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A novel range-free localization algorithm to turn connectivity traces and motion data into localization information

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ABSTRACT

This paper presents a novel range-free localization algorithm that has been originally designed to help in the characterization of human behavior by turning connectivity traces of mobile nodes into localization information. It is based on an error function that uses connectivity between nodes and information about their maximum velocity and that is solved by iterative minimization using unconstrained optimization. The resultant trajectories are evaluated with respect to the localization solution space (LSS), a multi-dimensional space consisting of all solutions that satisfy completely the conditions of the problem. The algorithm is evaluated through extensive simulations in scenarios with different levels of connectivity and under regular and irregular conditions in the communications. The complementarity with other localization algorithms is presented by using their results as initialization stage for this algorithm. Finally, it is applied to a real database that provides information about Bluetooth-based connectivity and motion of people in an office scenario, rendering satisfactory results and hence, validating the practicability of the proposed algorithm as a framework to obtain localization traces.

1. Introduction

The characterization of human behavior at different levels has been a matter of interest in many disciplines. How humans interact, when, with whom and where, are some questions of interest in social networks. Beyond the analysis of social networks in the Internet, there is an increasing trend in the research community that offers answers to the former three questions in the form of social interaction based on the physical proximity of humans. The irruption of small electronic devices with wireless communication capabilities has encouraged the use of wearable devices that measures proximity by the detection of near devices (connectivity traces), which is used as an indicator of the interaction between humans. In addition to the use of connectivity traces for the analysis of human interaction, the information about localization of people can be used to achieve a more complete characterization of human behavior. Despite the high number of existing initiatives to collect connectivity traces and analyze human interaction using different wireless technologies such as WiFi [1,2], cellular communications [3–6], Bluetooth [7–9] or combinations of them [10–12], most of them do not have information about the localization of the individuals under study. Outdoors, the use of specific localization technologies such as GPS makes easier to obtain accurate position of humans, but indoors, localization is much more complex,

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and usually less accurate when the means to obtain their position are the same used to measure their interaction: connectivity and motion.

The original motivation of this work is our necessity of a complete human characterization based not only on their interaction, measured in terms of proximity, but also on their localization. This is the continuation of the work presented in [9], which describes a connectivity trace system based on Bluetooth able to obtain high reliability connectivity traces and information about the motion of people. This paper presents a new range-free localization algorithm based on connectivity and maximum velocity of nodes (LACMV) to turn connectivity traces and motion data into localization information.

The nodes participating in a localization problem can be classified in two categories: target nodes, which are entities whose position must be obtained, and beacon nodes, which are entities of known position that are used as localization references. LACMV uses two types of connectivity data: between target nodes and between target and beacon nodes. LACMV is a flexible localization algorithm that can work with both connectivity and motion data, or only connectivity data, and unlike other localization algorithms, it can be applied to networks with low connectivity between nodes (sparse networks). Its flexibility makes of LACMV a useful tool for the research community to turn easily connectivity traces (with or without motion data) into localization information.

Its applicability is straightforward to real connectivity databases, as it is shown in Section 5, which describes the procedure to apply LACMV over a sample of the Humanet database of [9]. This database was collected in an office scenario under particular conditions (summarized in Section 5), which demonstrates the adaptability of LACMV to be used in any type of network and scenario that provides just connectivity information and, if they are available, motion data. The whole database has been made public for the research community in [13].

LACMV can be applied to different scenarios and for different purposes, usually related to human activities and the necessity to understand better their behavior in order to optimize some tasks. Some examples of such cases are: the health care sector, to monitor wandering individuals (elderly people in nursing homes, people with mental disorders, etc.) and collect information about their routes that correctly processed can offer personalized information about their status and their evolution over time (alteration of habits, impact of treatments based on their motion, etc.), without requiring too many carers; the security sector, to collect information about the security staff routes that correctly processed allow to optimize their work, detect inefficiencies, negligences and points to strengthen; in general, any economy sector susceptible to improve its productivity through the information about localization of their human resources.

Fig. 1 shows a high-level description of the role of LACMV in a generic scenario. In this scenario, people carry personal tags with wireless capabilities (target nodes) to detect other tags and beacon nodes in their proximities over time (1 if they detect each other, 0 otherwise).

The main contributions of this work are:

- A new range-free localization algorithm based on connectivity and maximum velocity of nodes that has been especially designed to turn connectivity traces and motion data into localization information. It can work with both connectivity and motion data, or only connectivity data, and unlike other localization algorithms, it can be applied in very sparse scenarios.
- This paper shows how distance between real and obtained trajectories is not a fair metric to asses the performance of range-free localization algorithms and presents a new metric that evaluates whether the obtained trajectories belong to the localization solution space (LSS), a multi-dimensional space that encompasses all solutions that satisfy completely the constraints of the localization problem.

The manuscript is structured as follows: Section 2 presents a summary of the related work, whereas Section 3 describes the LACMV algorithm. Section 4 discusses the performance of the algorithm through a set of experiments in synthetically generated scenarios under regular and irregular conditions. Section 5 details the applicability of LACMV for the transformation of real connectivity traces into localization information. Finally, Section 6 summarizes the main conclusions of this work.

2. Related work

There are two main groups of range-free localization algorithms: those focused on static networks, and those with mobile nodes that consider the localization problem as a time-varying problem.

Multidimensional scaling (MDS) [14] is probably the most prominent technique applied to the localization problem in static networks. MDS is a technique of dimensions reduction and data projection that turns the distance matrix between pairs into a representation of points in two or three dimensions (for visualization purposes) that preserves the distances as well as possible. The first localization method is originally proposed in [15] using classical MDS, a type of MDS that it is solved through singular value decomposition (SVD). Subsequent improvements of localization methods based on classical MDS are made by applying MDS locally to small patches of the network to avoid the implicit problem in distance estimations with irregular networks [16,17].

Localization methods based on classical MDS require full connectivity between nodes of a network, i.e. all nodes must be connected directly or indirectly through intermediate nodes, which is a problem in sparse networks. Metric MDS is a variant of MDS that allows no connections. The localization methods based on metric MDS use stress functions that are minimized by using function majorization until the final solution is reached [18,19]. More recent works have complemented MDS methods with other resources such as barycentric coordinates [20] or fingerprinting [21].

With respect to mobile networks, a relevant quantity of works is based on the use of Sequential Monte Carlo (SMC) methods [22]. SMC methods use just connectivity between