A performance study of the UWB positioning system for the player tracking in tennis

Anton Umek, Anton Kos
University of Ljubljana, Faculty of Electrical Engineering, Ljubljana, Slovenia
anton.umek@fe.uni-lj.si, anton.kos@fe.uni-lj.si

*Abstract***—Precise tracking of the tennis player's location gives important information for the tennis game analysis. We designed a prototype system that uses an ultra-wideband (UWB) positioning technology for players tracking on the tennis court and wireless inertial sensors for detecting the ball impacts. We verified the accuracy of the UWB positioning technology in the tennis court by the high-precision optical tracking system. The results of the field tests confirmed that UWB technology is useful for player tracking in tennis coaching applications.**

*Keywords***: UWB positioning system, optical tracking system, wearable sensors, tennis game analytics**

I. INTRODUCTION

Tennis ranks as the fifth mass sport worldwide, and the number of young tennis players is increasing. Many technical tools and IMU sensor systems are already in use in tennis, such as Zepp Tennis 2 [1]. A very popular professional camera-based tracker officially adopted in tennis is Hawk-Eye [2]. Precise tracking of the tennis player's location gives essential information for the tennis game analysis. We designed a prototype system that uses an ultra-wideband (UWB) positioning technology for players tracking on the court and wireless inertial sensors for detecting the ball impacts.

Motion tracking with the possibility of real-time feedback [3] is becoming important in the motor-learning process, in the enhancement of sports training, and medical rehabilitation. Many commercially successful systems use optical tracking with many cameras, which are both expensive and requires complex equipment and well-trained operators. For precise positioning in the centimeter ranges, where satellite systems are insufficiently accurate, UWB technology is becoming commercially available.

UWB localization is implementable in many indoor and outdoor scenarios. Our interest lays in its use in sports applications. Some basic general localization requirements in sports are: the positioning error should not exceed 15-20 cm, and the sampling rate should not be lower than 10-15 Hz [4]. The accuracy of radio localization depends on the wavelength and modulated pulse width of a signal. Standard IEEE 802.15.4a, which defines the UWB physical layer, has been developed for the purpose of the radio localization. The UWB physical waveform is based on a band-limited impulse radio signaling scheme [5]. The standard also defines several independent frequency bands, among them, are also high-frequency channels with frequencies in the range of 5.8 GHz to 10.6 GHz, which theoretically gives a positioning accuracy in the centimeter range. The analysis of three different UWB positioning systems: Ubisense 7000, BeSpoon, and EVK1000, conducted by [6], showed that the DecaWave EVK1000 system has the best accuracy.

In the following paragraphs, we list some of the related work in localization in sport.

The authors of [7] performed a study of the performance of the DW1000 system through the use of the DecaWave evaluation kit TREK1000. In their scenario, a basketball field was chosen for the experiments, which is a clear LOS environment. The positions of anchors form an 8×20 square meter rectangle. It includes three TREK1000 anchors that provide the estimated locations with the lowest error distance when operating in S2 mode (short frame on 3.933GHz channel). The 2D localization error is less than 10 cm, 20 cm, and 30 cm, with the probability 60%, 90%, and 98%, respectively.

A study performed by [8] is based on home-care scenario experiments with DecaWave EVB1000 evaluation boards. The study presents preliminary results of a broader research on Home Robot monitoring for elderly people. In the LOS distance estimation scenario, the positioning error was below 15 cm, when the node was closer than 12 m from the target.

Authors of [9] present an interesting solution for a cricket ball spin and 3D trajectory tracking. They use inexpensive sensors and radios embedded in the ball. The experiment platform is composed of an Intel Curie board (IMU + DecaWave UWB) integrated into the ball. Eight Vicon IR cameras are used as a reference measurement system. Reported results from 100 different throws show the median location accuracy of 8 cm and orientation errors of 11 deg. The authors also explore the limitations in measurements of other parameters for the rotating ball movement.

Another study [9], presents an analysis of UWB systems for monitoring the movement in sport based on two examples: cycling and running. Two different localization algorithms (with particle filter and Kalman filter) are implemented, and both show similar performance with an average position error around 20 cm. The head of the athlete is found to be the best tag attachment position and has the lowest average positioning error. The side of the arm and the neck positions are also good alternatives. UWB is considered the most promising cost-effective technology for obtaining centimeter-level positioning and is therefore recognized as a suitable technology for analyzing movement in sport.

The most recently published study is presented by authors of [11], who evaluated the UWB positioning system for indoor track cycling. The optimal position for UWB tag was found to be on the lower back, and the communication range was measured between 32 and 43 meters with a median positioning error of 22cm.

The accuracy of UWB positioning depends on several technological factors and the mode of sensing and calculation of the position. A real-time locating system (RTLS) algorithm can be based on different operation schemes. The trilateration position determination method is based on measuring the signal time of flight (TOF) to a number of anchors placed in different positions. Multilateration is an alternative method based on measuring the time difference of arrival (TDOA) of the signal. DecaWave DW1000 chip [11] allows the accuracy in the range of 10 cm for the line-of-sight (LOS) conditions [6]. It determines the position based on the measuring of the two way signal delay, known as two-way ranging (TWR). Similar research done by [13] states that the most accurate commercial product is DW1000, with a standard deviation of 5.5 cm for the measured distance. It can be said that the DW1000 is the state-of-the-art commercial product for UWB localization at the time of writing; therefore, it has been most often selected for laboratory tests. Authors of [14] have achieved the multipath indoor localization accuracy under 50 cm. The same UWB chip was used by [15] for the research on possible communication protocol improvements between the UWB positioning devices.

The first research question is how to use UWB technology to track the movement of players on the tennis court and to determine the positions in the moments of ball impacts. Another research question, however, is if the selected technology can meet the requirements for precision position tracking on a tennis court. Some basic general requirements for localization in sports are: the positioning error should not exceed 15-20 cm, and the sampling rate should not be lower than 10-15 Hz [16].

II. EXPERIMENTAL MEASUREMENT SYSTEM SETUP

The real-time tennis player positioning system consists of (a) Localino 2.0 [17] in configuration with one UWB tag and several UWB anchors, (b) one IMU device with MEMS accelerometer and gyroscope, and (c) a custom-made LabVIEW application for the synchronization of all signals. The UWB tag position and the tennis racket position were also measured by a professional optical tracking system Qualisys [18].

Fig. 1. shows the attachment of sensors and reflective markers to the body of the player. UWB tag is attached to the cap placed on the top of the player's head. The UWB tag position should allow minimal packet loss in wireless communication with the PC and practically 100% line-of-sight UWB channel conditions to the pair of anchors. The achieved location measurement update rate with Localino 2.0 was around 20 Hz. The exact position of the player and the racket during the action were monitored by the reference optical tracking system Qualisys QTM [18]. For that purpose, we have prepared two rigid bodies for the optical tracking system: one body with three reflective markers at the location of the UWB device was attached to the player's head, another body with four reflective markers was the racket with the local coordinate system origin in its center, as seen in Fig. 1. In the addition to the Localino and Qualisys systems, we have used one IMU

Figure 1. Attachment of wearable sensors and reflective markers. UWB tag is attached to the cap, ball impacts are detected by a sensor attached to the wristband, battery is attached to the belt. For the optical tracking system, the UWB device position object is defined by three reflective markers and the tennis racket is defined as a solid object with four reflective markers with the origin in the racket head center.

device, attached to the tennis player wrist, for sensing the time of ball impact. All measurements from all of the above-mentioned systems have been synchronously recorded in real time by LabVIEW application running on the laptop.

Optical tracking system was composed of eight Oqus 3+ IR cameras arranged around the tennis court. Fig. 2 shows the ground plan of the half of the tennis court with the positions of all Oqus 3+ cameras (c1 to c8), the two Localino 2.0 anchors (L1 and L2), and a wide angle camera. The coordinate system origin is placed at the center of the half-court at the crossing of the serves lines that is at the distance of 6.5 m from the net, as seen in Fig. 2. Consequently, the UWB anchors are behind the player's back at the locations of L1=(-5.45 m, -9.85 m) and L2=(+5.45 m, -9.85 m). Cameras c2 and c5 are at the hip height, all the other cameras are at the heights between 2.5 and 3 m. The entire action was recorded by the GoProHERO6 camera (cam) placed at the net on the left-hand side of the court near camera c1.

III. TEST RESULTS

We have measured the accuracy of the UWB localization system in the LOS conditions on the open space tennis court. The 2D tracking results for the three consecutive forehand strokes are shown as trajectories in Fig. 3(a). The path acquired by the UWB system is given as red line trace; the reference results obtained by the QTM system are shown as blue circles. It can be noticed that the QTM trajectory is interrupted at times when the optical tracking system could not fully see and identify the rigid body at the head of the player. This occurred because of the challenging outdoor conditions that interfered with the Qualisys camera system (strong natural IR light, reflections, etc.).

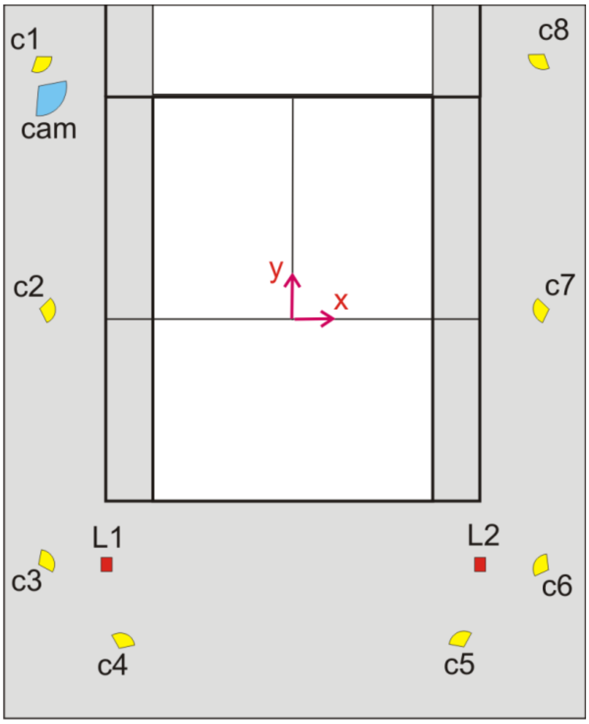

Figure 2. Localization systems field setup: (a) Eight Qualisys cameras (c1-c8) are covering half of tennis court, two UWB anchors are located behind the court (L1, L2), and a wide angle video camera (cam) is positioned near c1.

For the example given in Fig. 3(a) the QTM trajectory is present in the 41% of the entire path, which accounts for 12175 measured positions. For those 2D positions, the mean positioning error of the UWB system is 17.8 cm. The measured positioning error is less than 33cm in 95% of measured position points.

Players' positions at ball impact are essential information for the analysis of their tactics. A series of N=20 measured positions of the player at the time of impact is given in Fig. 3(b). At all identified impact positions measured by the UWB system, we also acquired the accurate positions by the QTM system. The most probable reasons for such success are the relative low speed of the player during the stroke, and markers are seen by many cameras. Because the accuracy of the UWB also depends on the speed of movement, it is no surprise that the measured average positioning error at impact is 11.3 cm, which is lower than for the entire path in Fig. 3(a). The maximum impact positioning error is 22 cm.

Measurement results from the open space tennis court confirm that UWB systems are accurate enough for the acquisition of the 2D trajectory of the player. The time of impact is acquired precisely through sensing the change in values of the absolute acceleration and absolute angular velocity vectors from the wrist-attached IMU.

The record of the consecutive player positions on the tennis court gives accurate feedback information to the coach and also to the player, who assesses the position and movement subjectively. The player is focused primarily on the ball and is not aware of the precise position. Important information is also the classification of strokes (forehand, backhand, volley), which can be acquired from the wrist-attached IMU.

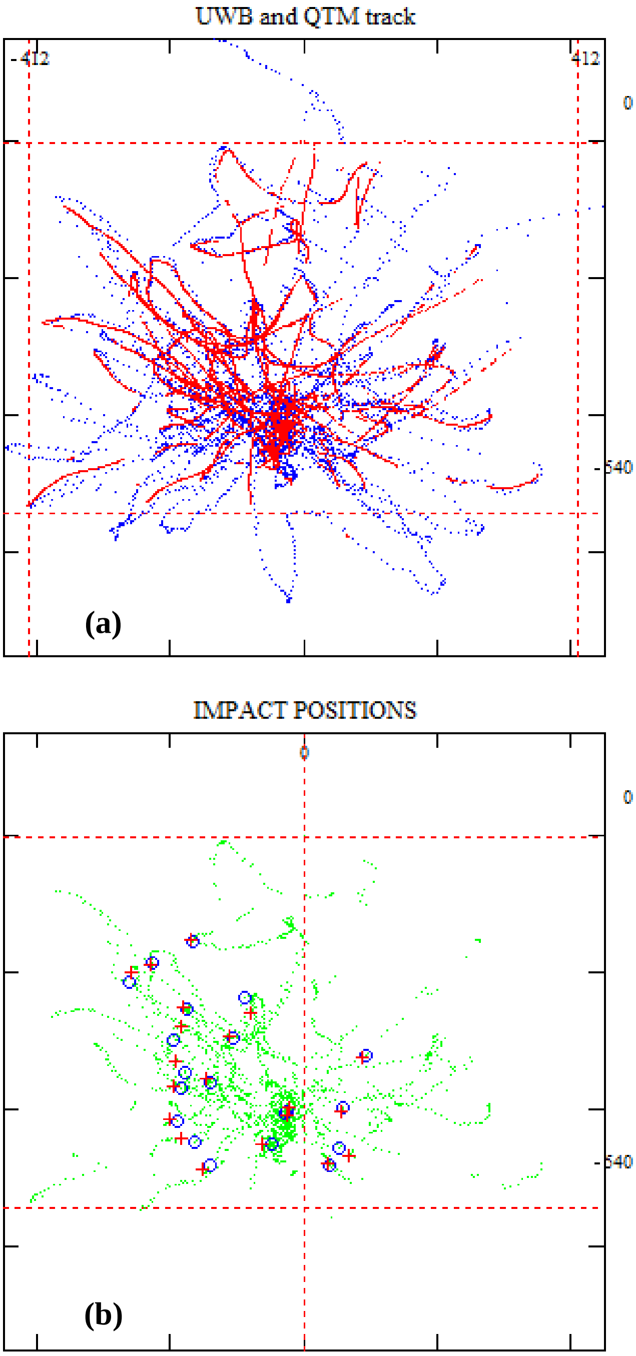

Figure 2. Player's trace and impact positions on a tennis court. (top) Players trace during a long rally: blue points represents UWB localization trace and red points represent high precission measurement results by Qualisys optical tracking system QTM, an average positioning error is 17.8 cm. (bottom) Players positions at measured N=20 impacts: red solid crosses represent UWB localization system results and blue circles represent positions measured with the reference QTM system, an average positioning error is 11.3 cm.

A special challenge would be the acquisition of two additional key parameters of the tennis game: the height of the ball (racket) and the speed of the racket at impact. Those two parameters are accurately acquired by the optical tracking system, as shown in Fig. 4, but much more difficult and less accurate by the available UWB and IMU signals.

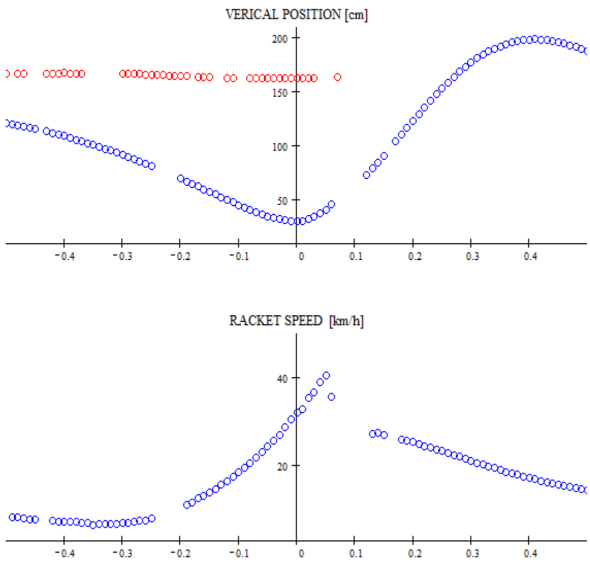

Figure 3. Some additional parameters can be precissely aquired by the optical tracking system. (top) Tennis racket center (blue) and players head (red) distance to ground [cm]. (bottom) Tennis racket center velocity vector magnitude around the impact [km/h].

IV. Conclusion

Our research results show that the development of robust and relatively inexpensive equipment for real-time tracking of the tennis player's trajectory and ball impact positions, based on UWB positioning chipsets and MEMS IMU sensors, is possible. Optical tracking systems are accurate, but expensive and complex for use. Their successful physical and functional set-up requires well trained personnel with a lot of experience. In addition to that, their usability in open space is reduced due to natural sources of IR light, many possible reflections, and they may obstruct the actions. Radio based systems will most probably be considerably cheaper and much easier to use. Their accuracy will not be able to match that of the optical systems, but will most probably be high enough for motion tracking in many sport disciplines. We are confident that in future the UWB positioning technology will play an important role in systems for motion tracking and analysis in sport.

Acknowledgment

This work is sponsored by the Slovenian Research Agency within the research program ICT4QoL - Information and Communications Technologies for Quality of Life (research core funding No. P2-0246) and within the bilateral project between Slovenia and Serbia titled Sensor technologies as support systems for the detection and selection of talents in sport and monitoring the performance of athletes (research core funding No. BI-RS/20-21-023).

References

[1] Zepp Tennis 2 (2020), available online: https://www.zepp.com/shop, accessed 31.8.2018.

[2] Hawk Eye (2020) available online: https://www.hawkeyeinnovations.com/about, accessed 10.1.2020.

[3] Kos, A., Umek, A. (2018). Biomechanical biofeedback systems and applications. Springer.

[4] Leser, R., Baca, A., & Ogris, G. (2011). Local positioning systems in (game) sports. *Sensors*, *11*(10), 9778-9797.

[5] Karapistoli, E., Pavlidou, F. N., Gragopoulos, I., & Tsetsinas, I. (2010). An overview of the IEEE 802.15. 4a standard. *IEEE Communications Magazine*, *48*(1).

[6] Ruiz, A. R. J., & Granja, F. S. (2017). Comparing Ubisense, BeSpoon, and DecaWave UWB location systems: Indoor performance analysis. *IEEE Transactions on instrumentation and Measurement*, *66*(8), 2106-2117.

[7] Chantaweesomboon, W., Suwatthikul, C., Manatrinon, S., Athikulwongse, K., Kaemarungsi, K., Ranron, R., & Suksompong, P. (2016, March). On performance study of UWB real time locating system. In *Information and Communication Technology for Embedded Systems (IC-ICTES), 2016 7th International Conference of* (pp. 19-24). IEEE.

[8] Bonizzoni, E., Puiatti, A., Sapienza, S., Ros, P. M., Demarchi, D., & Bonato, P. (2018, May). UWB Tracking for Home Care Systems with Off-the-Shelf Components. In *Circuits and Systems (ISCAS), 2018 IEEE International Symposium on* (pp. 1-5). IEEE.

[9] Gowda, M., Dhekne, A., Shen, S., Choudhury, R. R., Yang, L., Golwalkar, S., & Essanian, A. (2017, March). Bringing IoT to Sports Analytics. In *NSDI* (pp. 499-513).

[10] Ridolfi, M., Vandermeeren, S., Defraye, J., Steendam, H., Gerlo, J., De Clercq, D., ... & De Poorter, E. (2018). Experimental Evaluation of UWB Indoor Positioning for Sport Postures. *Sensors*, *18*(1), 168.

[11] Minne, K., Macoir, N., Rossey, J., Van den Brande, Q., Lemey, S., Hoebeke, J., & De Poorter, E. (2019). Experimental evaluation of UWB indoor positioning for indoor track cycling. *Sensors*, *19*(9), 2041

[12] DW1000, DecaWave (2018) available online: http://www.decawave.com/products/trek1000, accessed 31.8.2018.

[13] Jiménez, A. R., & Seco, F. (2016, October). Comparing Decawave and Bespoon UWB location systems: Indoor/outdoor performance analysis. In *IPIN* (pp. 1-8).

[14] Kulmer, J., Hinteregger, S., Großwindhager, B., Rath, M., Bakr, M. S., Leitinger, E., & Witrisal, K. (2017, May). Using DecaWave UWB transceivers for high-accuracy multipath-assisted indoor positioning. In *Communications Workshops (ICC Workshops), 2017 IEEE International Conference on* (pp. 1239-1245). IEEE.

[15] Mikhaylov, K., Tikanmäki, A., Petäjäjärvi, J., Hämäläinen, M., & Kohno, R. (2016, March). On the selection of protocol and parameters for UWB-based wireless indoors localization. In *Medical Information and Communication Technology (ISMICT), 2016 10th International Symposium on* (pp. 1-5). IEEE.

[16] Leser, R., Baca, A., & Ogris, G. (2011). Local positioning systems in (game) sports. Sensors, 11(10), 9778-9797.

[17] Localino v2.0 Kit (2018) available online: http://www.localino.net/shop/research/11/localino-v2.0-kit, accessed 31.8.2018.

[18] Qualisys QTM (2020), available online: https://www.qualisys.com/software/qualisys-track-manager/, accessed 10.1.2020.