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High power leds in localization of underwater robotics swarms

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Abstract: In this paper we propose the use of a cheap power led system to support acoustic devices in the localization and formation control tasks for an underwater robotics swarm. The system is based on light signal exchanged between the machines and uses power led of different wavelength to calculate distances between them. The unknown water conditions, affecting the light propagation, ask for special strategies to make the approach robust enough to be a reliable data source. Local measurements of absorption coefficients are used to measure distances between the machines for cooperative localization; power and flash time of the leds are stressed to vary emission conditions. The system is patent pending.

Keywords: Autonomous vehicle, Underwater systems, localization strategies.

1. INTRODUCTION

ENEA is working in robotics since a long time; in particular underwater robotics is a key topic of our laboratory. It is many years we have moved our studies from a single autonomous underwater vehicle (AUV) to a swarm of very low cost cooperating robots. One of the most important tasks for an underwater vehicle is its localization into the sea; a swarm has the supplementary task to build its configuration, which means to be aware of the relative position of the robots that are part of group. Talking about the geometric arrangement of robots in space, at least one element of the swarm must have an absolute localization to get an the whole swarm localization. , A typical example is the manoeuvre to comes out on the surface and fix its position by GPS. This is normal for single AUV so as for members of a swarm. In the case of the Swarm the knowledge of the configuration is a very important issue for many applications often depending by the the assigned task that can also vary during the mission. One of the reasons to do that, is relevant to the capability to have the most efficient perception (vision, acoustical data, magnetic measurements) of the surrounding environment, but there are also needs connected to the optimization of internal and external communication network. This is accomplished in a the first release of underwater network using the time-of-flight of a dedicated modem to achieve the distance among the first neighbours. Unfortunately it is well known as reflections, fading and other phenomena make difficult and sometimes not reliable measurements involving acoustic devices. The need to continuously exchange data among the nodes to get the distances and it represents a considerable burden for the network operation to calculate the network configuration, also using suitable algorithms (Anon s.d.), because it force to frequent short messages that strongly

deoptimize the exploitation of the communication channel, mainly for the long times needed to switch from a message to another one. A possible solution, which improves both the time allocation in the acoustical protocols and unloads the acoustical channel burden, is to couple the acoustic protocol with optical device, with the intention to collect distance measurements between the robots more precise, using sensor data fusion.

It must be outlined that only dense swarms can take advantage of such an approach because only in these situations, with internal distances ranging from few meters to a maximum of 20 meters, there are the conditions suitable to use light signals for sync and measurements. Also, backup solutions based on the “all acoustical” approach, must remain available because it is always possible to meet dirty waters with no practical possibility to use light signals.

In this paper we present preliminaries results we have performed using commercial cheap led diodes. The aim of our currently work is the build up of the swarm configuration (Dell'Erba 2012), (Moriconi & dell' Erba 2012), (dell' Erba & Moriconi 2012) using all the signals the swarm exchanges among its elements. The recent results confirm as, in clear or medium transparency waters, a system based on power led diodes with a suitable optical can be a valid support to an acoustic traditional system.

2. SHORT REVIEW OF UNDERWATER ROBOTICS

The use of underwater autonomous vessels or rovers has been proven to be a powerful tool in many underwater tasks for monitoring, exploration, search and rescue and many other

applications, but it is considerably expensive, mainly because it asks for the support of an equipped ship. Many problems are still to be solved to make AUV competitive with rovers, especially for the issues relevant to power availability, information processing, navigation, and control (Leonard et al. 1998), (Anderson & Crowell 2005), (Joordens 2008)

An improvement of the AUV technique can be achieved by the use of a large number of very low cost mini AUV, (Kopman et al. 2012). In fact a swarm is able to perform tasks in a more fast and robust way with respect of a single machine; but the most important point is perhaps that a swarm, owing to its capability to span from the surface to the basement, allows to ensure a quasi-real time communication and therefore to interact with the underwater system also using a remote console that can be located also on the coast. This could limit the use of the expensive surface ships to the deployment phase, taking advantage of the parallel exploration to shorten times and have many other advantages (Anderson & Crowell 2005), (Shah s.d.).

Other advantages of the swarm approach is in the speed-up coming by the parallelism and in the increase of reliability by redundancy (Xian-yi et al. 2006), provided that the lack of one member can be easily managed by redistributing the job among the others like, in natural systems, for the bees (Karaboga 2005). Last, but not least, a swarm can interact with a human operator as a single object, without the problem of controlling a large number of individuals.

The concept of robot swarms is a study theme by the scientific community since several years. The realization of swarms of different numbers of cooperating robots has been successfully attempted, but in underwater environment it is still a challenge (Bachrach et al. 2010), (Liu Bo s.d.), (Chiesa et al. 2012).

2.1 Our prototype

In Fig. 1 and 2 the prototype, named Venus, realized in our laboratory, is showed. Its characteristics are the following: Max depth 100m; Max speed 4 Km/hr; Weight about 20 Kg; Autonomy 3hrs; Dimensions are 1.20mX0.20m diameter.

Standard sensors include a stereoscopic camera, sonar, accelerometer, compass, depth meter, hydrophones side-scan sonar.

We are dealing with a system thought as to be a component of a swarm of about 20 objects. The distances between robots are between 3 and 50 m. Therefore, the maximum distance possible between two robots is about 1000 m, as a very particular alignment case; the average value of the distances was considered about 10 m.

In underwater world a severe limitation to our communications technology is, perhaps, the main drawback: the physical medium only permits acoustical channels, since electromagnetic waves are rapidly damped (Mark Rhodes 2004). The acoustical technology has limited performances; the band pass increase with the frequency but the signal is more rapidly damped, limiting useful range, (Dunbabin et al. s.d.). Technology of dense swarms is an answer to these problems with larger acoustical bands and allowing other

physical channels to be exploited. This paper explores the opportunities offered by simple and economical optical sources to perform swarm localization.

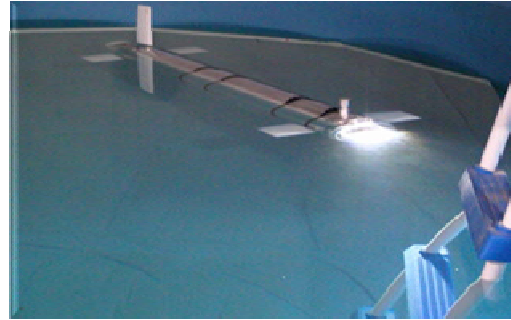


Figure 1 Robot prototype during test in pool.

3. LOCALIZATION

Localization and possibly mapping is the key of a successful navigation in autonomous mobile platform technology and are fundamental tasks in order to achieve high levels of autonomy in robot navigation and robustness in vehicle positioning and values of the data (Leonard & Shaw 1997). Robot localization and mapping is commonly related to cartography, combining science, technique and computation to build a trajectory map that can be used to correlate spatial information with the data collection. Therefore an autonomous robot should be able to construct (and/or use) a map and to localize itself in it. The localization makes sense not only for the localization of the robot itself but also to reach mission objectives. An example cooperative localization can be realized, if the swarm recognizes a landmark putting together different pictures taken by different robot (Bahr & Leonard s.d.), (Dunbabin et al. s.d.).

So far our aim is to know the distance between the robots by acoustic or optical devices. In Cartesian way if we know the distances between the robots we could calculate their geometry. We are dealing with something of similar to a trilateration problem but, in our case, we do not know the position of the beacons and this render the problem very hard.

In a previous work we got the configuration also in case of lack of data (Anon s.d.); the calculation was based on trilateration between three or more robots in different steps of motion. The minimum data used in the calculation was the orientation of the robots and the distance between the robots.

We have showed as configuration can be obtained using the following elements transmitted in a communications: 1) ID of the vessel; 2) Time; 3) orientation 4) neighbours information that has the mean of the same three data for its neighbours. From the time of fly, of the acoustic signals, we obtain the relative distance between the robots. At this point we face a trilateration problem but, differently from the standard problem, we do not know the position of the beacons so it is very difficult. From algebraic point of view this problem is classified as a Non Polynomial Hard problem. It has some

similarities with the problem to determine the conformation of the proteins starting from the molecular distances obtained by NMR experiments (Davis et al. 2010), (Moré & Wu 1999); but in our case we are sensitive to some symmetry conditions that make more difficult the calculation. In fact starting from the distances between the robots we obtain many possible solutions, owing to the high degree of the non linear equations system. We have built a simulator (by the Mathematica software of Wolfram Research) able to manage this task, by constrained multivariate optimization process.

4. OPTICAL APPROACH

Optical methods are very powerful but their performances are affected by many strongly variable parameters like salinity, turbidity, the presence of dissolved substances, that change the colour and the transparency of the water in different optical bands. Moreover the amount of solar radiation heavily affects the signal to noise ratio. The current approach uses a mixed strategy based on the variable exploitation of the optical channel depending on the environmental conditions. In favourable conditions the transmission protocol will freely decide which channel to adopt depending on the priority, i.e. distance-to-cover and dimension of the message itself. In less favourable conditions the optical channel will be limited to the fundamental synchronization task, generating a light lamp that will optimize the message passing through the optical channel.

4.1 Components

We have used two leds a ENSW10-1010-EB1 by EDISTAR (white led) and XLED code 21.00.50B (blue led) together with a photodiode OSD100-E by Centronic. Their technical specifications are available on the web, but the only public data refer to the static features of electric power and luminance so that we have been carried out a more precise characterization of these products to study their applicability in signaling and communication. This work has been performed by HR4000 instrument, by Ocean Optics, that has a resolution of 0.5 nm wavelength. The software used for symbolic calculation was Mathematica by Wolfram Research.

4.2 Basics of light propagation in water

Light absorption by a medium, as a function of distance from the source and the wavelength, is a well known phenomenon. In a first approximation we can assume an exponential law for the decay of the signal intensity.

$$I = I_0 e^{-a(\lambda)d}$$

Where I is the measured intensity signal, I_0 the starting intensity, $a(\lambda)$ the absorption function and d the distance.

The $a(\lambda)$, describing how the signal is attenuated as function of the wave length λ , is strongly affected by the water conditions; it is known as high visible frequency are adsorbed less than lower in clear water. Owing to the great variability

of the unknown $a(\lambda)$ we planned to overcome this difficulty proceeding in two ways. First we considered that each machine is arranged to perform a measurements from the head to the tail of the Venus to get local absorption curve $a(\lambda)$. Therefore we are assuming that water characteristics do not vary in the volume containing the robots. Three separate and high efficiency Leds are the sources so we will have the function's values only for these three frequencies. The uses of more than one frequency allow us to expand the range dynamic of signals. Red source extinguish in tens of centimeters or meters, with respect to blue Led or also solar spectrum devices (white led).

4.3 Diodes characterization

In figure 3 and 4 the measured emission characteristic plot of the first two diodes considered: a a white cold LED (Fig.3) and 50W blue LED, produced for pool lightening (Fig.4). The curves are taken at standard work condition (35 Volts 100 watt power absorption for the white led and 27Volts 50 watt for the blue) as indicate by the producer, are shown; they

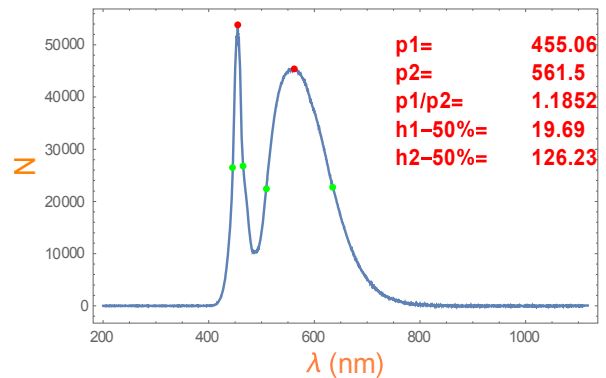


Figure 3 White Led emission curve.

have been normalized by subtracting the background. As usual the white led is composed by a blue peak and a wide fluorescence peak.

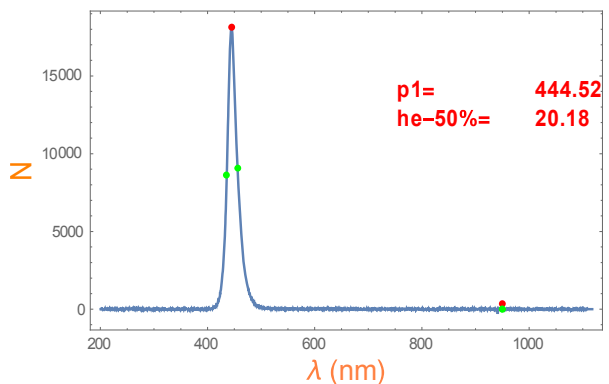


Figure 4 Blue Led emission curve.

Calculation of the emission curve in watt it has been performed using the scotopic correction curve to take in

account the human eye sensitivity. This allows converting the emission power from Lumen to Watt. The results tell us that the power emission in watt, over the sensitivity range of human eye, of the white Led is about 15 watt, according to the literature data on the led efficiency (Kraftmakher 2011).

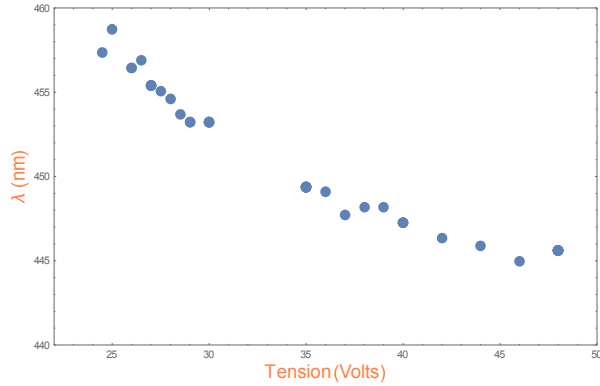


Figure 5 White Led peak value vs tension.

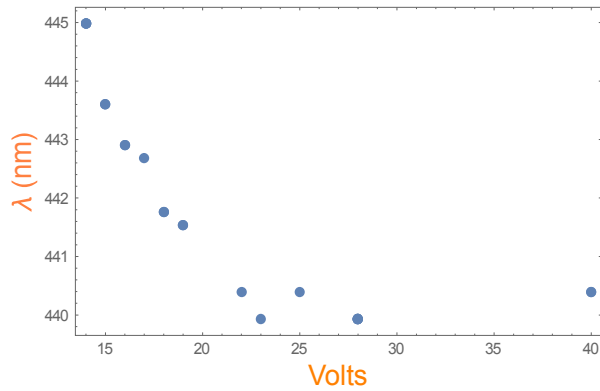


Figure 6 Blue Led peak value vs tension.

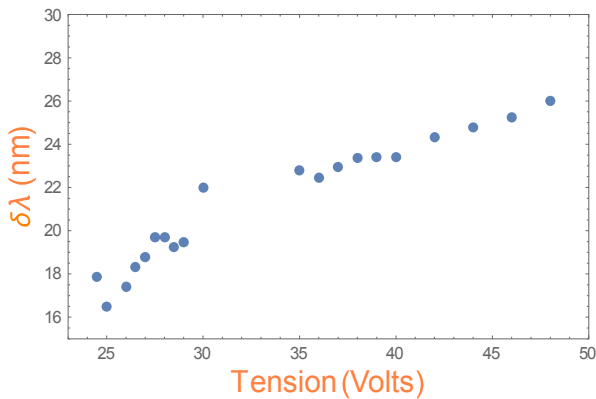


Figure 7 First peak enlargement white Led vs tension.

Later we have stressed the diodes in different power working conditions and different time emission. The aim is to change emission of the leds working in different conditions to enhance the measurements precision. Therefore we have changed tension and used very short lamp (microseconds) to see how the emission was changed. In figure 5 and 6 the dependency of the emission peak on power tension can be

outlined; the behavior is quite similar for the two Leds but it is more marked for the white Led. We can note as the emitted wavelength decrease with increasing the tension. The second peak, present only for the white led, shows no dependency on the tension.

A dependency on tension was found, in both the diode, in the half-height of the peak, as shown in figure 7 and 8, much less marked for the blue led.

No dependency for the second peak of the white led was found. We have to remember that second peak of the white led is a fluorescence peak and we should be using more measurements to characterize it, because the data are quite spread. Also the ratio between the two peaks height (only for white led) seems to show no dependency by the tension

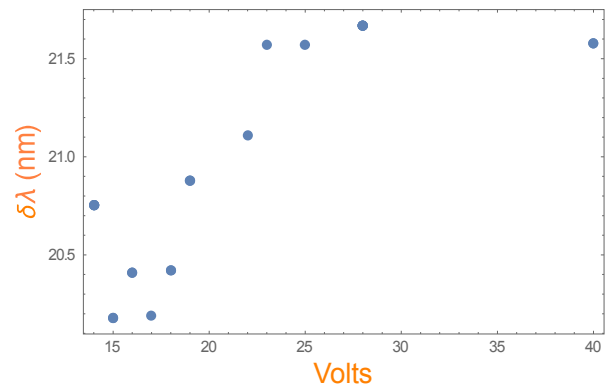


Figure 8 First peak enlargement blue Led vs tension.

Regarding the dependencies on the flash duration we can outline as the measurements are not enough to see a clear tendency. Very preliminary results seem to that the first peak length wave increase with increasing flash time, while it's flaring is decreasing. We hope to vary emission considering that for very short flash time the led has no time to reach regime work conditions.

4.4 Error considerations

The need to have more than one device can be understood intuitively from the wider dynamic available as function the distance at which the signal was collected. Moreover we can observe that, fixed wavelength, λ_1 , we have:

$$d = \frac{1}{a_1} (\log I_0 - \log I)$$

Where a_1 is the absorption coefficient at the λ_1 . Consequently the square of error on the measured d is

$$\Delta d^2 = \left(\frac{\partial d}{\partial a_1} \Delta a_1 \right)^2 + \left(\frac{\partial d}{\partial I} \Delta I \right)^2 + \left(\frac{\partial d}{\partial I_0} \Delta I_0 \right)^2$$

Therefore, owing the presence of a_1 at the denominator we observe that error is increase, decreasing a_1 value, that's mean, typically, at high frequency. This is one of the reasons to use more than one wavelength. It is important to stress that the ratio among the signals, I_1/I_2 , given by sources with

different wavelength values remains more stable than the current given by a single source when the integral absorption is modified for a significant factor. Depending on the principal absorption mechanism and on the degradation of the water transparency the choice of the frequencies that can give the maximum sensitivity can change. Working on the ratio I_i/I_j of the different frequencies we can enhance our measurements. We are currently selecting sources and classifying standard water qualities, to determine the most suitable functional (i.e. the mentioned intensity ratio) and the approach led as to the maximum sensitivity of the system. By this way we can be much less sensitive from the variation of the function $a(\lambda)$ and to get an indication of the water pollution degree by comparing the values of the single wavelengths with their ratio.

5. CONCLUSIONS

In this paper we have presented as a set of commercial cheap led diodes could be a valid aid to an acoustic device to measure distances and speeds for an underwater robotics swarm. Simultaneous use of different Led, managed by different power and different signal length can be used to substantially reduce the effect of unknown transparency water conditions on the measurement. This is still more effective if a local test of the absorption light curve can be performed in situ by the single machine on a known distance head-tail of the robot. In conclusion, the use of more than one led allow us to reduce experimental errors and increasing the sensitivity of the signal to the measured distance, by enlarging the responsivity dynamic.

These measurements can be used to build the swarm configuration and the relative velocities between the swarm elements.

So far this preliminary results has shown as the emission characteristic of commercial LED can be varied in a simple way and can be used for distances measurements if local estimation of the absorption coefficients are performed before. Preliminary results show as a single Led can be stressed to vary its emission characteristics in a simple way. An attempt to stress Led working conditions allow to treat one single Led as quite multicolor is under investigation. The use of two or three leds of different color enhance dynamic of the measurements increasing the precision of the results.

Calculations of the distances in a simulated way show that the error on estimated distance can be significantly reduced.

Many questions are still open like a better management of the Led emission to render a single light source multi-source in a controlled way and experimental results are in progress.

Moreover we are using a new diode whose emission is in the red area to cover another area of the spectrum.

The work is in progress in our laboratory with experimental campaign into the Bracciano Lake, close to our laboratories.

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