Smart PDR integration for ubiquitous pedestrian navigation service

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***Abstract*—Quite recently, considerable attention has been paid to pedestrian navigation services, since they provide people with guidance and tracking information everywhere especially in an unfamiliar environment. In the literature, indoor and outdoor navigation has been widely investigated. However, studies on the continuity of pedestrian navigation service, still lacking. This paper presents a novel positioning technology selection algorithm able to integrate the pedestrian dead reckoning (PDR) technique, for short-term, through the navigation process either to improve the calculation of the mobile unit's (MU) position and/or to maintain the continuity of the service. The integration of the PDR is inferred based on the fuzzy logic approach. In fact, the proposed algorithm defines a fuzzy variable called "margin" which identifies four different states, namely, confidence, intermediate, confusion and critic. The PDR technique is only incorporated in the last two states in two ways: either fused with the used radio frequency (RF) positioning technology or stand-alone if no RF technology is available. The algorithm performance is evaluated based on an empirical study.**

***Index Terms*—Pedestrian navigation system, selection algorithm, positioning technology, PDR, fuzzy logic.**

I. Introduction

In the last few years there has been a growing interest in pedestrian navigation services in helping the MU's user to find his position and to guide him to the intended destination. Outdoor, the global navigation satellite system (GNSS) remains the reference of outdoor navigation. On the other hand, indoor navigation has extensively researched and still in its infancy with the lack of standards. However, most of the previous studies have scarcely investigated the seamless transition between these two environments.

Our core research issue is to develop an ubiquitous pedestrian navigation prototype that provides a continuous navigation service everywhere, particularly in indoor environments. This goal can only be achieved if the MU's position can be calculated, anytime, from launching the application until reaching the desired destination. In fact, two main groups of positioning technologies have been defined in the literature to compute the MU's position. Firstly, the RF based technologies such as the WiFi, the Bluetooth (BT), the GPS and the radio frequency identification (RFID), and secondly, the MU's sensors based technologies. The key challenges to overcome are: *(i)* the selection of the best positioning technology(ies) in order to calculate the MU's position and *(ii)* the seamless switch between the available positioning technologies, also known as a handoff, to maintain the service continuity everywhere.

In fact, to achieve an ubiquitous navigation service, the integration of the PDR either stand-alone or fused with another technology is required, especially when the MU's position is hardly provided. This integration should preferably be for short-term as the PDR technique is based on the MU's sensors data and its use for long-term rapidly drains the MU's battery. In this paper, we propose a new algorithm able to integrate the PDR technique at any time throughout the navigation process using the fuzzy logic approach. This integration is temporary and can be fused with another technology or stand-alone if no technology is captured.

The remainder of this paper is structured as follows: Section II reviews the PDR technique and the fuzzy logic approach. Section III summarizes the related work. Section IV outlines in details the proposed algorithm. Section V presents the empirical results and section VI concludes the paper.

II. Background

In this section we briefly review the PDR algorithm and the fuzzy logic technique.

A. Pedestrian dead reckoning (PDR)

The PDR algorithm calculates a relative 2D MU's position using signal information transmitted from specific sensors incorporated in the MU such since the accelerometer and the gyroscope without the need of a pre-installed infrastructure [1], [2]. This technique is based on the latest previous know position and defines two different concepts:

- *The traveled distance:* is determined by recording the number of steps the user takes and computing their length.
- *The heading update:* is estimated according to two various directions: *(i)* an absolute direction transmitted from several sensors (i.e., digital compass) and (ii) a relative direction provided by the gyroscope sensor.

Two main types of PDR were highlighted in the literature [1]:

1) Inertial navigation system (INS): depends only on the sensor as it computes the MU's position by estimating the sensor 3D trajectory.
2) Step-and-Heading System (SHS): depends on the pedestrian as it calculates the position based on 2D vector information: {the step or the stride length, the heading}.

B. Fuzzy logic approach

The fuzzy logic is proposed by Zadeh in 1965 [3] to fix conflicting problems in a similar manner as the human reasoning. This approach consists of three steps [4], as illustrated in figure 1:

1) *Fuzzification:* in this step each input data is converted into fuzzy data by assigning it with different linguistic values, depicted by a membership function (MF). The MF takes many forms such as the triangular and the Gaussian waveforms.
2) *Inference engine:* in this step a list of IF-THEN rules is developed to describe the final decision to be taken. These rules are expressed in terms of the linguistic values and a set of logical operators.
3) *Defuzzification:* in this step the fuzzy output is converted into a classical data.

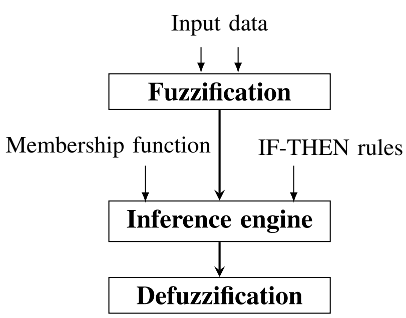

Fig. 1. Fuzzy bloc

III. Related work

In this part we start by surveying the PDR's integration in some pedestrian navigation applications and then we summarize the principle of our previous algorithm [5].

A. PDR's integration in the literature

In the last decade, the PDR technique was widely integrated for navigation services in the form of INSs, specifically, for long-term, in two different ways: stand-alone or fused with other RF positioning technologies [6], [7], [8].
In [6], the authors proposed a continuous pedestrian navigation algorithm using the INS throughout the navigation process either fused with the BT if the user is indoor or with the GPS if the user is outdoor.
In [7] a positioning technology selection algorithm was developed to achieve an ubiquitous positioning service. This algorithm compared the position information provided by the GPS, the BT low energy (BLE) and the INS and selected the positioning technology with the accurate information. The proposed solution involved a significant number of handoff, causing a fast discharge of the MU's battery.
In [8] a seamless indoor/outdoor pedestrian navigation approach based on the GPS, the INS and the WiFi was designed. Outdoor, the implemented approach fused the INS with the GPS to provide an accurate positioning service, whereas inside the buildings the WiFi was used stand-alone or integrated with the INS.

B. Our previous selection algorithm

In our previous work [5] we developed a selection algorithm called UCOSA (User-Centric pOsitioning technologies Selection Algorithm), as outlined in figure 2. The UCOSA began by inferring the need of triggering a handoff process between the available positioning technologies using the fuzzy logic approach. If a switch process was required, then a selection procedure of the best positioning technology was launched. The UCOSA mainly focused on the RF positioning technologies and have used the PDR solely when no RF technology was captured. The UCOSA introduced a specific parameter: "**margin**" to trigger the selection procedure and its value was inferred according to three criteria: the positioning technology metrics (e.g. the received signal strength (RSS), the signal noise ratio (SNR)), the MU's motion pattern (e.g. walking, standing, etc.) and the MU's battery level. The margin parameter defined three major states:

- *Confidence:* in this state, the MU's position was easily provided ensuring high performance of the navigation application.
- *Intermediate:* in this state, a navigation service was characterized by an acceptable level of performance.
- *Critic:* in this state, the MU's position was hardly calculated, thus the application should initiate a handoff process to select the best available positioning technology to switch on.

IV. Proposal algorithm: UCOSA*

In this section we start by describing the principle of the proposed algorithm UCOSA*, then we present the developed rules able to infer the need of integrating the PDR technique and we finish by detailing the different steps of the UCOSA*.

A. Proposed algorithm: UCOSA*

1) Principles: based on the algorithm presented in our earlier work [5], the purpose of this paper is to develop an algorithm able to integrate the PDR technique, for short-term, through the navigation process either to improve the calculation of the MU's position and/or to maintain the continuity of the service. The main issue is to identify when this technique should be initiated. This decision depends on many criteria, as shown in figure 4, and on several ambiguous propositions. Therefore, we adopt the fuzzy logic approach to solve this problem.

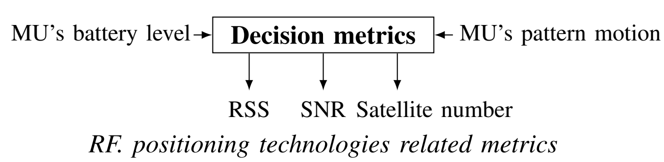

Fig. 4. Decision metrics

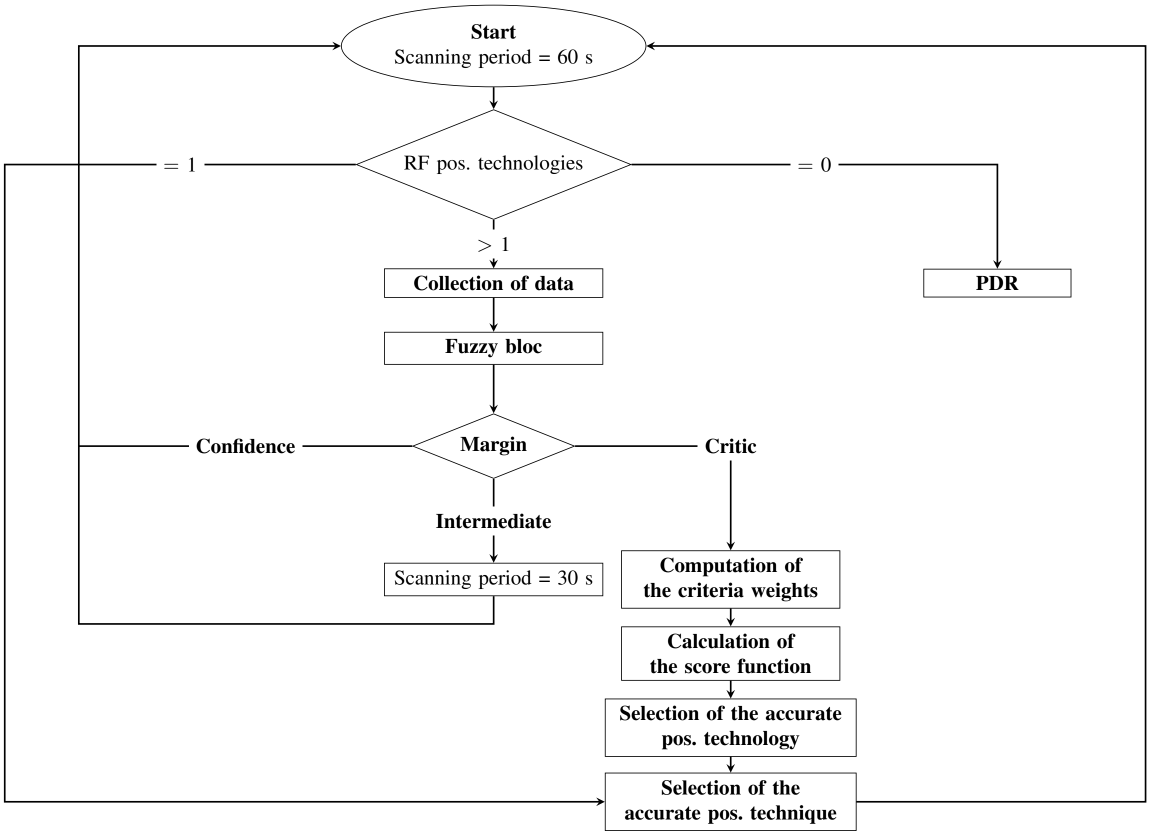

Fig. 2. UCOSA algorithm [5]

As in our last work [5], we use the same parameter "margin" to infer the need of integrating the PDR and initiating the handoff process. We define four linguistic values, instead of three, namely confidence, intermediate, confusion and critic (see figure 5). The two first states are described in section III and the two last states are depicted as follows:

- *Confusion:* this step is specified by the performance degradation of the different criteria values that affect the margin parameter. In this stage, the calculation of the MU's position is improved by fusing data from the used RF positioning technology and the MU's sensors.
- *Critic:* this step is marked by a significant degradation of the various criteria values, involving the initiation of the handoff process to another available positioning technology.

2) IF-THEN inference rules: we present on this part the IF-THEN rules which infer the margin states: critic and confusion (i.e. the two states that integrate the PDR technique). The two steps confidence and intermediate are provided in the same way as in the UCOSA. But, before explaining the different rules, we start by identifying the various linguistic values of the input parameters. For each parameter, we specify, as shown in table II, the linguistic, the actual and the standardized values. For the RF positioning technologies metrics, we assign the following linguistic values: {very low, low, medium, high},

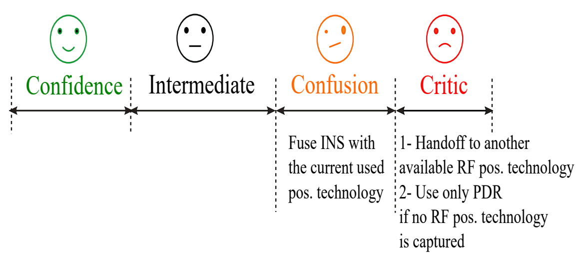

Fig. 5. Different states of the margin parameter

instead of the three considered values in the UCOSA case: {low, medium, high}. In fact, among the defined linguistic values only "*very low*" and "*low*" are used to develop the IF-THEN rules since the PDR is integrated when the received signal of the used technology is weak. The actual values of the MU's motion pattern and the RSS WiFi were adopted from [9].

The inference rules are developed to meet the following baseline conditions:

1) To get the most accurate MU's position.
2) To maintain an acceptable level of the MU's battery as long as possible. This requirement implies firstly, the minimization of the number of handoffs and secondly, the integration of the PDR for short-term.

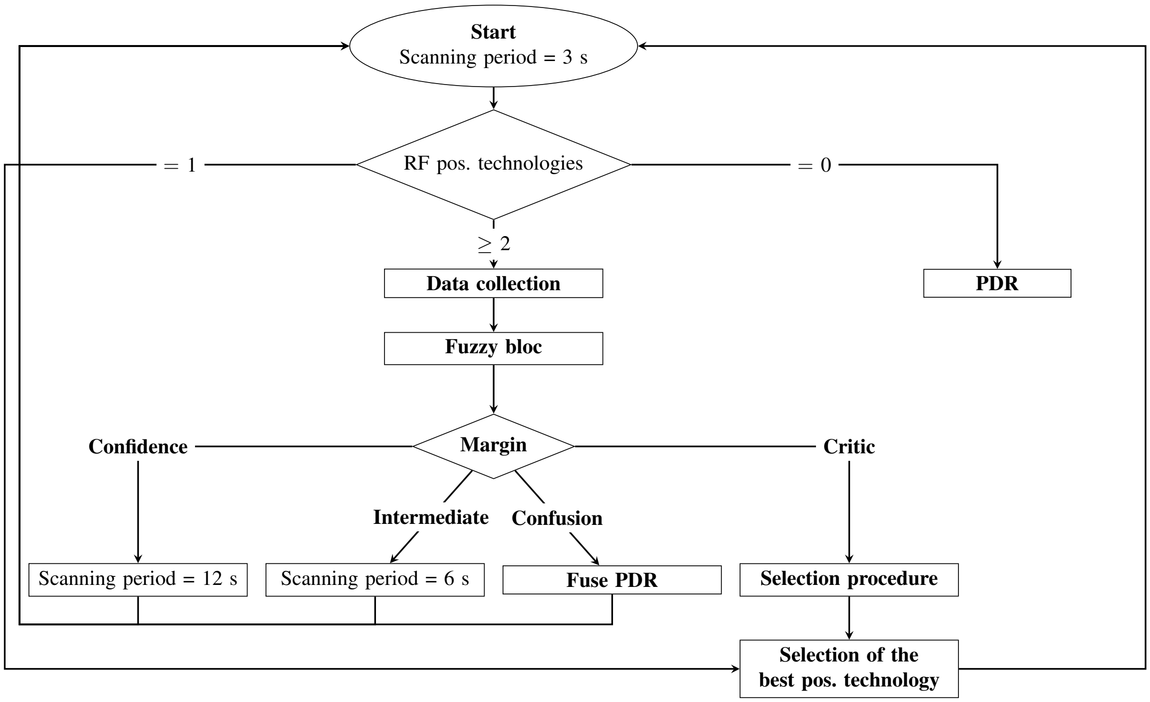

Fig. 3. UCOSA* algorithm

The critic state is defined by:
- The metrics values of the used positioning technology are very low. In this case the MU is losing connection. Thus, whatever the level of the MU's battery and the physical activity of the MU's user, a handoff to another technology is required for the navigation service continuity. This state is described by the first row of the table I and corresponds to the following rule:
↪ *IF Metric Value IS Very low THEN Margin IS Critic.*
- The metric value of the used positioning technology is low and the MU's battery level as well as the MU's motion pattern are able to trigger the switch process without greatly affecting the MU's battery level. This case is depicted by the second and the third row of the table I and is expressed by the below two rules:
↪ *IF Metric Value IS Low AND MU's Battery level IS High THEN Margin IS Critic.*
↪ *IF Metric Value IS Low AND MU's Battery level IS Medium AND MU's motion pattern IS Standing THEN Margin IS Critic.*
The confusion state is defined to improve the accuracy of the navigation application and to avoid the handoff triggering as long as possible. This state is given by the following two rules:
↪ *IF Metric Value IS Low AND MU's Battery level IS Medium AND MU's motion pattern IS On the Move THEN Margin IS Confusion,* (fourth row of the table I).
↪ *IF Metric Value IS Low AND MU's Battery level IS Low THEN Margin IS Confusion,* (fifth row of the table I).

3) Algorithm: the algorithm UCOSA* is only applicable through the navigation process and not at launching the application since the PDR calculates a relative position. The UCOSA* is triggered if any of those conditions are present:

1) the MU captures a new RF positioning technology.
2) the MU loses connection with an old RF positioning technology.

As highlighted in figure 3, the algorithm starts scanning the available RF positioning technology(ies). If no technology is detected, then the unique solution is the use of the PDR. If only one RF technology is available, so skip to the step: "*selection of the best pos. technology*". Otherwise, the application collects all the input data and injects them into the fuzzy bloc to infer the margin's linguistic value. Based on this value, four different actions are possibles:

1) *Confidence:* in this state, the parameter "*scan period*" that specifies the time after which we determine the available RF positioning technologies, is increased and equals to 12 s.
2) *Intermediate:* this case is marked by a double increase in the initial scan period.
3) *Confusion:* this step leads to the fusion of the PDR positioning with the used RF technology.
4) *Critic:* this step involves the disconnection from the current RF positioning technology and thus the switch to another available RF technology to continue the navigation service. The selection procedure consists of calculating a score for each available positioning technology based on a score function and the technology

TABLE I
INFERENCE OF CRITIC AND CONFUSION MARGIN STATES

	Positioning metrics values		**MU's battery level**			**MU's pattern motion**		**Margin**
	Low	*Very low*	*High*	*Medium*	*Low*	*Standing*	*On the Move*	
1		*		–			–	Critic
2	*		*				–	Critic
3	*			*		*		Critic
4	*			*			*	Confusion
5	*				*		–	Confusion

– whatever the entered value

with the highest score is chosen.

The different values of the parameter *scan period* are appointed arbitrary and it will be proven or modified experimentally.

V. EMPIRICAL RESULTS

In this section, we first describe the implementation steps of the fuzzy bloc and then turn to present the empirical results of the application of the algorithm UCOSA* on a considered scenario.

A. Fuzzy bloc implementation

The fuzzy bloc was implemented based on the open source Java library JFuzzy logic [10], [11] which designed to create the fuzzy variables and the inference engine.

1) Fuzzy variables implementation: the fuzzy bloc has three input parameters, namely, the metrics values, the MU's battery level and the MU's motion pattern and its single output parameter is the margin.
Figure 6 shows the membership function of the parameter *Margin*, for which the universe of discourse varies between 0 and 1 and defines the four linguistic values:

- Confidence [0, 0.25[
- Intermediate [0.25, 0.5[
- Confusion [0.5, 0.75[
- Critic [0.75, 1]

The standardization function is given as follows:

$$N_x = \frac{Current_{value}(x) - Min_{value}(x)}{Max_{value}(x) - Min_{value}(x)}$$

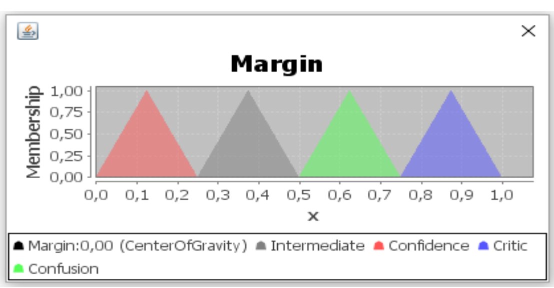

Fig. 6. Membership function of the margin parameter

2) Considered scenario: the performance of the proposed algorithm is evaluated based on the path shown in figure 7. The user is moving from the source S to the destination D via the positions: S_0, S_1, S_2, S_3, S_4 and S_5 and throughout the navigation process, his MU can capture one or more of the following positioning technologies: GPS, WiFi and RFID.

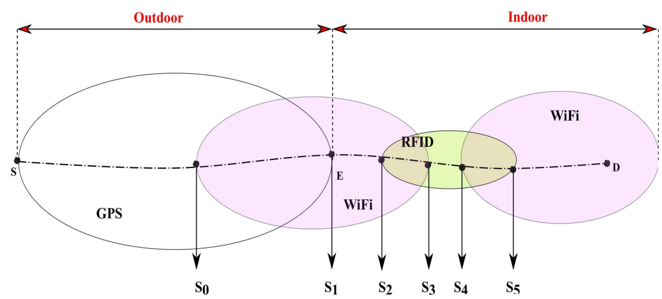

Fig. 7. On the move from *S* to *D* via S_0, S_1, S_2, S_3, S_4 and S_5

3) Results: the algorithm UCOSA* is implemented in Java. The overall input values as well as the margin state of each position are summarized in table III.
- *At position S*, the navigation process is initiated using the GPS as the only available RF positioning technology.
- *At position* S_0, the MU starts capturing the WiFi than the UCOSA* is triggered and since two positioning technologies are available the margin is calculated and its value is equal to 0.625, which coincides with the confusion state. From this point the PDR technique is integrated to improve the MU's position computation.
- *At position* S_1, the MU is losing the GPS connection. The UCOSA* is initiated again and the margin value corresponds to the critic state (see table III). At this point, a switch from the GPS to the WiFi is launched and the use of the PDR is interrupted.
- *At position* S_2, the MU begins detecting weak signals of the RFID technology. Thus the UCOSA* is triggered and the margin value is equal to 0.624 (e.g. confusion state). From this place the PDR is integrated.
- *At position* S_3, the MU is losing the WiFi connection. Hence the UCOSA* is launched and the margin value is equal to 0.873 (e.g. critic state). A handoff between the WiFi and the RFID is needed and the PDR positioning is suspended.
- *At position* S_4, the MU is located within the overlapped area of the RFID and the WiFi. The UCOSA* is inaugurated and the margin value corresponds to the confusion state (see table

TABLE II
INPUT PARAMETERS ACTUAL AND STANDARDIZED VALUES

Input parameters	Linguistic values	Actual values	Standardized values
MU's battery level	High	[50 %, 100 %]	[0.5, 1]
	Medium	[15 %, 60 %]	[0.15, 0.6]
	Low	[0 %, 20 %]	[0, 0.2]
MU's pattern motion	Standing	[0 m/s, 14 m/s] [9]	[0, 0.5]
	On the Move	[0 m/s, 27 m/s] centered at 14 m/s [9]	[0, 1] centered at 0.5
RSS WiFi	High	[-41 dB, -11 dB]	[0, 0.28]
	Medium	[-63 dB, -35 dB]	[0.16, 0.51]
	Low	[-80 dB, -51 dB]	[0.36, 0.7]
	Very Low	[-93 dB, -70 dB] [9]	[0.63, 1]

TABLE III
RESULTS

		S_0	S_1	S_2	S_3	S_4	S_5
Technology		GPS	GPS	WiFi	WiFi	RFID	RFID
SNR		0.57	0.82	0	0	0	0
RSS_{WiFi}		0.9	0.5	0.56	0.95	0.95	0.4
RSS_{RFID}		0	0	0.9	0.3	0.65	0.87
Motion pattern		0.6	0.74	0.55	0.3	0.7	0.2
Battery level		0.4	0.4	0.3	0.3	0.2	0.2
Sat_{num}		0.57	0.82	0	0	0	0
Margin	**UCOSA****	0.625 ⇓ Confusion	0.875 ⇓ Critic	0.624 ⇓ Confusion	0.873 ⇓ Critic	0.697 ⇓ Confusion	0.874 ⇓ Critic
	UCOSA	0.594 ⇓ Intermediate	0.681 ⇓ Critic	0.627 ⇓ Intermediate	0.830 ⇓ Critic	0.618 ⇓ Intermediate	0.830 ⇓ Critic

III). From this location, the PDR positioning is fused with the currently used technology.
- *At position* S_5, the MU is in the border zone of the RFID technology. The UCOSA* is initiated and the margin value is equal to 0.874, which complies with the critic state. A handoff to the WiFi is triggered and the use of the PDR is interrupted again.
The results have obtained are compatible with the principle of the algorithm UCOSA*. A comparison between UCOSA and UCOSA* is made, as illustrated in table III, shows that the two algorithms give the same results in the critic margin case, whereas the difference consists of inferring the intermediate margin.

VI. CONCLUSION

This paper proposes a novel positioning technology selection algorithm which integrated the PDR technique in an intelligent way based on the fuzzy logic approach in order to improve the MU's position calculation and to maintain the continuity of the navigation service. The performance of the proposed algorithm is proven by an empirical study. In our future work, we intend to concentrate on the development of an Android application for actual results.

REFERENCES

[1] Robert Harle. A survey of indoor inertial positioning systems for pedestrians. *IEEE Communications Surveys & Tutorials*, 15(15):1281–1293, 2013.

[2] Wiem Fekih Hassen and Faiza Najjar. A positioning handoff decision algorithm for ubiquitous pedestrian navigation systems. In *Advanced Information Networking and Applications (AINA), 2016 IEEE 30th International Conference on*, pages 487–494. IEEE, 2016.

[3] Lotfi A Zadeh. Fuzzy sets. *Information and control*, 8(3):338–353, 1965.

[4] W Fekih Hassen and F Najjar. A positioning technology switch algorithm for ubiquitous pedestrian navigation systems. *13th IEEE/IFIP International Conference on Embedded and Ubiquitous Computing*, pages 124–151, Porto, Portugal, October 21-23, 2015.

[5] Wiem Fekih Hassen, Faiza Najjar, Lionel Brunie, Harald Kosch, and Yahya Slimani. User-centric positioning technology selection algorithm for pedestrian navigation service. *Wireless Personal Communication*, Submitted, 2017.

[6] Xianghong Li, Dongyan Wei, Qifeng Lai, Ying Xu, and Hong Yuan. Smartphone-based integrated PDR/GPS/Bluetooth pedestrian location. *Advances in Space Research*, 59(3):877–887, 2017.

[7] Kenichi Tabata, Hiroki Konno, Koichi Tsuno, Wataru Morioka, Akihiko Nishino, Madoka Nakajima, and Naohiko Kohtake. The design of selective hybrid positioning by utilizing accuracy information for indoor-outdoor seamless positioning and verification in Tokyo station. In *Indoor Positioning and Indoor Navigation (IPIN), 2015 International Conference on*. IEEE, 2015.

[8] Jiantong Cheng, Ling Yang, Yong Li, and Weihua Zhang. Seamless outdoor/indoor navigation with WIFI/GPS aided low cost inertial navigation system. *Physical Communication*, 13:31–43, 2014.

[9] Anita Singhrova and Nupur Prakash. Vertical handoff decision algorithm for improved quality of service in heterogeneous wireless networks. *IET communications*, 6(2):211–223, 2012.

[10] Pablo Cingolani and Jesús Alcalá-Fdez. jfuzzylogic: a java library to design fuzzy logic controllers according to the standard for fuzzy control programming. *International Journal of Computational Intelligence Systems*, 6(sup1):61–75, 2013.

[11] Pablo Cingolani and Jesus Alcala-Fdez. jfuzzylogic: a robust and flexible Fuzzy-Logic inference system language implementation. In *FUZZ-IEEE*, pages 1–8. Citeseer, 2012.