How to measure distance between the elements of an underwater robotic swarm by power Leds in unknown sea water conditions

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ABSTRACT

One of the most important tasks of an underwater swarm is to know its geometric configuration; this can be achieved from the knowledge of the relative distances between the swarm elements as geometry distance problem. The method we propose here can be a possible support to compute them. Aim of this paper is therefore to measure distance between underwater AUVs swarm using cheap power Leds as light source and photodiode as receiver in unknown light water adsorption conditions. The method is based on light signal exchanged between the machines and the distances are calculated by the unknown water adsorption coefficient; the receiving photodiode produces a current we can correlate with distance and water adsorption coefficient, resolving the unknown parameters by moving the robots and stressing the emission conditions of the diode. In a previous paper we stressed work conditions of a power Led, we are using as optical modem in shallow water, to vary its emission characteristics. On these results we can perform a set of measurements leading to the knowledge of distances and adsorption coefficient $a(\lambda)$.

Keywords: Power Leds, Underwater robotic swarm, distance measurement.

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1. INTRODUCTION

It is well known as a robotic swarm presents advantages with respect of a single Underwater Autonomous Vehicle (AUV). These are in the speed-up coming by the parallelism and in the increase of reliability by redundancy [1], provided that the lack of one member can be easily managed by redistributing the job among the others like, in natural environmental, as used by the bees [2]. A swarm can interact with a human operator as a single object, without the problem of controlling a large number of individuals; job sharing between the elements is an internal swarm task. Moreover the human operator has the possibility to examine an object concurrently from more than one point of view, leading to a better perception of the surrounding environmental. A swarm is able to perform tasks in a more fast and robust way with respect of a single machine; but the most important feature, we are working, is its capability to span communication from the surface to the basement. This can allows a quasi-real time communication and therefore to interact with the underwater system also using a remote console that can be locate on the coast. Practically we can realize a multi-hop network with variable geometry. The swarm can adapt its configuration depending on the exploration mission and communication task. 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 [3], [4]. ENEA is working in robotics since a long time (1961) and underwater robotics is a key topic of our laboratory [5]–[10]. Some years ago, (2006) 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; for a swarm there is also the need to know its geometric configuration. To get absolute localization at least one element of the swarm must have a precise position (typically on element emerges and fix position using GPS); localization of the whole swarm follow. The knowledge of the configuration is a very important issue for many applications often depending by the assigned task that can also vary during the mission [5], [11], [12]. Configuration can be computed from distance measurements [5] that is the purpose of this paper. Usually is done by ultrasonic measurements but our intention is to use absorption light coefficient as support to traditional measurements.

1.1 State of art

Acoustic communications are the standards in submarine environmental [13]. Unfortunately reflections, fading and other phenomena make difficult and sometimes not reliable their measurements. The need to continuously exchange data among the nodes (the swarm elements) to get the distances represents a considerable burden for the network operation to calculate the network configuration, also using suitable algorithms, because it force to frequent short messages that deoptimize the exploitation of the communication channel, mainly for the long times needed to switch from a message to another one [14]. 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 [15], [16]with the intention to collect distance measurements between the robots more precise, using sensor data fusion. 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 color and the transparency of the water in different optical bands [17]. Moreover the amount of solar radiation, in shallow water, heavily affects the signal to noise ratio. Our current approach uses a mixed strategy based on the variable exploitation of the optical channel depending on the environmental conditions. In favorable 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 favorable conditions the optical channel will be limited to the fundamental synchronization task, generating a light lamp that will optimize the message passing through the acoustic channel. So far we have realized an optical modem with cheap power Leds that it is working together acoustic system. 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. Moreover, backup solutions based on the "all acoustical" approach, must remain available because it is always possible to find dirty waters with no way to use light signals. In this paper we work about the problem to calculate distance using optical signals. In a previous paper we proposed the use of a cheap power led system to support acoustic devices in localization and configuration computation of an underwater robotics swarm [18]. The system was based on light signal exchanged between the machines and used power led, of different wavelength, to calculate distances between them. The unknown water conditions, affecting the light propagation, required a local measure of the absorption function $a(\lambda)$ using a known distance. Moreover we investigated as power supply and flash duration of the Leds can be stressed to vary light emission spectrum. By this experience now we are able to measure distance without the local measure of the absorption function. In this paper we show as, modifying spectrum, we shall be able to measure $a(\lambda)$ and, consequently, the distance d.

1.2 Our prototype

In Figure 1 and Figure 1Figure 2 the swarm element, named Venus and realized in our laboratory, and the optical modem prototype are shown. 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. In the optical modem the Leds' chips and photodiode are visible; the system is repeated on three faces to cover 360°.

Figure 1 Robot prototype during test in Bracciano's lake

Figure 2 Optical modem

Note 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. Technology of dense swarms is an answer to these problems need larger acoustical bands and allowing other physical channels to be exploited.

2. RESULTS

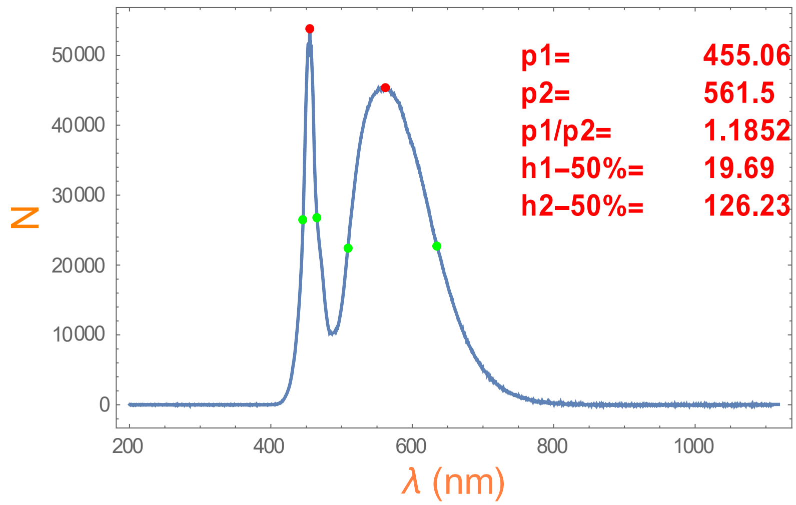

Figure 4 White Led emission

In a previous paper [18] we have considered cheap power Leds that we are using to build an optical modem and tried to stress power supply and flash duration to vary the characteristic of light emission; typical emission of the white Led is shown in Figure 4 while one experimental result, concerning the peak emission value vs. power supply, can be seen in Figure 3. We used white Led ENSW10-1010-EB1 by EDISTAR together with a photodiode OSD100-E by Centronic. The measurements have been performed by HR4000 instrument, by Ocean Optics, with a resolution of 0.5 nm wavelength. The reason to attempt to vary the Led's emission characteristics is economic: owing to the large number of swarm elements the use of complex variable frequency system is not sustainable. So we modify the peak shape emission by the power tension and perform distance measurements based on water light adsorption. The water adsorption is generally unknown so, in the previous work, we performed a local measurement of the attenuation coefficient by a measure on the known distance head-tale of the robot. Unfortunately this implies we have Leds emission on the head of the torpedo-like robot and photodiode on the tale. This determines constructive problems of the optical modem so far we want got rid of this architecture looking for another solution. So far stressing Led emission we get information useful to model water attenuation coefficient and, consequently, the distance. Practically we vary the spectrum emission of the Led, varying power supply, and perform an attempt to model absorption coefficient. In this paper we propose a theoretical way to compute it with not yet experimental data but simulating how could be the collected current from the photodiode using a simple equation. Only the data concerning the emission of the Led are experimental. Later we try to match the current using some water categories, or linear combination of them, from the literature.

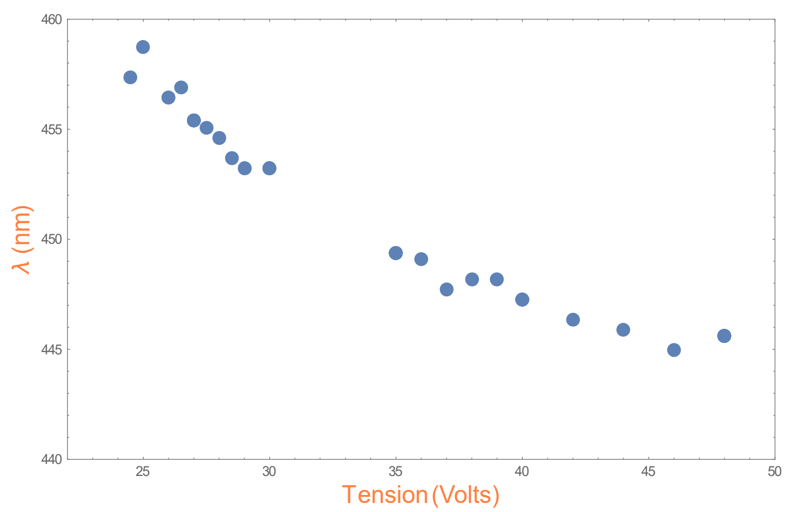

Figure 3 White Led first peak wave length shift value vs tension

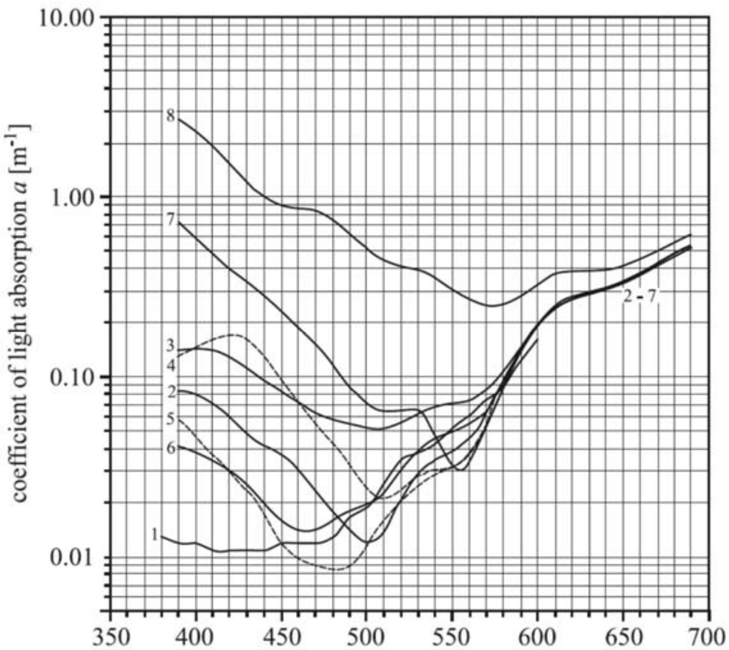

Figure 5 Light absorption in sea water in different condition [14]

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

$$I = f(\theta, \varphi) \frac{I_0 \, e^{-a(\lambda)d}}{d^2} \qquad (1)$$

Where I is the measured intensity signal, I_0 the emitted intensity, $a(\lambda)$ the absorption function, $f(\theta,\varphi)$ a shape factor and d the distance. We do not consider here the shape factor, known for the characteristics of the Led and of the photodiode leading to a modify of the spherical shape. Typically you should consider an emission diagram of 60°x60° therefore the energy is spread on this solid angle. The $a(\lambda)$, describing how the signal is attenuated as function of the wave length λ, is strongly affected by the water conditions as can be seen in Fig. 5 due to the courtesy of [19]. We are assuming that water characteristics do not vary in the volume containing the robots. There is no way to obtain, $a(\lambda)$ and d separately by a simple measure if the intensity I. In a previous work [20] we used monochromatic sharp peak blue Led to stress so we can measure the derivative of Eq. 1 respect to λ that give us the product $a'(\lambda)*d$. Computing it for two, unknown, distance d_1,d_2 we can obtain the ratio d_1/d_2 that is what we need. So far, considering the ratio of Eq.1 for the two distances, we can obtain the product $a(\lambda)*d_1$. Now, considering the Log of Eq.1 we have $a(\lambda)*d_1 + 2Log(d1)$ and consequently d_1, without any model of $a(\lambda)$.

This is very nice but we are now using real white Leds so we use, in this case, a semi-experimental procedure. We use experimental stressed emission curves of the white Led together with the, furnished by the factory, responsivity of the photodiode to calculate the collected current at different, unknown, distance. The collected current is computed by the integration of the product of the experimental emission curves, the responsivity of the photodiode and Eq.1. We use, as $a(\lambda)$, the eight curves of Fig.5 to build a database. If we stress our Led emission on different unknown distances we obtain a set of curves like Fig.6 and Fig. 7, depending on water quality. We now use the eight curves of Fig.5 as preliminary database, so we have 8 plots like Fig.6. Now we perform our measurements in unknown water and distances, stressing the Led in 40 different ways, obtain a 40 points set. These points are a vertical line on one of the 8 plots like Figure 6 posed at unknown

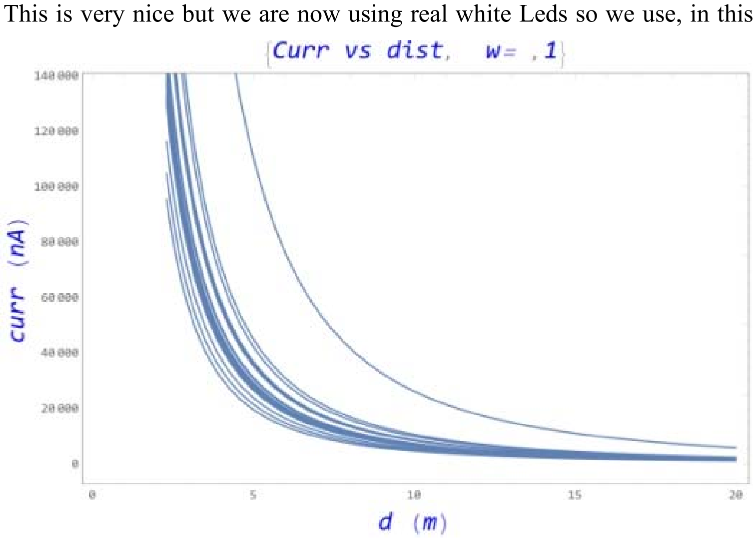

Figure 6 Collected current by photodiode for different Led stress vs distance in clear water (w=1)

distance; the points must coincide on the curves. We repeat the operation for some other unknown distances. We have to match our 40 points set into one of the 8 plots at a certain distances. One measurement could be present ambiguities leading to multiple choices so we repeat the measure at other distances as well as at the same one. At the end will be only one possible solution to match all. As "match" we mean a procedure concerning the minimization of the distances of our set of points from the curves, through optimization procedure. We are assuming the water behavior can be described by Figure 5 or by a combination of its curves; this could be reasonable because the figure is considering a very large water conditions cases. If, as usual, our water is not comprise into the eight curves we generate it from linear combination of them loosing in precision. Practically the steps are the following. 1) Simulate the data. We choose one of the eight kind of water (2 in our example or linear combination of them) and a distance *d* (7.1 in our example). The collected current *C* form the photodiode is:

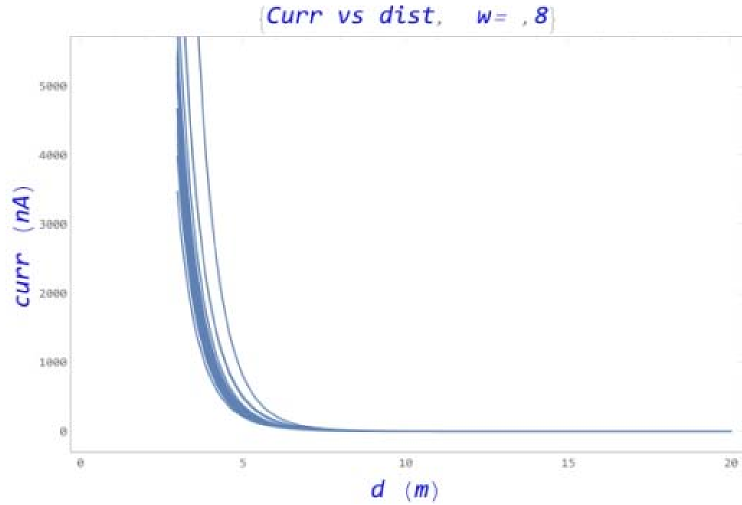

Figura 7 Collected current by photodiode for different Led stress vs distance in turbid water (w=8)

$$C = \int_{390}^{700} R * \mathrm{EmLed}(\lambda) * \mathrm{Eff}(\lambda) * f(\theta, \varphi) \frac{I_0\, e^{-a(\lambda)d}}{d^2} d\lambda$$

Where EmLed is the emission curve of the Led (Figure 1) in 40 different stress conditions and Eff is the efficiency response of the photodiode; we have also introduced a random noise *R* of the 10%. 2) With this data we try to match, for each picture like Figure 6 and Figura 7 (or linear combination of them) the set of 40 points until we find the distance *d* as can be seen in Figure 8 and Figure 9. In the figures our measurements are the vertical points and there is just one distance, in a particular kind of water, to minimize the distances of the points from the curves; we move the vertical lines to find the distance for the best match between the curves and the points.

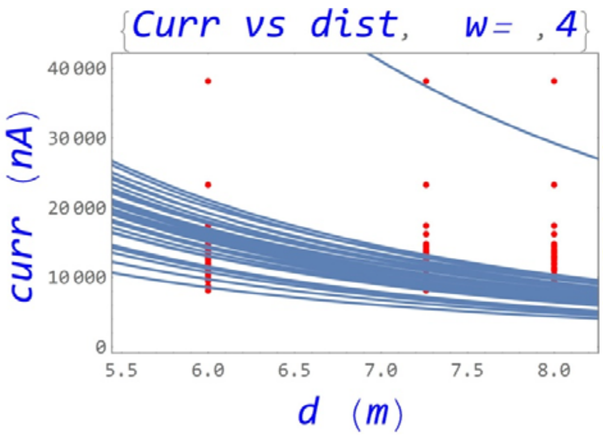

Figure 8 Collected current by photodiode for different Led stress vs distance in water (w=4) and distance=7.1m. The red points are our, simulated, measurements. We try to match the curves without success

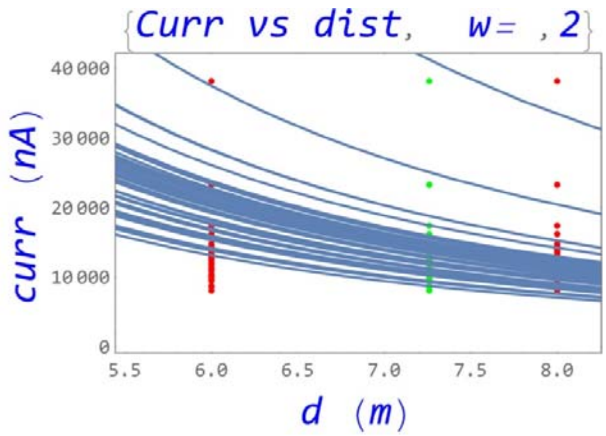

Figure 9 Collected current by photodiode for different Led stress vs distance in water (w=2) and distance=7.1m. The red points are our, simulated, measurements. We try to match the curves: best result is for d=7.26 m

Simulation computing can be seen in Table 1 where the simulation for ten different distances is shown. Therefore we perform 40 flashes for each distance and 50 measurements with random errors, stressing the Led in different conditions, for ten unknown distances. The results are quite good. Take in account that each simulated measurements is affected by a random 10% noise generate to make more realistic the computing. In Table 2 we report the results of mixed water conditions (Linear combination of water of kind 2 and 4). The results are less accuracy, especially at low distances, but still useful.

Real distance	**Estimated distance**	**Standard deviation**
2.8	2.6	0.5
3.2	3.1	0.1
3.5	3.5	0.19
4.2	3.7	0.9
7.2	6.9	1.6
10.1	9.8	0.8
12.1	12.1	0.7
12.5	12.4	1.5
17.3	16.5	2.6
19.1	15.8	4.8

Table 1 Estimation of the unknown distance *d* using one of the eight water of Figure 5

Real distance	**Estimated distance**	**Standard deviation**
0.2	2.0	0.5
0.8	3.1	0.1
3.7	3.3	0.1
5.2	3.7	0.9
8.3	6.9	1.6
10.8	9.9	0.8
12.6	12.1	0.7
13.4	12.4	1.5
16.5	16.5	2.6
19.1	15.8	4.8

Table 2 Estimation of the unknown distance *d* using mix of the eight water of Figure 5

3. CONCLUSION

We have proposed a method to measure distances and extinction coefficient in unknown underwater conditions by using cheap power Led whose emission is stressed by power source. The method could be a support to standard acoustic measurements and can be used to calculate configuration of an underwater robotic swarm that we are developing in our laboratory. We have built an optical modem by using cheap commercial Leds and modifying power tension we are able to modify emission peak. In this paper we proposed semi- experimental results where the emission peak is experimental but the collected current form the photodiode is computed by simple equation. Simulating these collected current we use a database of water condition, or its linear combination, to match the data. Varying the unknown distances we can build a set of compatibility to identify the extinction coefficient of the water.

Experimental measurements are in progress to verify the concrete possibility to estimate extinction coefficient a(λ) by this method. Errors sources are many. This method must be considered as an iterative method whose precision is increasing with many measurements. These measurements must be integrated with some other source like acoustic, as usual in robot science. The use of more than one Led, with different frequency emission, suddenly increase precision [18]. This because working on the ratio intensity at the different frequencies we can enhance our measurements owing to the increasing stability of the photodiode current, with respect of that of a single source. Practically we increase the sensitivity of the signal to the measured distance, by enlarging the responsivity dynamic. The work is in progress in our laboratory with experimental campaign into the Bracciano Lake, close to our laboratories.

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