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ScienceDirect

IFAC-PapersOnLine 48-2 (2015) 288–293

Wireless Image Compression and Transmission for Underwater Robotic Applications ⋆

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Abstract: Nowadays, there is an increasing demand for underwater robotic intervention systems around the world in several application domains. Examples of applications include search and recovery (i.e. aviation or naval accidents), archaeology, offshore industry, environment protection and monitoring, etc. The commercially available systems are expensive and far from what it is demanded in many aspects, justifying the need of more autonomous, cheap and easy-to-use solutions for underwater intervention missions. Most of them consist of remote operated vehicles, relying on an umbilical cable for its remote operation. This umbilical provides high bandwidth and reliable communications between the vehicle and the operator, but also presents some drawbacks: high cost, movement and depth constraints, lack of autonomy, etc. The current trend is to advance towards less expensive and more autonomous systems, where the umbilical is not present, and the transmission of wireless information is necessary. This work analyses the use of an underwater RF link to provide affordable communications. Moreover, different data compression techniques that can be used to optimize underwater wireless communications are analysed. Image transmission performance results in pool conditions are presented and discussed.

Keywords: Wireless Communications, RF signal, Image Compression, Image Transmission, Underwater Robotics Intervention, Autonomy.

1. INTRODUCTION

Robotic applications, and particularly Autonomous Underwater Vehicles for Intervention (I-AUV) use to focus on image input to control the system in real-time and then, they send the information to the operator (see Fig. 1), which can normally interact with the system and adjust the task execution in a supervised manner (Sanz et al., 2010). This kind of control has been experimented in the FP7 TRIDENT project, to perform autonomous visually guided grasping in the sea (Prats et al., 2013; Sanz et al., 2013). Other related projects use the vision as the main input for underwater interventions, such as ALIVE (Evans et al., 2003), SAUVIM (Marani et al., 2009), and PANDORA (FP7-PANDORA, 2014). Moreover, within the TRITON project [1], the underwater vehicle performs a station docking to an underwater panel where the manipulator has to perform an intervention on a valve and a connector. The arm performs the action in three steps: first of all, it generates a 3D view of the panel by using a stereo camera and a laser, using the PCL library (Rusu and Cousins, 2011); then, using the data from the Point Cloud, a Grasping Determination algorithm calculates the stable grasps; and finally, the grasp execution is performed, always having the possibility for the operator to provide more information to the system such as alternative grasps.

Besides this, communications is a crucial subsystem in any robotic application, specially the ones that permit the user to interact remotely with the system. Because of that, image compression and transmission is necessary in order to send the required information at the lowest time-delay and without compromising the network and the whole system.

Although recent studies demonstrate that, using the most efficient modulation methods, it is possible to transmit video through an underwater channel using acoustic signals (Pelekanakis et al., 2003; Ribas et al., 2010) and *Blue Light* (Farr et al., 2010), both acoustic and optic signals are not capable to pass through solid objects that could be in the line of sight of the wireless transceivers. Moreover, the performance of these methods depends too heavily on the characteristics of the underwater scenario and the type of the channel. On the one hand, acoustic systems are very affected due to multi-path if the link is horizontal, and also by the acoustic noise originated by the human activity or the noise of the sea waves, animals, etc. The acoustic noise constrains the range of typical frequencies used in acoustic systems between the 8 and 155 KHz (Stojanovic and Preisig, 2009), which makes very difficult to achieve high data rates. On the other hand, the communication methods based on the visible light only works fine on very

⋆ This work was partly supported by Spanish Ministry of Research and Innovation DPI2011-27977-C03 (TRITON Project) and by Foundation Caixa Castelló-Bancaixa, Universitat Jaume I grants PI.1B2011-17 and PID2010-12.

[1] Web page: `http://www.irs.uji.es/triton`

10.1016/j.ifacol.2015.06.047

clear waters, are very affected by scattering, suffer attenuation by absorption and usually need accurate alignment.

Nevertheless, RF based solutions are not as affected by the typical problems of acoustic and optical methods, and are much cheaper. Moreover, RF signals can propagate easier from a medium to another, allowing the establishment of a communication link to an underwater transducer from the surface. The first problem of the RF is the high attenuation that it suffers when the waves go through the water. However, different studies (Zhang and Meng, 2012; Siegel and King, 1973; Shaw et al., 2006; Shen et al., 1976; Guarnizo Mendez et al., 2011) indicate that, with the necessary antennas, at lower frequencies and using the best modulation methods, it is possible to set up a communication link up to several tens of meters through the water. The application of the most advanced progressive image compression algorithms, as the ones presented in this document, would allow image transmission rates of several frames per second, at the typical latency of the radiofrequency communications. This proposal would overcome the communications challenge in most common underwater robotic interventions.

In this article, several progressive image compression techniques are introduced, and the way they can be applied to the field of supervised autonomous underwater vehicles for intervention is analysed. At the moment of writing, a compression image server is already implemented and the researchers are working to adapt it to the robot platform.

2. COMMUNICATIONS FOR SUPERVISED AUTONOMOUS UNDERWATER VEHICLES

Autonomous underwater vehicles can be connected to the user in different ways: wirelessly, using radio frequency (i.e. 433/866MHz) or acoustic signals, and through an umbilical (i.e. over an optical fiber Ethernet connection). In fact, depending on the real scenario, an Ethernet connection should be considered at a first glance. For cooperative applications, where more than one robot must be included, the user will need to interact with the system at lower rates, due to the limited bandwidth provided by wireless channels, such as radio frequency (only few meters) and sonar (low bandwidth).

It is important to consider the transmission of real images from the vehicle to the user, as they provide more information to the operator in order to adjust the autonomous behaviors or abort the operation in case of risk. Of course, the sonar solution will need to send only very few relevant data of the intervention scenario, such as grasping points. For example, if the system provides a laser scanner for calculating the point cloud of the environment, depending on the available bandwidth, the transmission of the images will be avoided, sending just the representative data of the point cloud.

3. IMAGE COMPRESSION TECHNIQUES

The objective of image compression is to reduce its entropy in order to store or transmit it in a more efficient manner. We can also clearly distinguish between lossless and lossy compression. In lossless compression, the decompressed image will be exactly the same as the original image while, in lossy compression, the decompressed image will be an approximation of the original image.

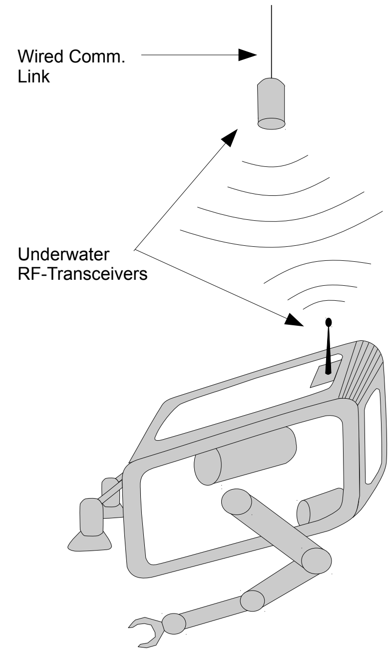

Fig. 1. Use-case application: Supervised Intervention Autonomous Underwater Vehicle

Digital images usually have 3 color components, which means that what we perceive as one color image is (without loss of generality), in fact, composed of a luminance channel (black and white version of the color image) and 2 color difference channels (which can usually be subsampled without much loss –see HVS below).

Progressive image compression is such that it is trivial and very inexpensive in terms of processing power (there is no need to decompress and recompress the image) to supply an image which is either resolution or quality progressive, meaning that the image data can be truncated at any point and we would still get a lower resolution or quality version of the original image (in this sense, lossless streams can become lossy by simple truncation). In the case of color images, we could also prepare the image in such a way that a monochrome version of it could be obtained with the same progressive characteristics as before.

As opposed to video compression, image compression does not address the compression of the high temporal correlation between adjacent frames in a video sequence, i.e., in the context of a video sequence, image compression is also known as intra-frame or key-frame compression. In fact, the reason why video compression actually compresses so well is that the highest gains come from an adequate compression of the temporal information using preceding and/or succeeding frames to actually predict the current frame and code the error between the current and the predicted frames. This prediction is usually done with the help of motion estimation and compensation and is usually quite a computationally-intensive task (most video compressors are highly asymmetric, where the compressor is usually slower than the decompressor). The resulting compressed frames are called inter-frames or delta-frames.