Method for Characterization and Classification of Localization/Tracking Systems

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***Abstract*—Due to the large variety of different tracking and localization systems intended for different applications from different disciplines, researchers and developers are faced with a problem when comparing these systems as they are not presented in a general form. This paper discuss and expands on the important aspects of two of the most helpful papers in the field in order to present a method for characterizing and classifying systems into a general form, enabling easier comparison of systems as well as making better design choices.**

***Index Terms*—Localiztion, Tracking, Classification**

I. INTRODUCTION

IN the world today we get into contact with tracking and localization systems almost on a daily basis. The system that is almost certainly the most well known is the Global Positioning System or GPS. In addition to GPS there exists a plethora of other tracking/localization systems that are not as well known. These include systems that vary from determining the position of nodes and users in a network, creating the opportunity for location aware applications, to tracking the movement of a persons head in augmented and virtual reality applications. Due to this variety of different applications, these tracking systems are found in a multitude of different environments and disciplines. This makes it difficult for researchers and developers to compare these systems and make informed decisions as to the best options when designing a system, as results usually differ from discipline to discipline and application to application.

We are currently in the process of developing a system to track objects in a specific environment and thus needed a framework for comparing different systems from all different application domains, but found that taxonomies and related work are mostly limited to specific application domains, for example [1] provides a survey on visual tracking methods while [2] provides information on localization and tracking in WSNs. From a literature survey we identified [3] and [4], although also aimed at specific application domains, as articles that describe the main aspects of tracking and localization systems in a general enough way to be applicable to systems from different application domains. Thus, this paper is based mainly on previous work done in [3] and [4]. It combines the aspects presented in the articles respectively and expands on them and how they interact. We also discuss other aspects we identified as important from a survey of tracking/localization systems. We then use these aspects and their relationships to propose a method of characterizing and classifying tracking/localization systems in a general form. Once classified in this general form it is easier to compare different systems with one another as well as make informed choices with regards to implementing new systems.

The rest of the document is organized as follows. In Section II definitions of ambiguous terms from the field of tracking/localization will be defined as they are used in this article. In section III a discussion on what to keep in mind when analyzing and comparing tracking/localization systems will be given. In Section IV the aspects and their relationships are described, followed by the proposed method for the classification of tracking/localization systems.

II. DEFINITIONS OF AMBIGUOUS TERMS

A brief definition of terms as used in this paper will now be given.

Localization refers to the process of determining the position of an object while the object is stationary.

Tracking refers to the process of determining the position of an object while it is moving. Tracking is normally not as accurate as localization, as it requires a finite amount of time to determine the position of an object and the position of the object will change in this time. *Note that in this paper the term Tracking will be used to refer to both Tracking and Localization*.

Accuracy defines the error of the measured position relative to the actual position of the object and is given as a distance in meters. *Precision* is a measure of how often the stated accuracy can be obtained and is usually expressed as a percentage.

III. INITIAL CONSIDERATIONS WHEN ANALYZING TRACKING SYSTEMS

We have found that when analyzing a tracking system it is helpful to start by asking three important questions. These are *What*,*Why*, and *Where*.

What is being tracked? This could be people, nodes in a network, cars, and other objects. It is important to know what is being tracked as this imposes limitations on the system and determines certain properties of the system. For example, if a car is being tracked, as the case may well be in a GPS system, power for the device can be obtained from the vehicle. If the object being tracked is a tag in a crate, issues may arise concerning the power source of the tag. What is being tracked also influences a variety of other factors for example size and computational power. All this needs to be kept in mind when analyzing and comparing tracking systems.

Why is the object being tracked? This question also affects the properties, principles and physical phenomena used in the system. For example, if a system tracks the position of devices in a network to determine what computer is nearest what printer or projector or other peripheral device, many properties such as the reference grid and resolution of the system are affected.

Where is the object that is being tracked? This refers to the environment in which the object is being tracked. This is important as it has a big effect on the physical phenomena used in the tracking system. For example, a magnetic tracking system cannot be used in an environment with lots of magnetic interference or with lots of reflective materials as the results obtained would be adversely affected. Keeping these three questions in mind will simplify the classification process as it will help with the identification and understanding of the systems requirements.

IV. CLASSIFICATION OF TRACKING SYSTEMS

To enable researchers and developers to better understand and compare different tracking systems from different engineering fields, it is necessary to define a set of guidelines that can be used to characterize and classify these systems into a general form. From research done, it seems that there are four important aspects to consider when analysing tracking/localization systems, these are *Properties*, *Principles*, *Location Computing Techniques*, and *Physical Phenomenon*. The properties as well as the location computing techniques described here are based mostly on [3]. The principles are based on [4]. Note however, that although the aspects described here draw strongly on the above mentioned articles, it does differ in certain areas. A discussion of the aspects and their relationship towards each other will now be given, followed by the proposed method for classification.

A. Properties

According to [3] their properties deal with a set of issues that arise when characterizing tracking systems and are normally not related to technology and techniques used in the system. We however found that in some instances, some properties may be affected by aspects related to the technology and techniques used when the relationships as described in this paper are taken into consideration. For example the limitations property may be influenced by physical phenomena used. The properties that are recommended for characterizing tracking systems are *Resolution, Accuracy and Precision (Accuracy and Precision)*, *Reference Grid (Absolute and Symbolic Location)*, *Physical Position and Symbolic Location*, *Computational Power (Localized Location Computation)*, *Scale*, *Recognition*, *Cost*, and *Limitations* (Note that the properties in brackets correspond to those used in [3]).

1) Resolution, Accuracy and Precision: Resolution, accuracy and precision are very important characteristics of a tracking system. In order to function correctly a system needs to provide accurate results consistently as stated in [3]. *Accuracy* is a measure of the difference in the measured position of the object being tracked relative to the actual position of the object. *Precision* is a measure of how often this accuracy can be achieved and is usually expressed as a percentage. For example a system may yield an accuracy of 10 cm for 95 % of the measurements made. *Resolution* is defined as the minimum accuracy of the system, which can be obtained with an acceptable precision, in order for the tracking system to achieve its goal.

2) Reference Grid: In order for the position information yielded by a tracking system to be of any use, it has to be given in terms of a reference grid. For example, the Cartesian grid as used in math and physics, or the grid used for GPS coordinates given in terms longitude, latitude and altitude.

Reference grids are mostly used in one of two ways. Position information can be given in terms of a fixed shared reference grid, like the one used by GPS systems. These systems are said to give an *Absolute location*. Alternatively position information can be given relative to the object tracking other objects or relative to the object being tracked. In this case the zero position of the grid is not fixed to a specific point. These systems are said to give *Relative location*. An example of such a system is a system where office equipment knows their location and those of equipment around them. For example, if a computer terminal knows the location of other equipment relative to its own position, it can print to the nearest printer. Note that position information can be converted from absolute to relative for a known grid as well as vice versa if enough relative locations are known.

3) Physical Position and Symbolic Location: A system provides a *physical position* if it gives position in terms of a physical reference grid, for example, GPS gives physical position in terms of latitude, longitude and altitude.

A *symbolic location* system provides an abstract location for the object being tracked. For example, the Active Badge System [5] tracks the location of employees to an abstract location within a building, like a certain room or corridor and can thus be classified as a system providing symbolic location.

Usually a system that provides a physical position has a higher resolution than a system providing symbolic location. If a physical position system has a high enough resolution it may be used to convert the physical position to a symbolic location. For example, if a warehouse is divided into certain 20 m x 20 m zones a physical position system with a resolution of 1 m can be used to determine the symbolic location of an item.

4) Computational Power: The computational power property refers to the computational resources available for implementing the system. For example the RIPS tracking system [6] is used for determining the position of nodes in a wireless sensor network without adding any additional hardware to the nodes. This imposes certain limitations on the complexity of the computations that can be done by the system.

The two main factors to keep in mind when identifying this property are the computational power of the object being tracked, as well as the computational power of the support hardware or external tracking hardware. These two factors influence aspects like where the location computation of the object can be done e.g. on the object self, or on the external hardware. It also influences other properties such as the accuracy and precision that can be obtained.

5) Scale: The scale of a system is affected mainly by two factors: The area covered by the system and the number of objects that can be tracked within infrastructure and time constraints. For example, GPS can be used by an unlimited amount of receivers and covers the whole world, while a system that tracks objects using RFID tags may only be able to deal with one object at a time and in a small space like a room [3]. The scalability of a system is thus influenced by how easy it is to increase the infrastructure and the cost thereof.

6) Recognition: In some tracking system the object being tracked needs to be identified. Recognition is usually achieved by designating each object being tracked or classes of objects of the same sort with a Globally Unique Identifier or GUID [3]. An example of a system that uses recognition is the Active Bat system [7].

7) Cost: According to [3] the cost of a tracking system can be assessed according to three different factors, *time*, *space*, and *capital*.

Time cost refers to the amount of time the installation and setup of the system requires as well as the amount of time it will take to administrate the system.

Space cost refers to the physical dimensions of the tracking system (form factor and size) as well as the amount of infrastructure that needs to be installed.

Capital cost refers to all financial costs of the system like the manufacturing and installation price of the system.

8) Limitations: The limitations of a tracking system refers to what the system cannot do. These limitations are mainly influenced by the environment and can differ from size constraints to the effect of the environment on the physical phenomena that can be used.

Note that the properties discussed above may influence one another. For example, if a tracking system is to be implemented in a limited space the limitation property of the system is influenced by the cost property (space cost).

B. Principles

Principles describe the basic method a system uses to track objects [4] and are thus one of the most important aspects to consider when analyzing and comparing tracking systems. It determines the core working of the tracking system and is therefore closely linked to the physical phenomena used to implement the system, which in turn is largely influenced by the environment the system is used in.

The principles as discussed here are based on [4]. Note that although [4] focus on principles used in tracking systems for augmented reality applications, it was found that the principles are applicable to most tracking systems.

The principles that will be discussed are *Time of Flight (ToF)*, *Spatial Scan*, *Inertial Sensing*, *Mechanical Linkage*, *Phase Difference Sensing*, and *Direct Field Sensing*.

It is also important to note that many systems are based on a combination of these principles and are then referred to as *hybrid* systems.

1) Time of Flight (ToF): Systems based on the ToF principle determine the distance between two points by measuring the travelling time of a wave from one point to the other. Thus the ToF principle is always implemented using the physical phenomenon of propagation. In order for the principle to be used accurately the propagation speed of the wave used should be constant (or as close to constant as possible) in the medium the tracking is implemented in.

Most ToF systems are implemented using sound waves; usually in the ultrasound range (greater than 20 kHz, normally 40 kHz) as these waves cannot be heard by humans. According to [4] other waves used to implement ToF systems are light waves, using for example pulsed infrared diodes as well as electromagnetic waves.

As ToF systems yield distances and from the physical setup angles can be obtained, it is normally used with triangulation techniques to determine position.

2) Spatial Scan: Spatial scan systems use optical tracking methods, usually for the recognition of known features and their positions, from which angles and distances can be computed. Another form of optical tracking is by measuring the time between a light beam passing one sensor and then another. In [4], spatial scan systems are divided into two categories, *outside-in* and *inside-out*.

Outside-in systems comprise external hardware looking for features on the object being tracked.

Inside-out systems use hardware on the object being tracked to identify features or reference points on/in the surroundings.

It should be noted that a main drawback of spatial scan systems is that a direct line of sight is necessary for the system to operate, implying that environment plays a big role in the viability of using a spatial scan system.

3) Inertial Sensing: Inertial sensing uses the physical phenomena of inertia to determine the orientation and acceleration of the object being tracked. It is usually implemented using accelerometers. From the acceleration data the distance the object has moved can be obtained by double integration over time.

A main drawback of these systems is the fact that the inertial sensors used in the implementation suffer from drift [8] and thus need to be calibrated very often.

4) Mechanical Linkage: Mechanical linkage systems are systems where the objects being tracked are physically linked to each other in some mechanical way. These mechanical links usually comprise some sort of arms that can rotate and extend. From the angles and distances the location of the tracked object as well as its orientation can then be determined.

It was found that mechanical linkage systems are not that common in modern tracking systems.

5) Phase Difference Sensing: Systems based on the phase difference sensing principle use the phase shift of a signal travelling through space to determine distance, as the phase shift is a function of the distance the signal has travelled. According to [4], these systems usually measure the phase of an incoming signal and compare it to a signal of the same frequency on a fixed reference. The implementation of RIPS [6] is a very good example of an innovative use of phase difference sensing, implementing it with an interference signal.

Phase difference systems can achieve high resolutions, in the order of centimetres [8]. According to [4], systems based on phase difference sensing can obtain a higher accuracy than ToF based systems due to their ability to generate high data rates.

6) Direct Field Sensing: Systems based on direct field sensing use measurements taken directly from some field e.g. a magnetic field or gravitational field to determine an object's distance from another and can in some cases also detect its orientation. These systems are usually implemented using the physical phenomena of magnetic coupling by creating an orthogonal field. Magnetic trackers are inexpensive, lightweight and compact; as a result they are widely used in the augmented and virtual reality realms for tracking body and head movement. Other magnetic phenomena may also be used as well as gravitation. An example of a position and orientation tracking system based on magnetic field sensing is discussed in [9].

C. Location Computing Techniques

The implementation of a tracking system using one or a combination of the principles mentioned above usually provides some sort of measurement e.g. the distance from one object to another, but normally the position of the object is still unknown.

Location computing techniques are used to determine the position of the object(s) being tracked according to the reference grid used by the system.

The three principle techniques identified in [3] are *Triangulation*, *Scene Analysis*, and *Proximity*.

1) Triangulation: The triangulation technique is based on the properties of triangles and uses distance and angle measurements to compute the position of an object [3]. This technique can be divided into two categories, *Lateration* and *Angulation*.

Lateration uses only distance measurements from known reference points to determine an object's location [3]. In two dimensions three non-collinear measurements are needed to locate an objects position. The position is determined by finding the intersection of the three circles with the reference point as centre and the distance from the reference point to the object as radius (see figure 1).

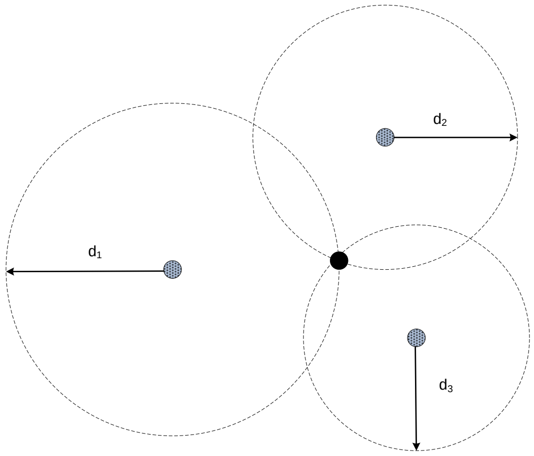

Fig. 1. Lateration in 2 Dimensions

This technique can also be used to obtain three dimensional position of an object if the distance from four reference points to the object is known (the distances have to be non-coplanar), by the intersection of the four spheres with the reference point as centre and radius the distance from the object to the reference point.

The amount of known ranges required may be reduced by domain specific knowledge; for example in the Active Bat System [7] measurements are made from an array of receivers in the ceiling of a building, three dimensional position can thus be determined from only three distance measurements as one of the two points of intersection (the one above the array of receivers) can be ignored [3].

Angulation uses a combination of angles and distances between reference points and the object to determine its position. Two dimensional angulation uses two angles and the distance between the reference points to determine the position of the object (see figure 2).

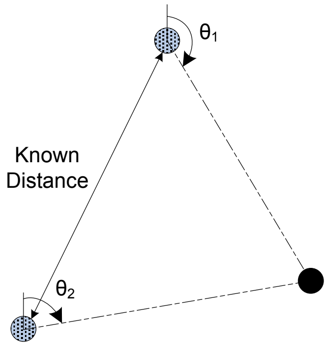

Fig. 2. Angulation in 2 Dimensions

Three dimensional angulation requires one length measurement, one azimuth measurement, and two angles to determine the location of an object [3].

The triangulation techniques as described above, can be used with all systems that yield distance and angle information. Systems that give these results are usually based on ToF, Mechanical Linkage, and Phase Difference Sensing. Some beam scanning systems based on the Spatial Scan principle could also yield the results required to use triangulation techniques.

2) Scene Analysis: According to [3] scene analysis uses features in a scene to estimate the position of the observer. The scenes are usually simplified to make feature recognition and comparison easier. There are two main forms of Scene Analysis, *static* and *differential*. *Static* scene analysis compares the features from the observed scene to a dataset. The dataset contains the location from where specific features were recognised. A features match in the dataset thus yields the approximate location of the observer.

Differential scene analysis uses the change in the scene to compute movement, as changes in the scene corresponds to movement of the observer. The position of known features enables the observer to determine it's position relative to the feature [3].

This technique is used with optical spatial scan systems, as they yield scene results that can be used as a way to implement scene analysis with feature recognition and comparison.

3) Proximity: According to [3] systems using the proximity technique determines an object's location near a known location using a physical phenomenon with limited range. The methods usually used for the implementation of this technique are *Physical Contact*, *Monitoring wireless access points*, and *Observing automatic ID systems*. It was also found that another common method for implementing proximity systems is by using beacons, placed in predetermined zones (like rooms in a building). Examples of systems using this technique are the Active Badge system [5] as well as the Cricket location support system [10].

Using *physical contact* to determine an objects position can be done by using pressure sensors or touch sensors [3]. As soon as physical contact is made it can be assumed that the object is near the location of the object that contact was made with.

By *monitoring wireless cellular access points* it can be determined when the object being tracked is in range of one or more of the access points. The position of the object is then known with accuracy the size of the area serviced by the access point [3].

Automatic ID systems include systems like credit card point of sales terminals and land line telephone records. By determining the location of the credit card point the location of the person using it can be tracked.

D. Physical Phenomena

We have found that the physical phenomena used to implement a tracking system, although closely related to the principle used, is an important aspect in system selection. It is influenced by the environment and is the factor determining in which environments the system will be able to function. We divided physical phenomena into four main categories: *Propagation*, *Optic*, *Inertia* and *Magnetic*.

1) Propagation: Propagation refers to all the physical phenomena using the propagation of waves through space to determine position. The distance a wave travelled through space is a function of the travelling time as well as the propagation speed of the wave and can thus be used to determine distance. The phase offset as a result of the travelling time of the wave can also be used to determine distance travelled.

2) Optic: Optic phenomena are used to implement spatial scan systems. Systems using these phenomena require a clear line of sight to or from the object.

3) Inertia: Inertia refers to the physical phenomenon as described by Newtons first law of motion. It is usually implemented with gyroscopes or accelerometers. The main drawback of systems using these technologies is that they suffer from drift [8] and thus need to be calibrated often to ensure accurate results. This physical phenomenon is used to implement the inertial sensing principle.

4) Magnetic: Magnetic phenomena are mainly used in the form of magnetic field sensing (magnetic coupling) where magnetic fields radiated by a source (usually comprised of three coils place perpendicular to each other to create an orthogonal field) induce a flux in a receiver. The flux is a function of the distance and orientation between the source and the receiver [4].

Systems can also use magnetic phenomena to measure its orientation with respect to a known magnetic field, for example the earths magnetic field.

E. Relationship between the main aspects

All the main aspects of tracking systems as discussed are related to each other. The principle that is used affects the location technique that can be used. The physical phenomenon used is in turn directly linked to the principle used. The properties of the system affect the choice of principle, location technique and physical phenomenon used by a system. Table I gives an indication of the aspects affected by the different properties of a system.

TABLE I
RELATIONSHIP OF PROPERTIES WITH OTHER ASPECTS

Property	**Principles**	**Location Techniques**	**Physical**
Resolution, Accuracy & Precision	x	x	x
Reference Grid	x	x	
Physical Position & Symbolic Location	x	x	
Computational Power	x	x	x
Scale	x		x
Recognition			x
Cost	x	x	x
Limitations			x

F. Proposed Classification Method

We propose that the following method be followed when classifying a tracking system:

1) Determine the system requirements: The system requirements can be determined by answering the three questions in section III.

2) Characterize the system according to the system properties: Characterize the system according to the properties using the requirements.

3) Identify the most important properties: Identify the properties most important to the success of the system. For example, if it is important that the system has a high accuracy and is intended to work in a highly reflective environment, the most important properties are the Resolution, Accuracy & Precision and Limitations properties.

4) Determine the Principle, Location Technique and Physical Phenomenon: Once the most important properties affecting the system have been identified, they can be used to determine the best principle, location technique and physical phenomenon. For example, if the most important property of the system is recognition, it would be best to first decide on a physical phenomenon that can be used to implement GUID.

The next step would then be to determine which principle and location technique can be used with the physical phenomenon.

G. Example of characterizing and classifying a system

As an example, the system we are currently working on will be classified according to the proposed method.

We start of by answering the three questions from section III.

What Spheres with a diameter of 6 cm are to be tracked.

Why The spheres need to be tracked to determine their flow paths.

Where The spheres to be tracked flow through a ceramic cylinder with radius 0.5 m and height 2 m .

We now characterize the system according to the properties.

In order to track the spheres to determine their flow the position of a sphere needs to be determined accurately enough to avoid ambiguity, thus the *resolution* of the system needs to be at least 3 cm.

As the flow paths need to be determined for different spheres in the same space an *absolute reference grid* providing a *physical location* need to be used.

The system needs to be very accurate, thus a system with good *computational power* will be needed as not to compromise accuracy.

The *scale* of the system is limited to the size of the cylinder (radius 0.5 m and height 2 m) and only a single object needs to be tracked at a specific time instance.

As only one object will be tracked at a specific time the system wont need *recognition* capability.

Our main *cost* concerns are the *space cost*, as the space on the sphere is limited and the *capital cost* due to the computational power needed.

The most important *limitation* on the system is related to the effect of the environment on the physical phenomena that can be used. Due to the environment the system will not be able to use optic phenomena

For this system to achieve its intended results the resolution must be within the constraints (3 cm), thus making the resolution property the most important.

Based on this as well as the limitations due to the environment we decided to implement the system using the *phase difference sensing* principle. This principle is based on the physical phenomenon of *propagation*. This implementation should yield the best results, if compared to results obtained by other systems using the same principle and physical phenomenon.

The implementation will yield distance data. To determine position from this data, the the *lateration* location computing technique will be used.

V. CONCLUSION

In this paper we discussed different aspects that can be used to characterize and classify tracking systems and proposed a method for the characterization and classification of tracking systems using these aspects. This method should enable researchers and developers to better compare different systems from the multitude of applications and disciplines and make decisions regarding the implementation of new systems easier.

We recommend that future work includes a proposed method for presenting results in a general form, for its specific classification. This will be a further help with the comparison of different systems.

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