TELEGEOMATIC SYSTEM AND REAL TIME SPATIO-TEMPORAL DATABASE

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ABSTRACT

Telegeomatics, geomatic and telecommunications, is currently in strong growth. Many applications require tools to manage and locate information on mobile data and/or real time. These applications require information processing systems able to exploit spatio-temporal and real time data. These data are issued from sensors and fixed or mobile systems of localization. Current GIS manage and allow managing of spatial data. These data are spatial and temporal and moreover, real time. The temporal aspect of the data is still badly introduced and not any real time DBMS is marketed nor a spatial-temporal and real time DBMS. However, the need is crucial in particular in terms of structuring and of querying of these data. Several questions arise: how to store this mass of data quickly without overflow? How to index these data in real time while privileging recent data rather than the old ones while allowing the requests in continuous time? How to manage mobility? Which are the specifications of architectures of collection, communication, of storage in the database?

Few works exist on this field. Existing works focus on the management of mobile telecommunications but not on the management and the exploitation of spatio-temporal and real time data. The objective of the paper is to present the problems of databases concerning spatio-temporal and real time aspects.

1. INTRODUCTION

Many applications require tools to manage and locate information on mobile data and/or real time. The management of fleet vehicles in real time (transport, taxis...), the follow-up of the environment, management of crises (catastrophes, fires...), urban risk management (motorway, road, industrial...) or environmental risk (risings, avalanches, volcanos...) require information processing systems able to exploit spatio-temporal and real time data. These data are issued from sensors and fixed or mobile systems of localization (Figure 1).

Current GIS manage spatial data. These data are spatial and temporal and moreover, real time. The real time we deal with here is the immediate real time about the second what has strong implications on the management and the exploitation of these data (structuring, storage, indexing, interrogation, visualization...).

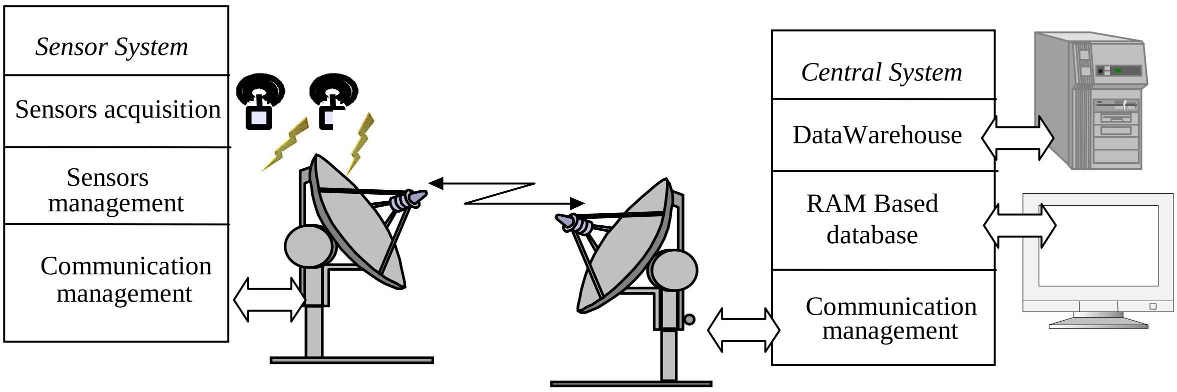

Figure 1: Example of real time sensor based system

However, the need is crucial in particular in terms of structuring and of querying of these data. Several questions arise: how to store this mass of data quickly without overflow? How to index these data in real time while privileging recent data rather than the old ones while allowing the requests in continuous time? How to manage mobility? Which are the specifications of architectures of collection, communication, of storage in the database?
Few works exist on this field. Current researches relate to the telegeomatics binding GIS and systems of telecommunication. Existing works focus on the management of mobile telecommunications but not on the management and the exploitation of spatio-temporal and real time data.
The objective of the paper is to present the problems of databases concerning spatio-temporal and real time aspects. After a part concerning telegeomatic systems and system architectures, problematics concerning real time spatio-temporal database are defined. One of the needs concerns new data structures to allow fast real time spatio-temporal access to data.

2. TELEGEOMATIC SYSTEM

One of the characteristics of a TeleGeomatic system is that processing is carried out in real time. It differs in that of the traditional systems which carry out processing *a posteriori* or jointly on primarily statistical data. Moreover, let us consider the cases where processing is carried out in real time on dynamic data.

This type of system must be able to provide an answer on several levels. Indeed, when the list of events which constitute a crisis is analysed, it is remarkable that there exist successive phases. During each of these phases, events, their consequences, the conditions of work of the operators responsible for management, are going to vary, and will have a different and relative impact on the actions to carry out. The operators will ensure in priority the missions which seem essential to them in the existing context.
For example, the essential goal during the crisis is the resolution of the crisis. I.e. everything that will be able to implement to avoid or reduce the consequences of the incident must be done. It is not time at this moment to search for the whys and wherefores, even if this search of information makes it possible to better include/understand the phenomenon. This operation will be delayed at one more favourable time.

Once the crisis overcame, and conditions returned to their normal state, i.e. comparable with those which were before the incident, it is time to include/understand exactly what occurred. Integration of this information within the future procedures will allow preventing this type of incident. If it is not possible to avoid completely the incident, the management of the crisis will facilitate, and will reduce consequences of this type of incident. So, we propose that the TeleGeomatic application has to be able to take into account the aspects described below:

- During the crisis: fast and easy answer, to facilitate the decision-making in order to regulate the immediate problem,
- After the crisis: deep analyzing in order to extract important information to prevent an other case, or to better manage the crisis if the incident cannot be avoided.
- Actions for long terms: capacity to support analyses based on the simulation of situations in order to control the various processes and to integrate counter measurements within the rules of exploitation.

2.1. Representation in databases

The structure of representation in database must take into account spatial data. Localization in space and time must be possible and stored in each structure of data in order to allow spatial and spatio-temporal queries. Different data, for examples textual, tabular, multi-media..., must be able to be attached to the data stored in the system.

2.2. Definitions of the objects

The information system will have to take into account various communicating objects which are fixed objects (stations, sensors…), agile objects (punctual location change: sensors), moving or mobile objects. There exists too other categories of object which have to be taken into account: objects of process, or modulates process, and objects of supervision or supervisor.

Architecture setting up must allow the communication and the co-operation between these various objects. It must moreover remain sufficiently flexible to adapt with the organisational structure of the organization which uses it. Figure 2 presents a hierarchical example of organization of this type of architecture mixing various typologies of objects.

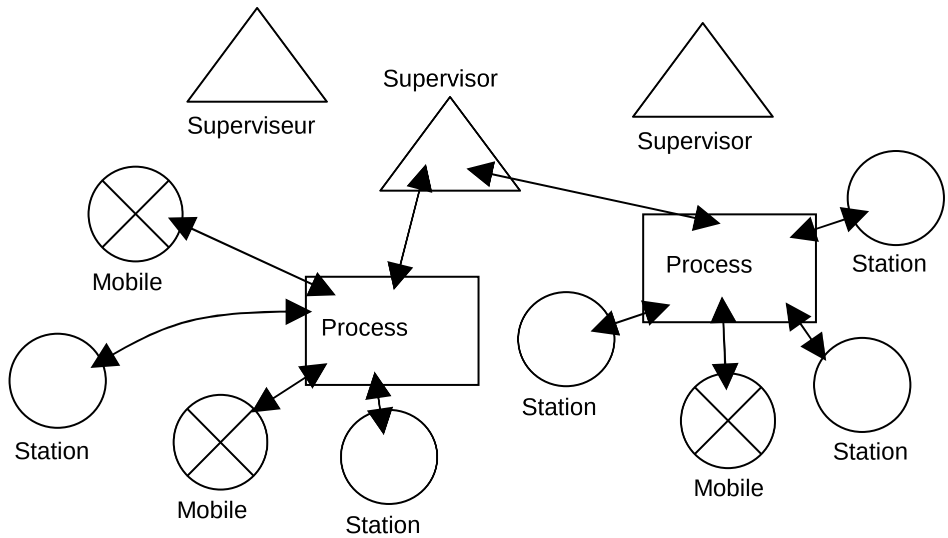

Figure 2: Hierarchy of the objects

2.3. Membership of several supervisory systems

In *(Laurini, 1992), (Laurini, 1998)* the presentation of a mode of operation or a vehicle is dealt with by several TeleGeomatic systems. Robert Laurini named this type of organization federate architecture. The example used to illustrate this possibility is that of the follow-up of a Transport of Dangerous Matter (TMD), for example a gasoline truck, at the time of the crossing of an urban zone. All along its course the mobile will be in relation to several centres of control in order to ensure the safety necessary for the transit in urban zone. These centres are, in fact, the one of the company of transport, the one of the municipality during all the transit on its territory, and the one of a more global system, like a system for an organization of regulation of the TMD at the national level. R. Laurini *(Laurini,1998)* defines relations between vehicles and the systems according to diagram of figure 3.

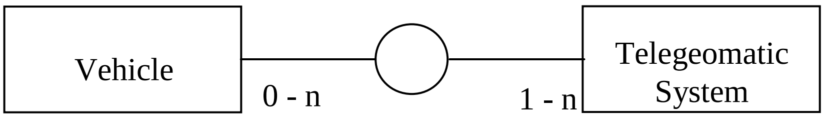

Figure 3.Relations between vehicle and systems

If relations between vehicles and systems are represented in accordance with time and space, the graph of figure 4 is obtained.

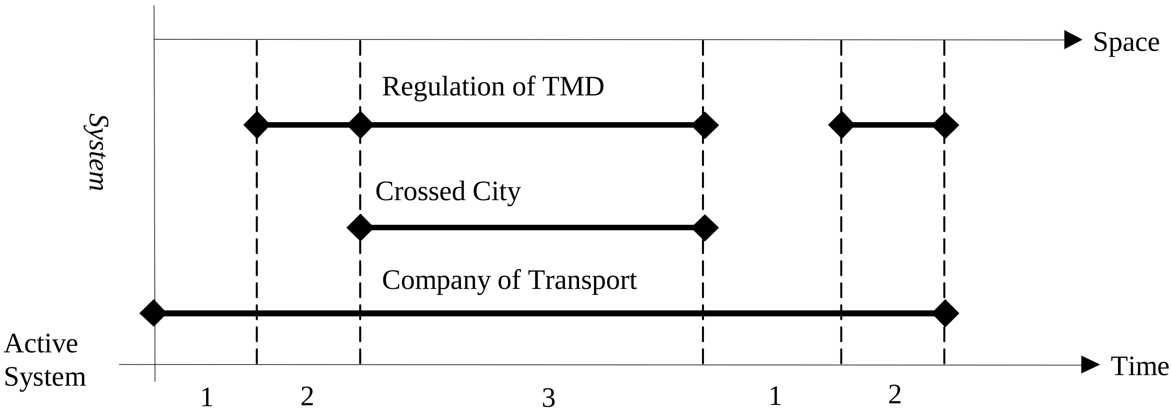

Figure 4: Temporal organization of convey systems

The graph shows that the system of the company of transport follows its mobile permanently. So the company has to follow its vehicles 100 % of the time and 100 % of defining space of the route. The system of the municipality will deal with the vehicle only for the period of time corresponding to the zone of space corresponding to its transit in the city. Let us suppose that the system of regulation of the TMD uses rules of follow-up controls by criteria such as for example, the potential risk compared to environment crossed by the vehicle. This time, the space cutting of follow-up will depend for example on the density of population of the crossed district, or types of infrastructures used (for example, tunnel, bridge, rapid ways...). To simplify, we can define that the temporal aspect will be governed by the fact that the mobile penetrates or leaves a critical zone.

2.4. Activation of the system

In reality, it would be useful to also manage the temporal cutting. Indeed, according to the speed of progression, the estimate of the arrival of the vehicle in a non critical space zone, but within one critical temporal interval, such as for example one peak hour, or at the time of the entry or the exit of the schools... It is necessary to modify the activation of the systems of follow-up, to even modify the policy of transport. It is seen here that the cycle of successive activation of the systems answers at the same time with a predefined strategy, which is defined in a theoretical way (and which corresponds to the best of the worlds), but must too to support modifications in real time of this strategy, according to events occurring during the mission of the vehicle. Accordingly to the pre-programming, it is possible to conceive in a simple way them activations of systems.

System	Activation	Release
Conveyor	100 % of mission duration 100 % of space of mission	
City	100 % of time in city 100 % of space of city	City enter City outer
TMD	100 % of time into critical area 100 % of critical space	User action Time assessment

Figure 5 : System activations

The table of figure 5 shows the difficulties existing during the implementation of the system. How to activate the system at the precise time and at the good place? One of the first solutions which comes to mind is the possibility for the operators of the mobile (conducting, assistance...) to inform the system the crossing of certain remarkable points of traverses, or with the occurrence of certain events (accidents, congestion, delays...). This communication can be carried out on various manners: use of radio, or of radiotelephone, automating the operation: for example by laying out a simple pushbutton on the dashboard of convey, which makes transparent the operation of communication for the user. However the major disadvantage is that the system is based on a voluntary operation of a human operator, here personnel of the truck. There is so a typology of traditional errors in this field: bad appreciation, carelessness, various refusals, erroneous interpretation, ill will...

2.5. Architecture of the system

Figure 6 represents an example of architecture of a traditional real time spatial information system traditional *(Tanzi, 1998).*

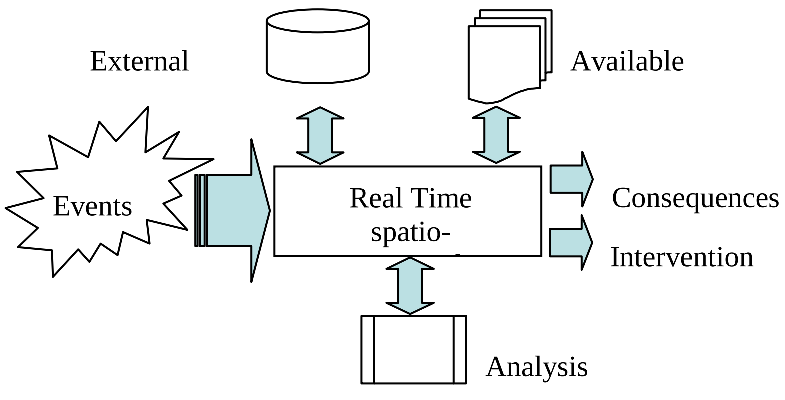

Figure 6: Real time spatial information system architecture

It becomes necessary to modify this diagram (see figure 6) in order to adapt it to a context of multi monitoring, corresponding to the contemporary use of several systems. We will show after that the internal working procedure of the real time spatio-temporal system (RTSTS) will not be changed. The adaptation consists in the opening and the development of the various access points, i.e. interfaces of the global system. The system comprises six points of interface which are:

1. Events acquisition,
2. Interface of communication with external data,
3. Dialogue with under system of decisions,
4. Dialogue with under system of analyses,
5. Consequences generation,
6. Policies of interventions generation.

It is possible to break up the system according to the diagram of figure 7.

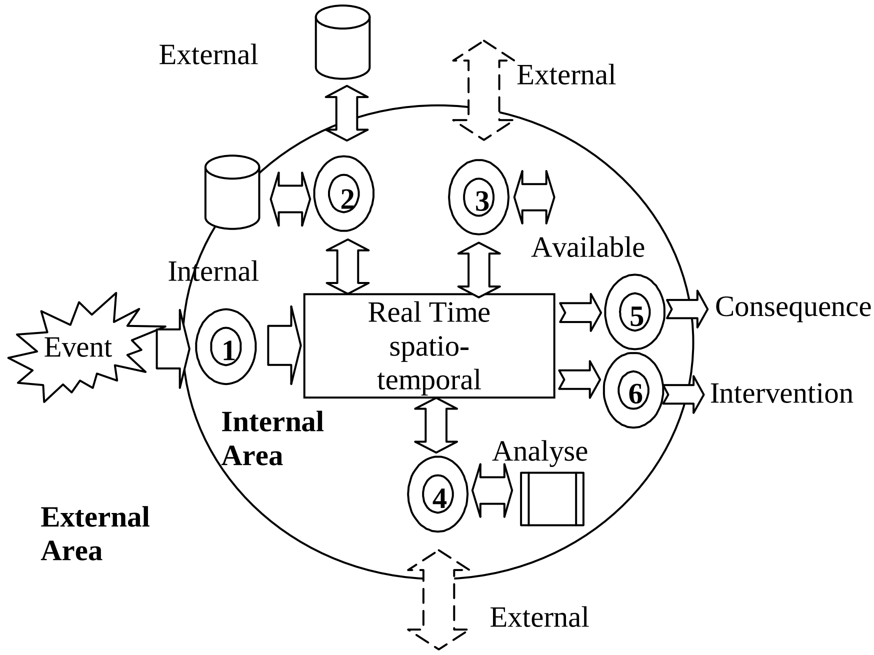

Figure 7: Adaptation of the architecture of the real time spatio-temporal system

The diagram of figure 7 shows well that the interface of communication with the external data constitutes a privileged terminal point between the internal and external space of the system. In usual real time spatio-temporal systems *(Tanzi, Servigne, 1997)*, *(Tanzi, Servigne, 1998)*, and *(Tanzi, Guiol, Laurini, Servigne, 1998)*, this interface was intended to allow co-operation with external bases of information. Co-operation between DBMSs require the implementation of a system of dialogue between all information systems. The queried database may be considered as a particular information system and it is so easy to adapt this communication to allow the co-operation between more general information systems. Here also, the concept of vulgarizing can be expressed as the system uses indifferently its data (internal data) or data with remote access (external data).

A very important use of this type of operation is the real time update of mass of internal data by external data. The goal is to carry out the temporal adaptation of the electronic with the image of real ground. A simple example is the update of an embarked cartography (great quantity of information so very quickly obsolescent) by a small quantity of information acquired in real time intended to carry out the adaptation of a diagram of progression (calculation of route) according to traffic information.

3. REAL-TIME SPATIO-TEMPORAL DATABASE

The use of real time spatio-temporal data makes emerge various needs concerning structuring, processing, querying, visualization of mass of data but also in term of quality and security of the data or of integration of various existing systems.

3.1. Data structuring

Data structures must to be fast accesses and thus require a real-time spatio-temporal indexing method for the database. The current techniques of spatio-temporal indexing are not adapted to real time applications, because they attach more importance to old data that with the news (which can be found in secondary memory (overflow), therefore lengthening the response times).

Indexing methods to be developed will have to comprise the following specifications:

- to allow a fast integration of mass of new data: data acquisition must be fast, therefore the method of indexing must allow the continual and real time storage of data,
- to allow an easy and real time consultation of the more recent data: the method of indexing must privilege the access time to recent data.

Data structuring must thus to allow a real time spatio-temporal data storage and a data indexation facilitating rapid access to recent data. The indexing method has not to be too sensitive to updates and the reorganization cost of the index has to be limited. Access methods to the data must be fast and has to allow the real time access of new arrived data.

3.2. Querying of fixed, agile or mobile data

Querying of real time fixed, agile and mobile data can be realized only using continuous and mobile spatio-temporal queries. Continuous queries can be computed to one given moment, and the response communicated based on various parameters: at regular moments, or at the time of event activation. The real time properties and the forecast of a rise in load require studying of economic mechanisms of detection of relevant changes of the database as well as differential update of answers.

3.3. Safety of information

Data acquired by sensors can be erroneous or missing (blocked sensors, deteriorated and even stolen). The quality of the data and thus the reliability of the sensors must be characterized. This characterization can be carried out either during the acquisition phase, or at the time of another secondary process. In addition, for critical applications and/or confidential, the encoding of information is necessary, in order to avoid the interception, and unauthorized exploitation of the data coming from sensorsµ. It is also necessary to ensure the strong authentication of the sensors and the decentralized entities, and to carry out rigorous credibility checks (spatio-temporal integrity constraints) on the data flows so as to avoid the falsification of information, and the input of distort data in the application layers.

3.4. Rapid data processing and computing

In the case of risk management, for example, the acquisition and processing of data of monitoring, probability calculation of occurrence, simulations of process, and the evaluation of the level of alarm, must be carried out in immediate real time. In order to accelerate the processing, parallel architectures may be considered. The difficulty is then to cut out efficiently proceesing in order to parallel them.

3.5. Integration of existing information systems

If various applications of monitoring and of simulation currently exist, they were developed on various systems and tools. The integration of these applications is paramount in order to avoid new expensive developments. It requires interoperability on the levels of the data but also on the level of process. Solutions of integration of information system architectures exist today in particular based on Web technologies and message oriented middlewares. These solutions seem to emerge in applications related to the business management, into the company itself or with their environment (of the A2A with the B2B), but do not seem to be tested neither within the framework of real time applications, nor within the framework of GIS.

3.6. Communication and visualisation of real time spatio-temporal data

The visualization of dynamic crucial spatio-temporal data requires a relevant semiology and a fast visual update so as to allow real time decision making. Attention of the user must be attracted on the crucial elements in the event of crisis without being drowned in a mass of non relevant information. Moreover, refreshing must be fast without stroboscopic effect due to the real time.

3.7. Quality of the real time spatio-temporal data, real time spatio temporal Quality of Service (QoS)

Quality of geographic database is defined by criteria stored in metadata identified by ISO standards. These criteria of quality are defined for static data used by traditional applications and were designed for geographic data producers. These criteria do no take into account the qualification of dynamic data issued from agile (non continuous location change) or mobile sensors, or data representing real –time measurements used by on-line applications like environmental, urban or industrial phenomenon monitoring. For these applications, data quality and data themselves contribute to the process of decision support. Specifications of real time spatio-temporal QoS and quality of real time spatio-temporal data have to be designed. It is also necessary to define means and tools to communicate quality information to the user.

3.8. Conclusion

As detailed above, a lot of needs emerge concerning real time and spatio-temporal data management for urban, industrial or environmental monitoring systems. One of this need concerns data structuring and some indexing solutions are detailed below to manage real time spatio temporal data stored in databases.

4. REAL-TIME SPATIO-TEMPORAL DATA INDEXATION

Indexing data issued by a sensor network often leads to determining a policy for real-time updates. However, the indexing solution must also be based on other factors. Spatiotemporal approaches have to face the variety of possible types of data: points, ranges, intervals (Wang, 2000). This leads to a distinction between three families of indexing trees: those that work with objects in continuous movement, those for discrete changes and finally those for continuous changes of movements. Another way of differentiating the families of index has been brought by (Mockbel, 2003). They have focused on approaches aiming at indexing past locations, present ones and future ones. However, neither classification focuses on the real-time preformances of the indexes.

4.1. Real-time indexing

Computers processing power increase regularly. That is a well known fact. Another well known fact is that memory cost drops regularly as well. However, what few people note is that memory access cost does not decrease in par with processors improvements. Real-time meant diskless data access for more than 20 years, with the T-tree *(Lehman, 1986)* as a figurehead. However, since the late 90's researchers have reached the conclusion that this was not enough *(Lu, 2000)*. Main memory data accesses are now considered as a bottleneck. Some researchers have provided models for a better management of memory buffers *(Cha, 2001)* (Hankins, 2002). While classical indexing structures such as the B+tree were ill-considered in the 90's, performances of experiments have shown that the processing capacity improvements could give them a new life in the Real-time community. Provided some changes were made. As such, the CSB+tree *(Rao, 2000)*, a cache-conscious B+tree limits the number of pointers in the structure, optimize the node length so as to fit the memory line length,... It has proven a real improvement over older Real-time structures that were meant to outlast the B-trees. Some researchers are now working on extensions of the ideas set up for the CSB+tree so as to provide other indexing systems *(Bohannon, 2001) (Raatikka, 2004)*. However, these solutions are still confined to laboratories, and few databases implement them.

4.2. Real-time results of existing qpatio-temporal indexes

Many trees have been developed to answer specific needs. Some trees tend to consider the temporal aspect as yet another spatial dimension, which has led to 3DR-trees *(Theodoridis, 1996)* and other structures based on R-trees. However, these indexes usually need to have a previous knowledge of the data to index, which often leads to poor real-time results *(Kalashnikov, 2004).*

While most of these approaches focus on the data as a whole, some specific indices focus on particular aspect of system monitoring. As an example, structures such as the SETI *(Chakkar, 2003)* or SEB-tree *(Song, 2003)* divide the global space in sub-zones for a zone-based spatiotemporal indexing. Other structures such as the FNR-tree *(Frentsos, 2003)* or MON-tree *(Almeida, 2005)* are dedicated to indexing data from an existing road or access network. With such structures, the focus is no longer the data themselves but more conceptual entities that can be used for more efficient querying or monitoring. While the first two structures are not perfectly real-time, the MON-tree has been developed with an implicit real-time data access focus. Recently, researches have lead to different structures based on mobility. Objects in the physical world can often move. Monitoring the movements of these objects has proved an interesting issue, particularly for systems trying to predict the future location of objects. TPR-trees *(Saltenis, 2000)* use velocity vectors to estimate the future location of an object or its future expansion. While these structures can be efficient in forecasting locations, they are usually not perfect for keeping tracks of past data and for more generic applications.

To sum it up, while some existing indexes may bear potential for real-time database use, most of them rely on technologies that have not been developed for real-time use. As a consequence, different groups have started studying real-time spatiotemporal indexes.

4.3. The development of real-time spatiotemporal indexes

With the development of pervasive systems, the now widespread use of GPS and the global need for spatial indexing of real-time data, different studies have lead to several solutions, usually based on R-trees.

4.3.1. The R-tree based real-time indexes family

To cope with the limitations of the R-tree, the CR-tree *(Kim 2001)* uses compression to limit the size of the tree. As the memory is now considered as the main bottleneck, it relies on more processing to limit the structure's size. A similar idea has lead to the PR-tree *(Sitzmann 2002)*, where shared sides of a MBR are used to limit the tree size. By combining both ideas, the PCR-tree *(Min, 2004)* further limits the tree size, using more processing.
Other solutions have been developed to deal with spatiotemporal archives *(Hadjieleftheriou 2006)* so as to cut down the computational cost through a better definition of the minimum bounding rectangles used in R-trees and through specific algorithms.
These structures offer better performances than traditional structures for the tested real-time stationary or mobile applications.

One aspect to note is the difference between mobility and agility. As a matter of fact, mobility is linked to the constant movement of objects. A car, bus or plane is accurate example of what a mobility-based indexing structure usually has to deal with. On the other hand, agility is linked to a more restrictive notion. The data sources can move, but usually stay in the same location for long times. A portable measurement station, set up at a location for one week then set up elsewhere qualifies for the definition of agility. Most current monitoring systems rely on some kind of sensor agility. The real-time spatiotemporal solutions developed do not take into account the difference between agility and mobility. They do not take into account the specificities of sensor databases, where the data are issued by a set of sensor databases. Two indexes have been developed with this in mind.

4.3.2. Sensor based indexes

The PoTree *(Noel,Servigne 2004)* and the PasTree *(Noel, Servigne 2005)* have been designed to index the data issued from a sensor network with a high data throughput in a main-memory database. They are access methods for spatiotemporal real-time data, with a focus on the most recent data. They both put the focus on data fast updates and easy access to the most recent data. Furthermore, they both use different subtrees. Each sensor is linked to a specific sensor sub-tree (temporal indexing). A spatial subtree is used to point toward the relevant sensor subtrees to process queries. This policy limits data access costs by limiting the range of data to be queried. Furthermore, a direct link between the root of the sensor subtree and the most recent data cuts down the querying and updating costs of the structure.

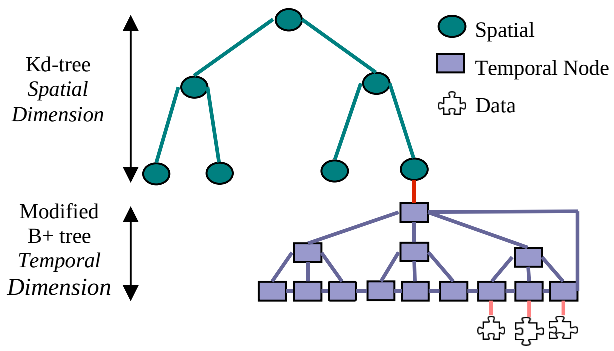

Figure 8: PoTree structure

The Potree (figure 8) aims at indexing data from a fixed sensor network with purely spatiotemporal queries. Typical queries are: 'Fetch the data from the sensor at location <X;Y> at time T' 'Fetch the data from the sensors between <X1;Y1> and <X2;Y2> between the times

T1 and T2.' The PoTree uses a kd-tree for the spatial indexing, each node pointing toward a specific sensor subtree. Each sensor subtree is a modified B+tree, with a direct link between the root and the last node of the tree. Queries are resolved by determining a set of relevant sensor subtrees through the kd-tree and by querying each of these temporal sub-trees. It uses the direct link whenever it is possible to cut down data access / update cost.

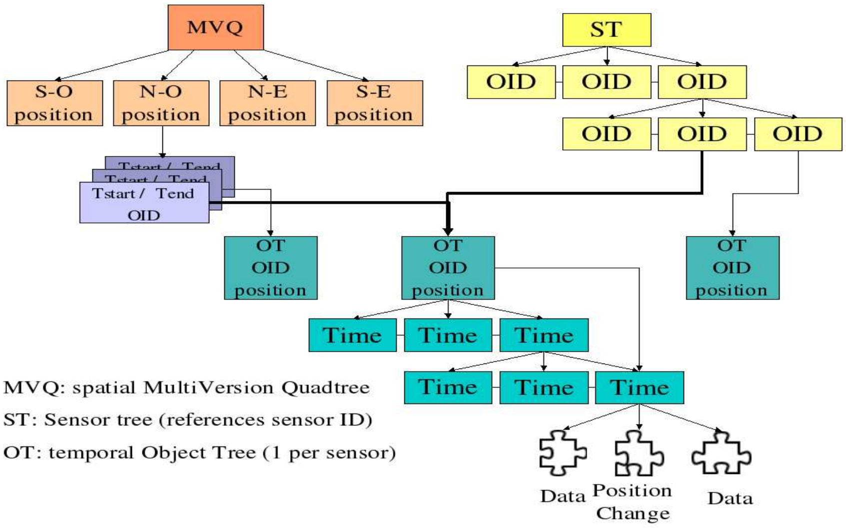

Figure 9: Structure of the PasTree

The PasTree aims at indexing data from an agile sensor network. It also adds multidimensional data access (spatiotemporal and through sensor identifiers). It can solve queries such as <Fetch the data of sensor 'RIJ4' at time T.' 'Find the different locations between times T1 and T2 of the sensor that was at location <X;Y> at T3.' Because of this multidimensional access and because of the sensor agility it has been decided to use a multiversion quadtree for spatial indexing and B+tree (indexing identifiers), both linking to modified, sensor specific B+trees. The sensor subtrees are similar to the ones used for the PoTree, with the addition of an abstraction layer to record the past locations.

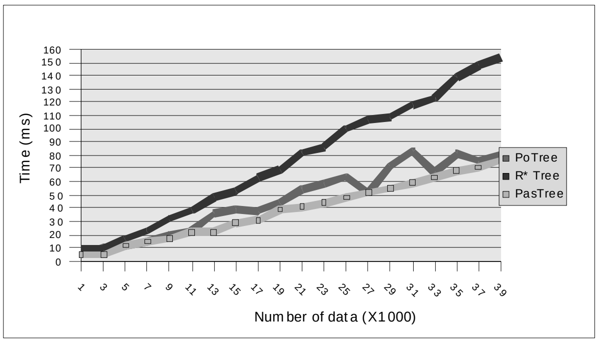

Figure 10: Spatial window / temporal interval query cost (fetch the last 10% of the data issued from 68 sensors)

Comparisons between these structures and the R*-tree have shown that both the PoTree and the PasTree offered interesting results. They both are significantly faster than the R*-tree for updates and slightly faster for queries. The PoTree is faster than the PasTree, but is more limited in terms of data access and offers no agility management.

5. CONCLUSION

In this paper, databases and telegeomatic information system were presented according spatio-temporal and real time management point of view. After a part concerning telegeomatic systems and system architectures, problematics concerning real time spatio-temporal database are defined. One of the needs concerns new data structures to allow fast real time spatio-temporal access to data.

Traditional indexing structures have shown strong limitations for real-time applications. This has lead to the development of real-time indexes, and of real-time spatio-temporal indexes. While these indexes offered good performances for generic applications, they did not focus on the specificities of sensor monitoring. More specific solutions have been developed to cope with them and are presented in this paper: The PoTree aiming at fixed sensor networks and the PasTree for agile sensors and multidimensional data access.

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