Anchors' Placement for UWB-Based Indoor Localization System for Water Polo

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Abstract
The study of position, speed and trajectories in elite sports is widely used to analyse the performance and work load of athletes. However, these techniques can also be used for strategic analysis. There are several methods for acquiring this information, such as video, Inertial Measurement Unit (IMU) and Radio Frequency (RF) systems. Based on RF technology, Ultra WideBand (UWB) provides high accuracy and is the most widely used in the world of sports. The objective of this paper is to propose a layout for an indoor localization system around the water polo field to obtain a position error of less than 30cm. With a particular focus on the attack/defence area (6x20m around the goal), where most of the game actions take place. This paper evaluates the UWB system by examining the position error according to the spacing of the transmitters. It then compares two different configurations, on the floor and above the pool. The system deployed achieves an accuracy of 29cm when the transmitters are above the pool and 30cm when the transmitters are on the floor in 90% of cases.

Keywords
Anchors configuration, Indoor localization, Water Polo, UWB, Dynamic accuracy

1. Introduction

In sports, it is becoming essential to analyse athletes performances and strategies in order to be able to monitor their progress and their workloads.

In aquatic sports, particularly water polo, a variety of technologies are employed to analyse the athlete performance, such as video, Artificial Intelligence (AI) and Inertial Measurement Units (IMU). To study the water polo game, these technologies are employed to visualise information like shots, speed, probability of goal or movement of the human pose. For instance, IMU is used to analyse ball throws and shots [1], AI to track the movement of the human pose by analysing visible joint points [2]. Hochstein et al. [3], use cameras to observe the area of the Voronoi-cells to determine the probability of scoring a goal. These methods are expensive and time-consuming to implement.

Concerning strategic analysis, the automatic detection of players in the pool by computer vision is difficult to implement due to the reflections of light on the water and the phenomenon of shadowing. The shadowing avoids direct view of players close to each other so they are not individually detected. There are various methods (Yoon, mixture of Gaussian models, Cb and Cr components of the YCbCr colour model) for subtracting the water and obtaining with difficult the position of the athletes [4].

In the context of water polo, radio frequency (RF) technologies, can be an alternative to measure players position and deduce speed, acceleration, trajectory and also for strategic analysis. In their surveys, Zafary et al. [5] and Farahsari et al. [6] examine the performance of various RF technologies, including Ultra WideBand (UWB), Bluetooth, Wi-Fi, Radio Frequency IDentification (RFID) and ZigBee, for indoor positioning applications with a focus on coverage, power consumption, and accuracy. UWB is the most accurate in terms of position estimation, with a static accuracy of approximately ten centimetres [6].

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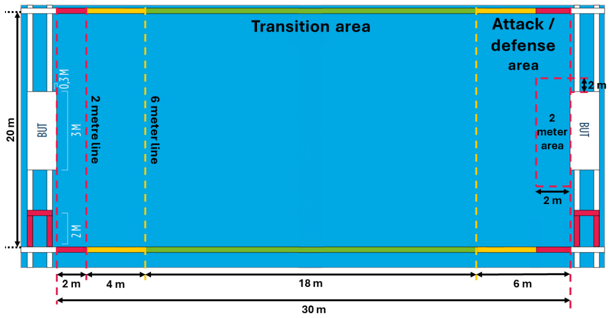

Figure 1: Water polo areas

Conteville et al.[7] proposes a method to assess the performance of positioning systems in high-level sports and test there method with a UWB system. they obtain a accuracy of 10cm in static scenarios and 20cm in dynamic conditions. Hodder et al. [8] use UWB to measure the inter-player distance and compared their results with the position obtained by camera. The Root Mean Square Error (RMSE) is 20 +/- 5cm. Santoro et al. [9] present static and dynamic using UWB, in static they obtain an error position lower than 20cm and in dynamic tests the error can reach 55cm. Alasiry et al. [10] make static monitoring in basket using UWB and obtain an average position error in the Line Of Sight (LOS) of 16cm.

In the literature, UWB is the most relevant and widely used RF system for sports applications due to its static position accuracy of about 10cm [6]. UWB technology has already demonstrated its efficiency for sports applications, but not yet in water polo. This is a challenging application because in addition to the effects of multi-paths, typical of indoor environments, there are the effects of water. The aims of this study is to determine feasibility of UWB technology to obtain a dynamic position in a swimming pool and the optimal configuration of an UWB system for locating polo players in a specific area namely attack/defense, in order to guarantee a position error less than 30cm. Polo player analysis is done for performance analysis and strategic analysis purposes.

The paper is organized into five sections. Firstly, we describe in section 2 the water polo playing areas and the UWB technology used to measure the position. In section 3, we study the static accuracy of the deployed UWB system. In section 4, we compare the accuracy of dynamic measurements for two different device configurations based on the observations made in section 3. Finally, we conclude with a discussion and give perspectives in section 5.

2. Environment and Measurement Equipment

2.1. Water Polo Environment and Playing Areas

Water polo is an aquatic sport played in an Olympic-sized pool (50x25m), where two teams of seven players compete (six players and a goalkeeper). The experiments presented were carried out in an Olympic indoor swimming pool of the *Institut National du Sport, de l'Expertise et de la Performance* (INSEP).The dimensions of the water polo field are 30x20m for men and 25x20m for women. We consider in this study the largest area. There are three playing zones described in Figure 1 :

- Transition area : Located in the center of the field between the 6 meter lines, with a length of 18m long. Players cross this area to reach the cages.
- The attack/defense area : Located between the goal and the 6 meter area. It is an area of high concentration because players from both teams (6 attackers and 6 defenders) can be there.
- The 2 meter area : this zone surrounds the goal and only attackers with a ball can be there.

Table 1
Data samples

Perimeter [m*m]	2x26	4x26	6x26	8x26	10x26	12x26	14x26	16x26	18x26	20x26	22x26
Number of acquired data	202	194	147	157	167	186	173	144	165	160	158
Percentage of valid data [%]	100	100	100	100	100	99.46	91.33	0	90.10	0	1.90
Mean acquisition time [ms]	148	152	204	191	179	161	170	207	180	184	189

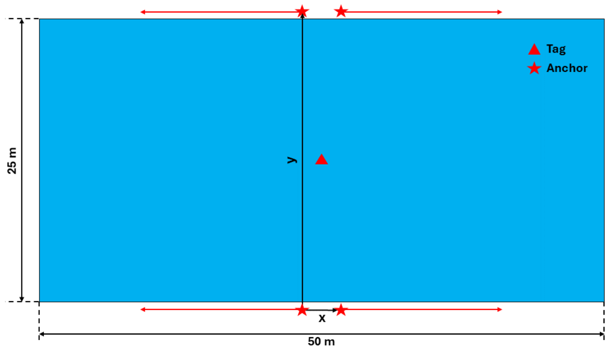

Figure 2: Experimental layout in static

2.2. Measurement Equipment

In this paper, the experiments are carried out using UWB modules, specifically the development kit MDEK1001 from Qorvo/Decawave [11]. The UWB modules can be configured to behave as an "anchor" for fixed nodes or as a "tag" for mobile nodes within the system.

Distance estimation is based on Time of Flight (ToF) measurement thanks to the Two-Way-Ranging (TWR) technique. The position of the tag is calculated by multilateration.

During the experiment, four anchors and one tag were employed, to find the best position for the minimum number of anchors, thereby limiting the size of the system and overall cost. The anchors are placed at a height of one metre around the pool. The tag acquisition frequency is set to 10Hz. For static experiments, the tag is placed on a plexiglas and plastic tripod, 30cm above the water surface. For dynamic experiments, the tag is placed under a swimmer's cap to obtain the position of the player. When the tag is under water, the signal is absorbed by the water. The UWB system operates at frequencies from 6 GHz to 10 GHz, at this frequencies, signals are strongly attenuated.

3. Protocol and Evaluation of the System for Static Measurements

This study aims to determine the distance between the anchors to guarantee a low position error ($<$ 30cm). This precision is required specially in the attack/defense area. In this section we consider static measurements.

3.1. Experimental Protocol

In this test four anchors are deployed and one tag is used as shown in Figure 2. The goal is to measure the tag position error when widening the perimeter made by the four anchors, which is the minimum numbers of anchors for positioning. The anchors are placed 50cm from the edge of the pool, thus, the initial surface is 2x26m. The anchors are moved apart by steps of 1m until they no longer receive the transmitted signal. The tag is placed in the center of the pool (25m, 12.5m) which corresponds to the center of the surface circumscribed by the anchors. The acquisition frequency is 10Hz and the acquisition time is 30s.

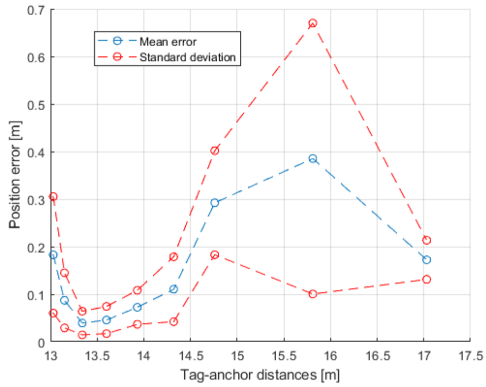

Figure 3: Position error relative to the tag-anchor distance

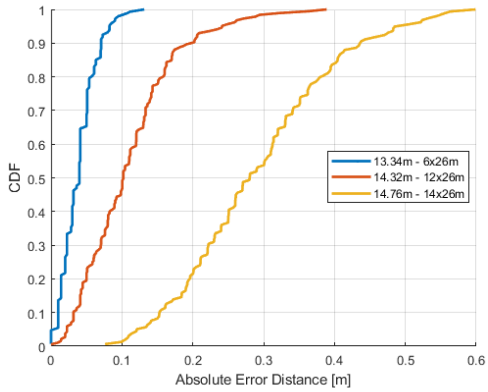

Figure 4: CDF of position error relative to tag-anchor distance

3.2. Static Results and Analysis

On the one hand, Figure 3 shows the mean position error vs. the tag-anchor distance. The biggest area (before loosing the tag signal) is 22x26m and the tag-anchor distance is 17.03m.

On the other hand, the maximum perimeter with an average error below 30cm is 14x26m, this corresponds to a tag-anchor distance of 14.76m, reaching an error of 29.2cm with a standard deviation of 10.9cm. Finally, the lowest mean error is 3.9cm with a standard deviation of 2.5cm for a tag-anchor distance of 13.34m (perimeter of 6x26m).

The Cumulative Distribution Function (CDF) of the position error in Figure 4 indicates that for a tag-anchor distance of 13.34m (6x26m perimeter), the error is less than 7cm at 90%. Whereas for a tag-anchor distance of 14.76m (14x26m perimeter) the error is less than 43cm at 90%. Since the perimeter of 14x26m (tag-anchor distance : 14.76m) has an error greater than 30cm, we consider the perimeter of 12x26m (tag-anchor distance : 14.32m) the maximum perimeter with an error bellow 30cm. The perimeter made by a tag-anchor distance of 14.32m (perimeter - 12x26m) has an error less than 20cm at 90%.

The results obtained in Table 1 show that the acquisition time varies and fluctuates between 148ms and 207ms. The table also shows the percentage of valid data. This information corresponds to the number of positions received minus the “NaN” (Not a Number) positions when the tag receives signals from less than three anchors. Up to a perimeter of 10x26m (tag-anchor distance 13.93m), all data received is valid. Once the perimeter exceeds 12x26m, the valid data decreases up to 1.90% for perimeter 22x26m (tag-anchor distance 17.03m).

Static analysis of the position error according to the the tag-anchor distance shows the best accuracy for perimeter 6x26m (tag-anchor distance 13.34m) with an average error of 3.9cm. Under these conditions, the CDF at 90% is less than 7cm error. In addition, all the data acquired within this perimeter is valid. This area corresponds to the dimensions of the “attack/defense area”, which needs the higher accuracy.

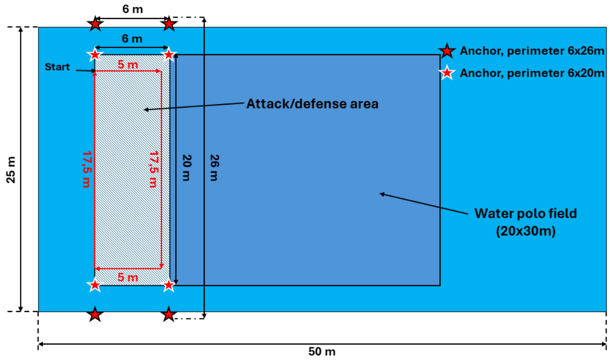

Figure 5: Experimental protocol diagram for dynamic tests

Table 2
Mean error and standard deviation along the trajectory with the "anchors on the ground" configuration

Segment	1	2	3	4
Mean Error [cm]	10	19	20	19
Standard deviation [cm]	5	15	22	15

Static position error analysis needs to be completed with a study in dynamic conditions to characterize the UWB system in the context of water polo.

4. Dynamic Validation of Anchors' Position

The attack/defense area is an area of high concentration of players due to the presence of 6 attackers and 6 defenders. The presence of a high number of athletes in a narrow area could bring an error in the system's accuracy. This is due in particular to the shadowing between players. In order to validate the perimeter of 6x26m to obtain a position accuracy better than 30cm and minimise the errors that can occur due to shadowing, we test in dynamic situations two layouts of the anchors : around the pool on the ground and above the pool. This second layout avoids shadowing and have direct paths between the anchors and the tag.

4.1. Dynamic Experimental Protocol

For these tests, the tag is placed under a swimmer's cap. The trajectory followed by the swimmer is marked out at the bottom of the pool. It delimits a 5x17.5m rectangle inside the perimeter made by the anchors. The dynamic evaluation of the device is carried out by calculating the position error relative to the trajectory. As shown in Figure 5 , in the first test, four anchors are placed on the ground around the pool with tripods at 1m height. Anchors make a rectangle of 6x26m. And in the second test, four anchors are hung to a cable above the attack/defense area at a height of 3m and make a rectangle of 6x20m.

4.2. Results and Analysis of a Test with Anchors on the Ground (6x26m)

The positions measured along the trajectory are shown in Figure 6 and results can be broken down into four segments, each corresponding to one side of the trajectory perimeter. We observe that there are fewer measurements along segment 3 than for the other segments, only 27 positions versus 117 for the first segment, 208 for the second and 167 for the fourth. Moreover, the perimeter trajectory is well followed except at 17m along segment 2. The results presented in the Table 2 show that the mean error with respect to the trajectory is 10cm to 20cm, with a standard deviation of 5cm and 22cm respectively.

In Figure 7 the CDF at 90% shows that the error is bellow 16cm, 19cm, 30cm and 33cm for segments 1, 2, 3 and 4 respectively. The accuracy error of segments 1, 2, 3 is compliant to the required precision.

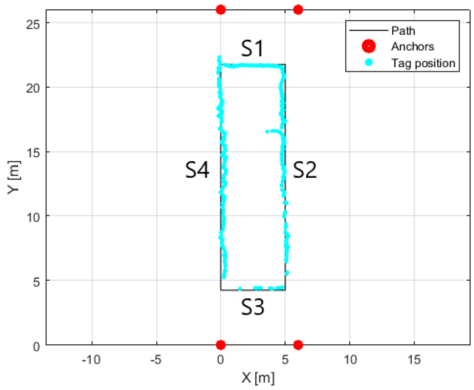

Figure 6: Dynamic position measurements along the trajectory for "anchors on the ground" configuration

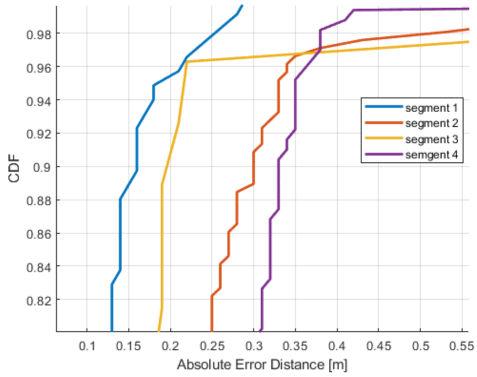

Figure 7: CDF of position errors along the the trajectory with the "anchors on the ground" configuration

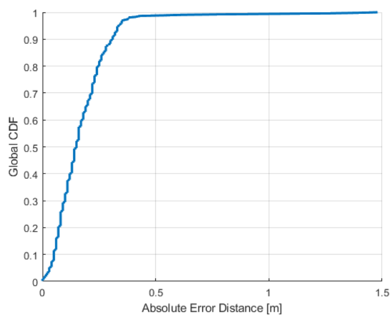

Figure 8: Global CDF for the "anchors on the ground" configuration

The accuracy error of the segment 4 is 3cm higher than the required precision. This first observation shows us that it is possible to obtain an error of less than 30cm in dynamics and in a swimming pool.

The global CDF is the CDF of all errors along the four segments. The global CDF at 90% is 31cm, see Figure 8.

The time acquisition of this dynamic experiment is 101s and the acquisition frequency is 10Hz. The Table 3 shows that 783 samples are acquired instead of 1010. In addition, 66.28% of these data are valid. The average acquisition time is 0.13s instead of 0.1s.

4.3. Results and Analysis of a Test with Anchors Above the Pool (6x20m)

The positions measured along the trajectory marked out at the bottom of the pool are shown in Figure 9. We observe that there are less measurements between 2m and 8m on segment 4 than on the other segments. We also observe that the trajectory is well followed except in the middle of the segment

Table 3
Data samples for "anchors on the ground" configuration

anchors on the ground (6x26m perimeter)	
Number of acquired samples	783
Percentage of valid data [%]	66.28
Mean acquisition time [ms]	133

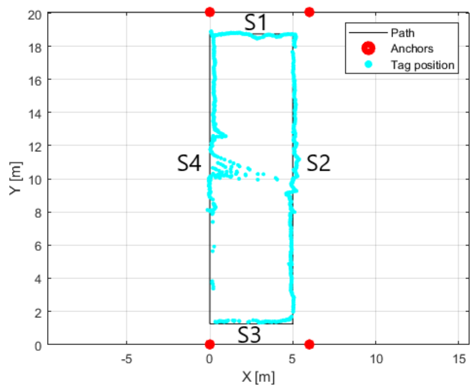

Figure 9: Dynamic position measurements along the trajectory with "anchors above the pool" configuration

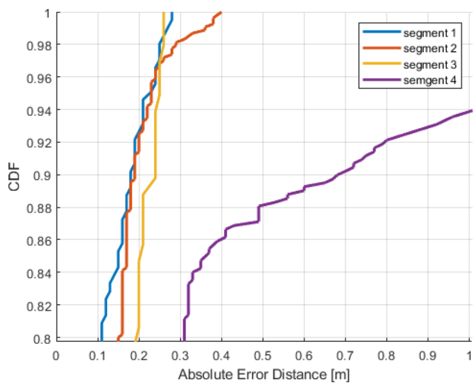

Figure 10: CDF of position errors along the trajectory with "anchors above the pool" configuration

4 where we observe that measurements can be offset by up to 4m on the X axis. Indeed, according to the values presented in the Table 4, the maximum mean error with respect to the trajectory of the segment 4 is 35cm, and the standard deviation is 53cm. The accuracy of the other three segments with respect to the trajectory is better, the mean error is 7cm to 15cm and the standard deviation 7cm and 5cm respectively. Looking at the fourth segments, we can conclude that the errors in the centre of segment 4 are due to the environment and can only occur there.

Table 4
Mean error and standard deviation for "anchors above the pool" configuration

Segment	1	2	3	4
Mean Error [cm]	7	11	15	35
Standard deviation [cm]	7	6	5	53

Figure 10 shows that the CDF at 90% is 18cm, 19cm, 24cm and 70cm for segments 1, 2, 3 and 4 respectively. The accuracy error of segments 1, 2, 3 is compliant to the required precision unlike the accuracy error of the segment 4. This result are due to the aberrant measurements observed in the middle of this trajectory see Figure 9.

However, the global CDF at 90%, which is the CDF of errors across the four segments is 29cm, see

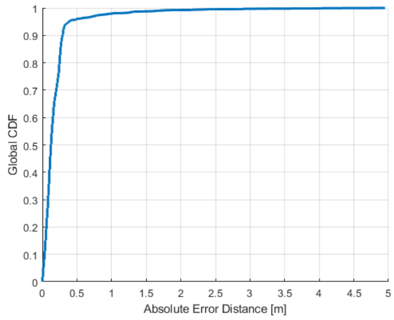

Figure 11: Global CDF for "anchors above the pool" configuration

Table 5
Data samples for "anchors above the pool" configuration

Anchors above the pool (6x20m perimeter)	
Number of acquired samples	1418
Percentage of valid data [%]	88.58
Mean acquisition time [ms]	129

Table 6
Table of comparison for the anchor on the ground and above the pool

Anchors perimeter [m]	6x26	6x20
Mean acquisition time [ms]	133	129
Percentage of valid data [%]	66.28	88.58
Global mean error [cm]	17	17
Global error in 90% of cases [cm]	31	29

Figure 11.

To complete the analysis of the dynamic measurements obtained for the perimeter 6x20m above the pool, the time acquisition is 180.2s and the acquisition frequency is 10Hz. The Table 5 shows that 1418 samples are acquired instead of 1802. In addition, 88.58% of these data are valid. The average acquisition time is 0.129s instead of the 0.1s.

4.4. Validation and Comparison of Results for Anchors on the Ground and Above the Pool

In this section we compare the results obtained with the two anchors layout : on the ground at 1m height and above the pool hung at 3m height with perimeters 6x26m and 6x20m respectively, to define the more efficient layout in the attack/defense area. We compare the results in terms of mean acquisition time, percentage of valid data and positioning accuracy.

Even if the four values (acquisition time, valid data, mean error and CDF at 90%) are almost the same for the both perimeters, Table 6 shows that there are no significant differences between the two configurations, except in terms of the percentage of valid data : 88.58% and 66.28% for the 6x20m and 6x26m perimeter respectively. The analysis of the global CDF at 90% shows a good accuracy in : 29cm for the 6x20m perimeter and 31cm for the 6x26m perimeter. The configuration above the pool offers no degradation in accuracy, and has the advantage of avoiding possible shadowing between the players.

Conclusion

The attack/defense zone (6x20m) is the area requiring the highest localization accuracy (error <30cm). In order to achieve this level of accuracy, a study of the anchors' layout is required. An initial study in static conditions determines the width of the perimeter made by the minimum number of anchors, i.e.

four anchors. For a perimeter of 6x26m, we obtained a mean error of 3.9cm and a standard deviation of 2.5cm. A study in dynamic conditions allows us to validate the deployment of the system established statically and prevent shadowing by observing two configurations: around and above the pool (6x26m and 6x20m). The position error relative to the trajectory varies between 7cm and 35cm, with respective standard deviations of 7cm and 53cm for a 6x20m deployment above the attack/defense area. This position error gives an overall mean error of 17cm, with 90% of cases having an error of less than 29cm. The results show that there is no significant differences between the two configurations. Furthermore, this study confirms the usability of UWB technology for measurements in water polo, with particular relevance for dynamic measurements, and provides good accuracy for applications in elite sports.

In future works we will improve accuracy by filtering and carrying out measurements in water polo game conditions (with 12 players) to observe the impact of a large number of tags on the system's accuracy.

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