Localization by analysis of the geometrical deformation of a network of communicating entities

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- Directeur de thèse : Luc Nel SAMAMA
- Co-encadrant(s) :
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Résumé du projet de recherche (Langue 1)

We propose in this thesis an approach for future localization systems which is radically different from the GNSS (global navigation satellite systems) standard. The idea is to think about the localization process in a relative way, i.e. to consider the entities with regard to each other. Of course, this can come true with the positions supplied by standard approaches, but the constraints are then quite strong. Here, we want to design a system in a relative way in order to simplify the practical aspects (low power because low range, no complex synchronization processes, etc.), but also in order to considerably improve the precision (by using local phase measurements of carriers typically). The work will consist in putting the approaches in equations, then in designing the mathematical methods of resolution as well as validations through simulations, and finally in partial experiments when it will be possible. This ambitious subject proposes a breakthrough compared with the current state of mind and offers quite important potential outlets: this is obvious for instance in the optimization of numerous disciplines (that are interested to geo-localization), but is still important in the field of the consumer applications. The current localization systems are almost all based on the abstract foundations which led to the development of Global Navigation Satellite Systems more than forty years ago, i.e. a real time available location everywhere, permanently, and in a "universal" geographical reference frame, even if some are relative. It is worth to notice that the GPS (Global Positioning System) was the first stone to reposition the geographical data at a level close to the time based data (the hour): individual, portable, shared and "absolute". Since then, very rare were the proposals which question these postulates, but one has to notice that the continuity of the localization "service" is still not being insured. The problem when we try to cope with pedestrians is immediate: the signals of these GNSS do not allow, today, the availability of the positioning data in all the environments [1]. In particular, the indoor localization is either impossible, or of poor precision with regard to the one that it is possible to obtain outdoors. Nevertheless, the industrial actors consider clearly that the continuity of the localization is not assured and that it is essential: this seems indisputable concerning the pedestrian, who remains mainly indoors (where GNSS are almost unavailable). Thus, after a few attempts in order to allow this continuity by only GNSS signals (high sensibility receivers and assisted receivers in particular [2]), and noticing the impossibility to reach this goal with the current version of the systems, numerous communities invested this playground. It is the case of the specialists of the radio waves of all kinds (mobile networks, local networks, physical networks, radars, Ultra Wide Band, Bluetooth low energy, etc.), but also the specialists of image processing, signal processing, algorithms, statistics or artificial intelligence, or still robots. Almost all the conceivable sensors have been considered: light, ultrasounds, infra-red, temperature, proximity, images, electric field, magnetic field, etc. In this very heterogeneous set must be also quoted in very good place the specialists of the inertial systems. Even if numerous approaches are proposed by the scientific and industrial communities, the three main systems dealt with for several years are the GNSS, the inertial and the Wi-Fi / Bluetooth [3]. The reasons of these choices are rather clear: the idea is not to deploy any specific infrastructure for indoor geo-localization. Other quoted techniques provide potential improvements, but they require an infrastructure. These "dominant" approaches however not being at a sufficient maturity level, mainly in terms of performances (in reliability first of all, but also in cost or still in autonomy and simplicity of use), it leaves some living spaces to new proposals. Everybody would like to have a free system, requiring no specific infrastructure, using mature and standardized technologies, proposing a very good precision, working in real time, supplying a continuous localization in both space and time in an absolute spatial reference frame, the implementation of which on current terminals would involve only "software" modifications, etc. The geo-localization thus appears as a complex domain due to numerous aspects and parameters that are involved. These parameters inter-penetrate in multiple directions leading to not trivial synthesis. In this context, we wish to draw the attention on two aspects that we discuss very rarely: the first one is that a localization system does probably not always need to be continuous in time and space. If we accept that this localization can be punctual in space, or in time, then the fields of investigation widen considerably, and also the constraints which it is possible to take into account. The second aspect, which is the basis of the present project, consists in not trying any more to have localization in a global reference frame. Thus, we are going to propose an approach based only on the determination of the relative localizations between entities. By "relative", one has to understand relative compared with the others, and not compared with any supposed initial known location (which is a more classic method). The closest approaches to what we propose are the ones based on a wide use of all the available radio signals, called "signals of opportunity" [4, 5], or based on the notion of "collaborative positioning" [6].

Résumé du projet de recherche (Langue 2)
The main idea is based on the fact that it is often sufficient to have a “local understanding” of the localization and that the knowledge of the “geometry” of the distribution of a set of entities allows us to perform the mission. Furthermore, we know that it is possible to achieve quite accurate relative measurements between two entities, by using measurements of phases of a carrier for example, as it is the case in the high accuracy GNSS systems in particular. In the thesis, we shall try to thoroughly describe the problem (equations of the problem, methods of resolution taken into account the uncertainties, validations by simulations and experiments) of what could be a system of precise positioning not requiring any specific infrastructure, and affordable in terms of technologies as well as low energy consumption. This is made possible by use of mature technologies and by the fact that the proposed radio communication links are carried out at short distances, only between two entities and by means of signals that we know how to code quite effectively [7]. Thus, we suggest using only Doppler-like measurements, for example from miniaturized broadcasting stations of “GNSS-like” signals implanted on every terminal (but many other solutions are possible). It would then be possible to know the value of the projection of the difference of the speed vectors of two entities on the axis which separates them. By using only this measurement between two terminals (entities), we shall try to define a new type of positioning, relative, as described previously. From this relative positioning, we shall also try to analyse the possibility to go back to an absolute positioning, sometimes made possible by the availability of absolute data, as distances or geographical coordinates of certain terminals. However, this objective of absolute positioning is clearly not the initial quest of this work. The problem can be described as follows: let us consider that A, B and C are three broadcasting and receiving terminals carrying out the Doppler measurements described above. We can also consider that A, B and C are communicating knots of a network. They have speed vectors Va, Vb and Vc and we know about the various projections of these speeds on the axes AB, BC and AC. In a first approach, we shall try to find out the speed vectors from the projections. In a second approach, we shall deal with geometry (the calculation of angles) while introducing measurements relative to a reference terminal, for example A. Having studied the feasibility to calculate the various angles, from only Doppler-like measurements of four terminals relatively with the others, we shall go back to the relative positions of knots (first theoretical works carried out within the Navigation Group, not yet published, seem to indicate that this is possible). The problem is however not trivial because numerous symmetries exist. A part of the thesis work will consist in solving the systems of equations, either with a pure geometrical approach if it turns out to be possible, or in a digital way (the first already quoted works allowed us to put the system in equations in a few use cases and both approaches seem to be possible). Problems will probably come from the introduction, essential according to us, of uncertainties in the measurements. Simulations, based on experimental data, will allow first validations. A third approach, still based on relative measurements between two terminals, consists in using distance measurements. We could envisage for example time of flight measurements between two Ultra Wide Band (UWB) knots. In such a case, the calculations are much easier. We could even go one step further by slightly changing the goal: it would no longer be a question of trying to find the geometry, but simply to analyse the way the network of knots changes its “shape”. The starting point remains Doppler or carrier phase measurements which allow us to quite accurately establish, in “standard” conditions, if two knots are getting closer (or the opposite) to each other. The amplitude of the Doppler values giving an idea about the “speed” of the deformation. This track will be studied in case of rapid achievements in the previous approaches. All these works being very exploratory, the progress will highly depend on difficulties we shall meet and the following descriptions are new potential tracks of investigation in case of fast success. The study of a system in 3D should be carried out, at least from theoretical and abstract points of view. It’s the same for the temporal aspects: if the extrapolation to “dynamic” aspects in the case of Doppler or distance measurements seems quite “natural”, it is not so obvious concerning the analysis of the deformation of networks. In this last case, the methodology to be followed and the concepts remain to be invented. References 1- A. Patarot et al., “Pedestrian indoor positioning techniques: A survey”, JETSAN 2013, Fontainebleau, France. 2- C. 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