Localization, Tracking, and Automatic Personal Identification in GPS-denied Environments

A Solution based on a Wireless Biometric Badge

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***Abstract*— The demonstration focuses on presenting the capabilities of a wireless biometric badge integrating localization and tracking functionalities along with an automatic personal identification mechanism to control the access to restricted areas with a high level of security. The wireless biometric badge is the result of R&D activities conducted by several professors, researchers, and students from the Center of Excellence in Research DEWS at the University of L'Aquila in Italy, as well as its R&D Spin-Off WEST Aquila S.r.l.**

Keywords - positioning, tracking, GPS-denied environments, biometric badge identification

I. INTRODUCTION

Future wireless communication systems will have to enable and provide a multiplicity of services for a tremendously increasing number of mobile users. In this context, it is very important that wireless technologies might provide these services in a secure and robust way to the final user, by guaranteeing the privacy of users regardless from the specific and requested service. In such a context, biometric technologies are expected to play a fundamental role for delivering wireless services in an always increasing secure way. Moreover, future services are expected to be more and more specialized to the user personal needs, as well as user's current location in space on a given time. In such a context, the accurate availability of user-location will be an integral part of future wireless devices to guarantee context-awareness functionalities.

II. AIMS AND MOTIVATIONS

A. Objective

The present work consists in showing that the badge designed by WEST Aquila represents an integrated solution for localization and tracking for radio-navigation applications, as well as for automatic personal identification in realistic GPS-denied environments, such as indoor buildings.

B. Badge Description

Our embedded biometric badge (Fig. 1) is a "system-on-badge", which can perform four main tasks: i) localize people using distributed localization techniques, ii) scan and verify fingerprints of people, iii) check if a user is the badge's owner based on fingerprint matching, and iv) send related outcomes wirelessly to the rest of the system (e.g., to a gateway, which interconnects the badge to the rest of the infrastructure), without the need to transmit biometric data of the user over the wireless medium (so, in a secure way from the point of view of transmitting critical data of the user).

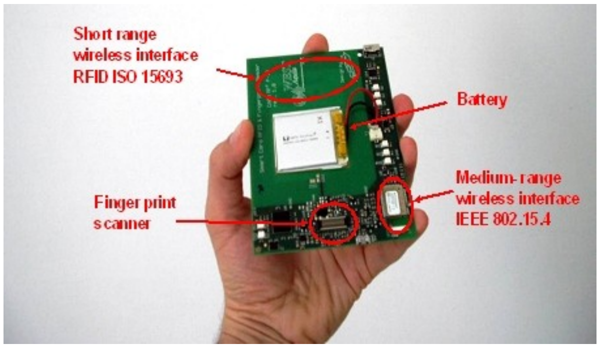

Figure 1. Biometric Badge

The badge is equipped with:

- the Texas Instruments' SoC CC2430, which embeds an INTEL 8051 micro controller and a radio transceiver CC2420 based on the IEEE 802.15.4 standard. It is used for wireless medium-range communications, as well as localization operations;

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- a fingerprint sensor reader with its embedded companion chip provided by UPEK. This chip is the key element for handling biometric data: it allows to authenticate people based on fingerprint information, as well as store data in a memory protected from physical external attacks. Moreover, only this chip and the gateway know how to decode the messages they send to each other;
- a RFID tag based on the ISO15693 standard and its companion chip provided by Montalbano Technology, which allow the microcontroller to get access to data stored in the tag;
- a rechargeable battery, its driver to monitor the charge status, and a user interface with 8 leds and a push-button.

III. ESD: AN IMPROVED OPTIMIZATION SW ROUTINE FOR POSITIONING

The wireless biometric badge consists of several components. In this section, we will briefly describe the module that allows to perform localization operations.

The badge is equipped with a novel distributed localization algorithm, which is called ESD (Enhanced Steepest Descent) [1,2]. In particular, since this method represents an improved version of the well–known Steepest Descent (SD), the latter one is briefly summarized as well. The following notation will be used to describe the algorithm (please, refer also to [2] for a more detailed description): i) bold symbols are used to denote vectors and matrices, ii) $(\cdot)^T$ denotes transpose operation, iii) $\nabla(\cdot)$ is the gradient operator, iv) $\|\cdot\|$ is the Euclidean distance, v) $\angle(\cdot,\cdot)$ is the phase angle between two vectors, vi) $\boldsymbol{u_j} = [u_{j,x}, u_{j,y}, u_{j,z}]^T$ denotes the estimated position of the unknown node U_j , vii) $\mathbf{u_j} = [u_{j,x}, u_{j,y}, u_{j,z}]^T$ is the trial solution of the optimization algorithm for the unknown node U_j, viii) $\mathbf{a_i} = [x_i, y_i, z_i]^T$ with i=1,..,N are the positions of the anchor/reference nodes A_i, and ix) $d_{j,i}$ denotes the estimated (via ranging measurements) distance between reference node A_i and the unknown node U_j.

A. Multilateration Methods

Both SD and ESD algorithms belong to the family of multilateration methods. In particular, in such methods the position of an unknown node U_j is obtained by minimizing the error cost function $F(\cdot)$ defined as follows:

$$\boxed{F(\mathbf{u}_j) = \sum_{i=1}^{N} \left(d_{j,i} - \|\mathbf{u}_j - \mathbf{a}_i\|\right)^2}$$

Figure 2. Error cost function to be minimized

The minimization of the error cost function can be done using a variety of numerical optimization techniques, each one having advantages and disadvantages in terms of accuracy, robustness, speed, complexity, and storage requirements [3]. Since optimization methods are iterative by nature, we will denote by the index k the k–th iteration of the algorithm, and with $F(\mathbf{u}_j(k))$ and $\mathbf{u}_j(k)$ the error cost function and the estimated position at the k–th iteration, respectively.

1) Steepest Descent (SD): The classical SD is an iterative line search method that allows to find the (local) minimum of the cost function of Fig. 2 at step k + 1 as follows [3, pp. 22, sec. 2.2]:

$$\mathbf{u}_j(k+1) = \mathbf{u}_j(k) + \alpha_k \cdot \mathbf{p}(k)$$

where α_k is a step length factor, which can be chosen as described in [3, pp. 36, ch. 3], and $p(k) = -\nabla F(\mathbf{u}_j(k))$ is the search direction of the algorithm. In particular, when the optimization problem is linear, some expressions exist to compute the optimal step length in order to improve the convergence speed of the algorithm. On the other hand, when the optimization problem is non–linear, as considered for positioning problems, a fixed and small step value is in general preferred in order to reduce the oscillatory effect when the algorithm approaches a solution. In such a case, we have $\alpha_k = 0.5\mu$ [4], where μ is the learning speed.

2) Enhanced Steepest Descent (ESD): The classical SD method provides, in general, a good accuracy in estimating the final solution. However, it often requires a large number of iterations, which may result in a too slow convergence speed for mobile ad–hoc wireless networks. The proposed ESD algorithm aims at improving the convergence speed of the SD algorithm, while trying to maintain its good accuracy for position estimation. The basic idea behind the ESD algorithm is to adjust the step length value α_k as a function of the current and previous search directions $\mathbf{p}(k)$ and $\mathbf{p}(k-1)$, respectively. In particular, α_k is adjusted as shown in Fig. 3, where $\theta_k = \angle(\mathbf{p}(k), \mathbf{p}(k-1))$, $0<\gamma<1$ is a linear increment factor, $\delta>1$ is a multiplicative decrement factor, and $\theta_{\min}$ and $\theta_{\max}$ are two threshold values which control the step length update.

$$\boxed{\begin{cases} \alpha_k = \alpha_{k-1} + \gamma & \text{if} \quad \theta_k < \theta_{\min} \\ \alpha_k = \alpha_{k-1}/\delta & \text{if} \quad \theta_k > \theta_{\max} \\ \alpha_k = \alpha_{k-1} & \text{otherwise} \end{cases}}$$

Figure 3. Adaptive step length rules for ESD

By using the four degrees of freedom γ, δ, $\theta_{\min}$ and $\theta_{\max}$, we can simultaneously control the convergence rate of the algorithm, and the oscillatory phenomenon when approaching the final solution in a simple way, and without appreciably increasing the complexity of the algorithm when compared to the SD method. Basically, the main advantage of the ESD algorithm is the adaptive optimization of the step length factor α_k at run time, which allows to dynamically either accelerate or decelerate the convergence speed of the algorithm as a function of the actual value of the function to be optimized.

IV. DEMO DESCRIPTION

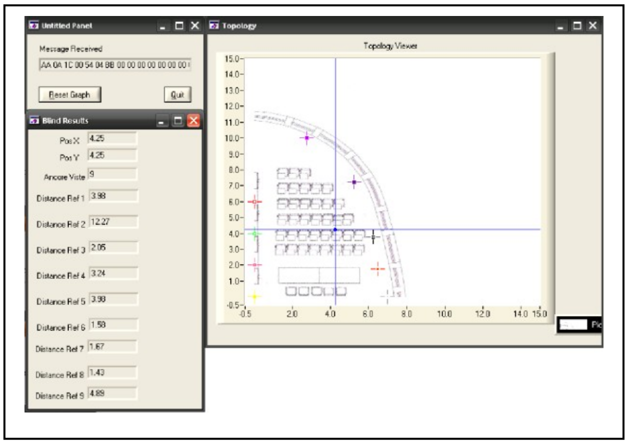
The aim of the demo is to show two main functionalities of our biometric badge. On the one hand, we show that every badge-provided user can be localized in a simple way by resorting to the aforementioned location algorithm [5,6], which runs in the badge's microcontroller unit. Localization is performed in a distributed and decentralized fashion by receiving data from the fixed anchor/reference nodes (see Fig. 4) and estimating the related distances based on RSSI measurements. On the other hand, we show that when a user approaches an area with restricted access, the system (e.g., a RFID reader in the proximity of the entrance) can detect it, as well as activate the authentication procedure of the user, thus either allowing or denying the user to get access to the area depending on the authentication outcome. This latter authentication procedure takes place via fingerprint matching. However, the system is designed to avoid any wireless transmission of critical users' data.

Figure 4. Battery powered anchor node

Although, in the current prototype, localization is performed using the SW routine briefly described in Section III, HW location engines, such as the TI's CC2431, are currently available on the market [7]. In particular, from experiments conducted in [5], we have shown that jointly using HW and SW localization algorithms can significantly improve positioning accuracy. A novel badge prototype is going to be developed integrating both HW and SW location engines.

Finally, Fig. 5 and Fig. 6 also show a typical measurement scenario where the demo is performed and the host application interface that a user has available to analyze the behavior of localization and tracking operations, respectively.

Figure 5. Measurement scenario



Message Received AA 0A 1C 00 54 04 BB 00 00 00 00 00 00 00

Pos X 4.25

Pos Y 4.25

Ancore Viste 9

Distance Ref 1 3.98

Distance Ref 2 12.27

Distance Ref 3 2.05

Distance Ref 4 3.24

Distance Ref 5 3.98

Distance Ref 6 1.58

Distance Ref 7 1.67

Distance Ref 8 1.43

Distance Ref 9 4.89

Figure 6. Host application interface

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