Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-23 (2016) 097–102

Teleoperated trajectory tracking of remotely operated vehicles using spatial auditory interface

A. Vasilijevic * **Z. Vukic** * **N. Miskovic** *

* *University of Zagreb Faculty of Electrical Engineering and Computing, Unska 3, 10000 Zagreb, Croatia (e-mail: antonio.vasilijevic@fer.hr, zoran.vukic@fer.hr, nikola.miskovic@fer.hr).*

Abstract: The majority of Human-Machine-Interfaces (HMIs) designed for teleoperation of Unmanned Vehicles (UVs) present information only visually. Frequent overloading of operator's visual channel may cause unwanted mishaps. In order to reduce such mishaps and improve overall operating performance, this paper proposes the extension of the HMI by hearing modality in the form of spatial auditory display for trajectory tracking, the most complex guidance task. The main novelty of the interface is introduction of guidance laws to generate the reference presented to the operator as a spatial auditory image of the virtual target to be followed. Guidance laws for teleoperated trajectory tracking are based on modified "lookahead distance" strategy, known from path following applications. The paper also analyzes the stability of the kinematic controller based on this new guidance control law. The experiments show that the novel guidance strategy provides comprehensible and effective reference providing excellent trajectory tracking performance.

Keywords: Robotics, Teleoperation, Human-machine interface, Auditory interface, Guidance systems, Control laws, Trajectory tracking

1. INTRODUCTION

Remotely Operated vehicles (ROVs) are robotic vehicles without a human operator aboard. They are remotely operated, controlled or guided by a person, via user interface. The user interface is connected through a cable to an ROV.

In order to accomplish different tasks, ROVs are equipped with variety of payloads making the ROV control room stuffed with screens presenting everything from navigation data and multiple video streaming to data acquired by various sensors and sonars. All these information is almost exclusively presented in visual form. The operator, often in situation to perform multiple tasks simultaneously, handles enormous quantity of information, dispersed on different screens and, as a result, his visual channel may get easily overloaded, preventing him from perceiving all important information related to the particular task. Although these unique operator-related issues, often resulting in failed missions or even mishaps, represent a significant problem in ROV operations, a little effort was put on their research (Ho et al. (2011)).

Humans prefer to receive spatial information visually because the spatial acuity of the visual channel is much better than that of the auditory channel (Shinn-Cunningham (1998)). However, in the extreme situations when visual channel is saturated, the introduction of a display using one of unused human senses may result in both unloading of the visual channel as well as gaining additional advantages specific to that human sense (Menelas et al. (2010)). Analysing alternative display modalities, audition is imposed as an obvious choice. Humans naturally use auditory modality for development and maintenance of situational awareness in their environment. Following the growing interest in research on spatial auditory displays (Wenzel et al. (2012)) the paper proposes the introduction of a novel auditory navigation interface.

Throughout the section 2 the motivation behind the research is revealed and the present state of knowledge. Basic formulation of the guidance problem and its solution and auditory interface with enhanced angular and distance perception are elaborated in Section 3. Description of experiments and corresponding results are provided and discussed in Section 4. Finally, a short conclusion summarizes the work presented in the paper.

2. MOTIVATION AND RELATED WORK

Teleoperation represents operation of the robot at a distance. It is human-in-the-loop system that consists of operator, i.e. controller, robot, i.e. process and the HMI presenting the data relevant for teleoperation. Typically, only visual interface has been used as HMIs, with the exception of several scientific studies. Fig. 1 illustrates GUI commonly used for ROV teleoperation, presenting the vehicle and the reference path.

Everybody knows that hearing and vision are not very much alike and it is obvious that path and trajectory

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.10.327

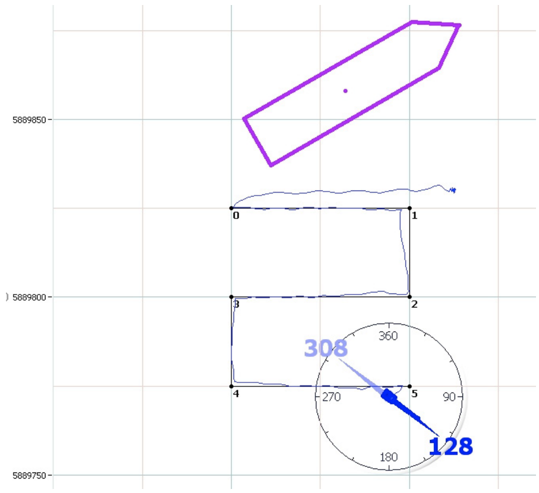

Fig. 1. Visual display presenting mission layout, support vessel and ROV position, attitude and realised path.

cannot be presented auditory in the form seen on the visual interface. This raises the first question - how to convey audio data to the operator for efficient teleoperation of an ROV?

All contemporary applications of auditory display presenting non-speech localisation cues for navigation through the space, rely on go-to-waypoint approach. This approach does not ensure real path following or trajectory tracking between the waypoints. There are also significant differences in the way spatial information is encoded in the presented acoustic signal e.g. in Walker and Lindsay (2006) or Schillebeeckx et al. (2010). For teleoperation of an ROV, the voice navigation system has been described in Omerdic et al. (2013). To our knowledge, no non-verbal auditory interface and no research in trajectory tracking using auditory interface has been reported, apart from our previous work (Vasilijevic et al. (2012); Vasilijevic et al. (2014)).

Our motivation comes from the fact that humans use hearing for orientation or guidance in our natural environment. We first detect and spatially locate the source of sound or target and then decide how to proceed. Examples of our innate responding behaviours, determined by the real life situations, are go-to target, follow the target or run away from the target. Selected behaviour generates our internal guidance laws, composed of speed and steering laws. Combining them in different ways, different motion objectives can be achieved. Example of behaviour relevant for our application is follow-the-target. Naturally, we turn towards the target, i.e. set azimuth angle relative to target to zero which is our steering law and adjust the speed to maintain fixed, arbitrary distance from the leading target which is our speed law. When creating the auditory system for human-in-the-loop guidance, these are the facts we have to have in mind and adjust our system to this prerequisites. Consequently, the interface, i.e. auditory display, presenting the spatial virtual target to the operator who was previously advised for instance to follow the target, does not require any further instruction, training or adaptation.

3. GUIDANCE SYSTEM

Trajectory tracking refers to the problem of making a ROV track a trajectory, i.e. a time-constrained reference curve in space (Pascoal et al. (2006)). In the other words, the vehicle has to be at specified spatial coordinates at specified instants of time. Therefore, the trajectory tracking requires control of both the orientation, direction of the velocity vector, and the speed, the size of the vehicle velocity vector. Consequently, reference generated by the guidance system consist of surge speed and yaw rate reference.

Fig. 2 illustrates the building blocks of the Audio Guidance System (AGS), proposed teleoperation system. The AGS includes trajectory generation, kinematic controller, reference re-mapping, auditory display and kinetic/dynamic control level which is always handled by the human operator in teleoperation.

3.1 Guidance laws

Generating the guidance reference using the virtual target is well know approach in robotic community. The theory and principals are used in variety of different marine applications (Lapierre et al. (2003); Bibuli et al. (2012))Taking into account the way humans navigate natural environments using hearing the virtual target guidance approach is logically imposed. For trajectory tracking application we have modified Lookahead-Based Steering which is the virtual target method for path following (Breivik and Fossen (2009)) that defines virtual target as a point vehicle should be heading to. The position of the target directly impose steering law as the point we should be heading to and surge law as the fixed distance from the target to be maintained. Presenting the spatial virtual target to the operator, we feed an operator with the surge and yaw rate reference. Position of the virtual target, i.e. our guide, is generated by the guidance laws. The controler/operator acts based on perceived reference and it's own "controller parameters". In Vasilijevic et al. (2012) it was shown that distance $d_r = 10$ meters provides optimal path following performance using auditory display and logically the same distance was used here for trajectory tracking.

The reference frames usually employed in order to describe marine vehicles motion are North-East-Down frame (NED), represented with the subscript N and Body frame fixed to the real or virtual vehicle of interest, represented with the subscripts F and W in the following figures. For our application, planar remote guidance of an ROV, it is sufficient to consider 3 DOF (Degree Of Freedom) and we will be using SNAME notation (SNAME (1950)). In order to apply virtual target approach the first step is definition of control objective for trajectory tracking:

$$\lim_{t\to\infty}(p(t) - p_D(t)) = \lim_{t\to\infty}(\varepsilon(t)) = 0 \quad (1)$$

where $p(t) = [x(t), y(t)]^T \in \mathbb{R}^2$ represents actual ROV position and origin of the $\{W\}$ frame, $p_D(t)$ desired ROV position and origin of the Serret-Frenet frame $\{F\}$ and $\varepsilon(t)$ tracking error as represented in Fig. 3. Tracking error is Euclid distance between actual and desired position and consists of the along-track error $s(t)$ and the cross-track error $e(t)$.