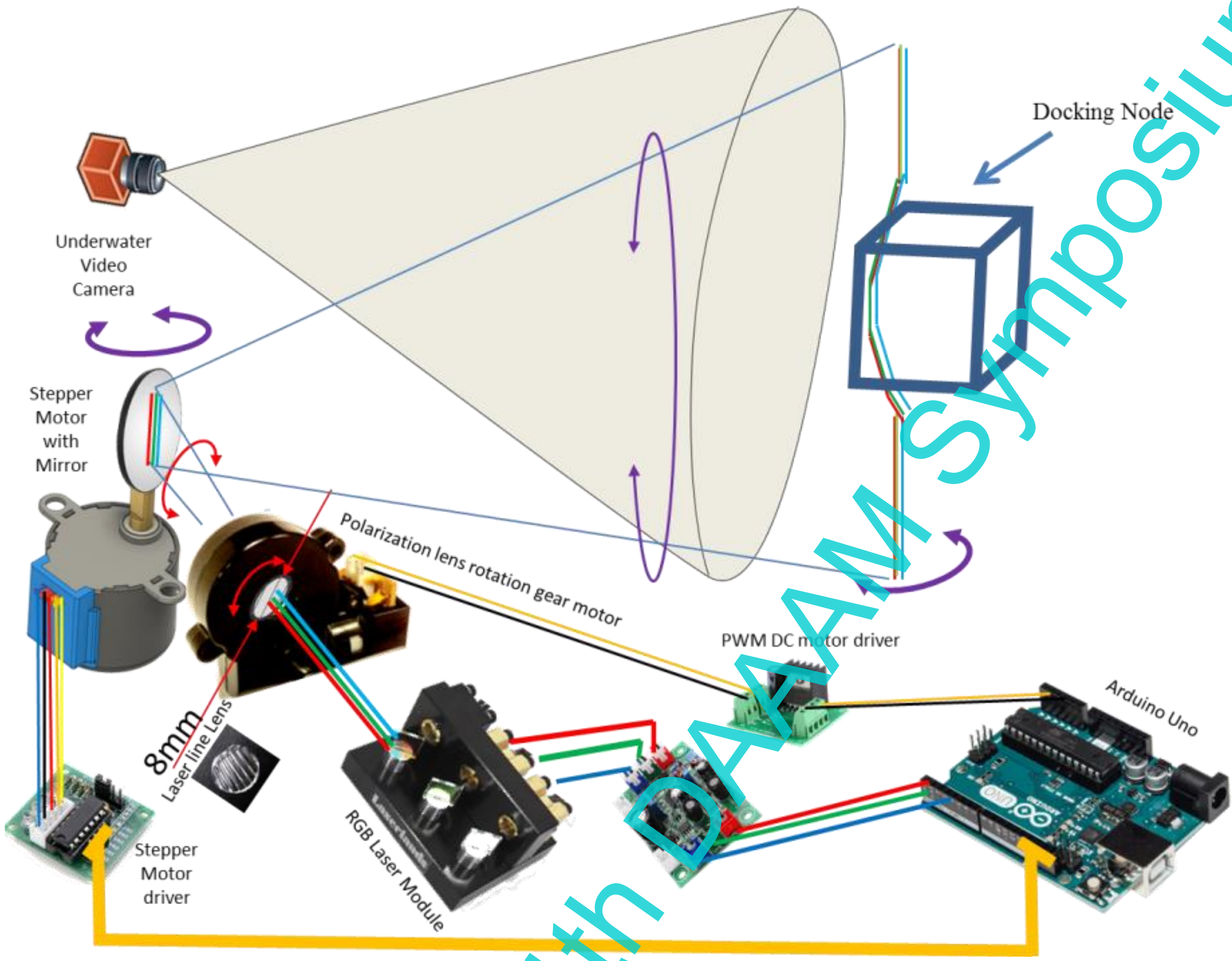

Fig. 2. Experimental Setup for LLS - laser line scanner

Conclusion

The already carried out experiments confirmed the feasibility of this approach for solving the problems of docking a small underwater vehicle with a base station, while the need for matching the polling frequencies of the sensors of the control cycle by extrapolating and interpolating sensor readings to ensure real time and minimize calculations using microprocessors was noted. The solutions also rely on our earlier developments [4], [5], [6], [7]. An effective solution has been found for the problem of finding a satellite docking station in the developed robotic complex, which allows significantly expanding the operational capabilities of the system. In the future, it is planned to switch from an experimental installation to the implementation of the system directly on a walking machine with the appropriate software refinement. The study was partially funded by the grant from the Russian Science Foundation № 22-29-01589

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