NEXUS –
POSITIONING AND DATA MANAGEMENT CONCEPTS FOR LOCATION AWARE APPLICATIONS

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Abstract: The research project „NEXUS“ aims at the development of a generic platform that supports location aware applications with mobile users. It is currently being carried out within a so-called research group supported by the DFG (German Research Council) in cooperation between the Institute for Photogrammetry, the Institute of Parallel and Distributed High-Performance Systems and the Institute of Communication Networks and Computer Engineering of the University of Stuttgart.

The main task of the platform concerns the management of dynamic spatial models that represent the real world as well as virtual objects. The virtual objects act as brokers between the platform and external information sources and services, so that information stored e.g. within the WWW can be structured spatially. The spatial data have to be delivered in multiple representations – from highly detailed 3D representations of indoor areas to coarse 2D town plans – in order to provide the adequate level of detail for each application.

Spatially aware applications which are using GIS models are available for the users on small handheld devices like PDAs. These computers are equipped with sensors for positioning and mobile communication. Therefore, the applications know the position of the users within the spatial models (they are „location aware") and can receive spatial data from distributed servers. Thus the NEXUS customers are not only able to move through the real but also through the virtual world. In order to support them on their way, GIS functionality has to be provided: users have to be able to perform spatial queries on their environment and to navigate through the virtual models and thus an interface to GIS has to be implemented. Within a first prototype, a commercially available GIS has been used to realize a Spatial Model Server. On the client side, a Java-API has been developed that takes advantage of the GIS features provided by the employed system: it allows client applications to carry out complex spatial procedures such as network analysis.

1 The general ideas of NEXUS

Within our world, the amount of information we are confronted with is increasing more and more. In order to find out which information is important it has to be structured. For this purpose, the spatial component of an information can be a decisive factor. Location aware applications, which „know“ the positions of their users, are considering this fact and prepare information according to a user’s location. For this reason, they have to refer to spatial models that allow the assignment of information to a certain position. The central part of the NEXUS platform consists of the management of these spatial models which represent the

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physical world. They provide the basis for the NEXUS infrastructure and not only have to serve for particular, but for location aware applications in general.

To extend the scope of information that can be delivered by NEXUS, external information sources like digital libraries or especially the World Wide Web must be accessible via the platform as well. Therefore, the concept of virtual objects (VOs) was introduced. The virtual objects augment the NEXUS world and can have different functions. Virtual Information Towers (VITs), for example, structure the data stored within other information systems spatially. Each VIT has a certain location and - according to its significance - a predefined area of visibility (see Figure 1).

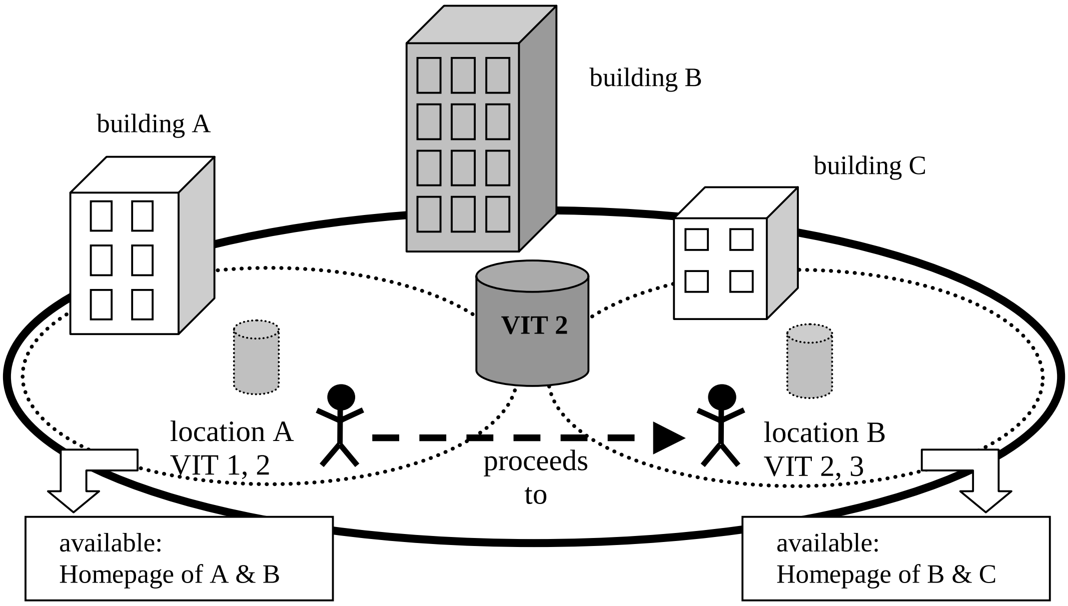

Figure 1: Virtual Information Towers and their different areas of visibility.

Due to the fact that the spatial object models include virtual representations, they are called Augmented Area Models (see Figure 2). Each Augmented Area Model (AAM) describes only a part of the whole NEXUS or Augmented World, respectively, e.g. an area of a city or only the detailed interior of a room. As an essential requirement, the models – which might overlap or include each other – must have a transparent structure so that their interoperability can be guaranteed

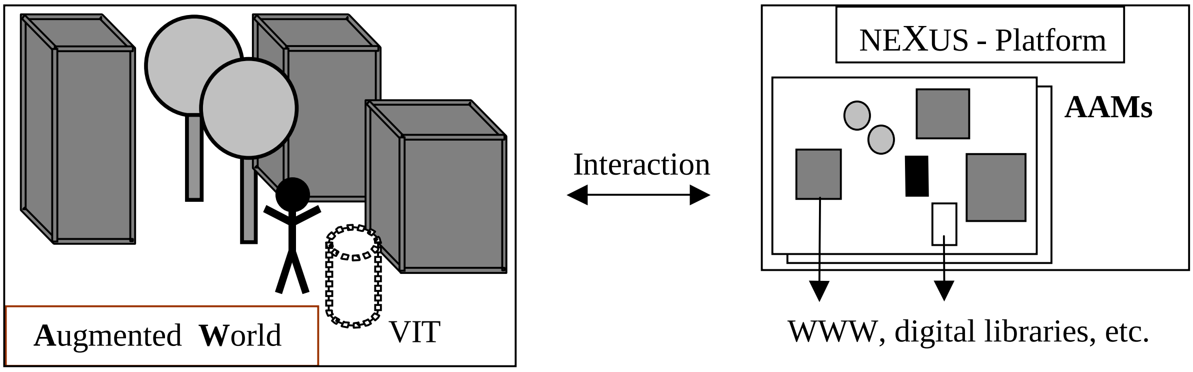

Figure 2: The Augmented Reality and its computer representation within NEXUS.

Since different applications need different resolutions of data sets, the spatial models have to manage data in multiple representations – from coarse to highly detailed levels. Furthermore, huge amounts of data must be stored and handled. For these reasons it is inevitable to use large and distributed databases as Spatial Model Servers (SMS). They have to function as a scalable Middleware layer that can be accessed by multiple users. In a first prototype, commercial GIS software (ArcView by ESRI) has been used to realize such a Spatial Model Server. Its functionalities like spatial selections or network analysis facilitate the support of the users on their way through the NEXUS world. With respect to Computer Aided Facility Management Systems (CAFM), not only the ability to perform geographical queries should be supported, but the interactive control of processes has to be realized, too. Therefore, an interesting objective comprises the implementation of active functionalities into the system in a way that objects of the real world can be controlled by their corresponding representations in the computer models and vice versa. Moreover, participants of the NEXUS system should be able to identify features of their surrounding by just pointing at them. For this reason, special sensors have to be integrated into the user's mobile device that allow the detection of directions.

The technical environment of NEXUS is assumed to be composed of so-called NEXUS stations – mobile, handheld computers like Notebooks, Personal Digital Assistants (PDAs) or Wearable Computers (STARNER ET AL. 1998) which additionally dispose of other facilities, especially for positioning and mobile communication. In the future, appropriate sensor systems to acquire information about aspects concerning the state of the environment of the user like temperature, lighting, etc. will also be attached to the mobile devices. To determine a user‘s location in outdoor areas, the Differential Global Positioning System (DGPS) is used in combination with several supporting sensors. Indoor positioning requires different methods based on infrared signals (e.g. “Active Badge” systems), radio networks or indirect positioning techniques like image interpretation. The positioning information that is obtained from the sensor systems will be managed within special, also distributed databases for mobile objects, forming a so-called Location Service (LEONHARDI & KUBACH 1999, HOHL ET AL. 1999). The NEXUS station needs to be able to connect to the platform and external information sources like the Internet using wireless communication.

2 Characteristics of location aware applications

Location aware applications know the current position of mobile users since they receive this information either directly from sensor systems or indirectly via a Location Service. Thus, they are able to determine user locations within spatial models and can therefore provide any information which is of special importance at the current position of a user immediately. Furthermore, location aware applications offer special services for their users, particularly concerning the solution of typical GIS tasks like navigation or spatial queries.

Generally, there are different kinds of applications dealing with location awareness. More global approaches like city-, traffic- or emergency information systems stand opposite to rather local applications like museum-, exhibition- or department store information systems. With regard to the requirements of the NEXUS infrastructure, it is a precondition that the users can switch between the different applications.

To get an impression of the functionalities that the NEXUS platform has to provide, this part will illustrate the main ideas by means of an application scenario: it is planned to establish a city information system for Stuttgart that employs NEXUS.

One could imagine a user who arrives at Stuttgart's central station and has to attend a conference in town. To find the way in the unknown environment, he utilizes a NEXUS station, a small mobile computer (PDA). The PDA knows the current position and is able to get in touch with the NEXUS platform by wireless communication. The NEXUS customer accesses the user interface provided by the system and finds a service which gives the possibility to search for trains and to cash the fare for public transport automatically. Having specified his destination, NEXUS is showing the foot path to the closest subway station, the line number and the departure time of the train which leads the user to the location where the conference takes place. After the meeting he is going to the city for a stroll. As he sees a historical building, he just points at it with the telepointing device integrated in the NEXUS station. Directly, all historical and architectural facts about the object are transmitted to his PDA. While he is proceeding, the mobile computer sends an audio signal and calls the attention of the user to an incoming message. A department store informs all the people passing by about special offers. The NEXUS station is able to filter messages because of the user profile that is generated for each user. This profile also provides information concerning the acceptance to receive external information. The user is attracted by one of the special offers and enters the building. Automatically, the NEXUS station switches to the department store information system that leads him to the product he is interested in. A virtual information tower (VIT) allows the user to obtain special information about it, e.g. technical details, WWW address of the manufacturer, etc. On the other hand, he is able to attach a virtual post-it to the VIT containing information about his personal experience with a particular product.

3 Architecture of the NEXUS-Platform

NEXUS is designed to be a generic infrastructure that can be accessed by all kinds of location aware applications. For this reason, a well-defined interface has to be provided that allows the appropriate use of the services for the different applications. The main task of the platform is the management of dynamic computer models of the real world in a distributed environment. The sensor systems determine the position of mobile objects and the state of those parts of the real world, which are described within the computer model. Different kinds of networks are used to realize the communication between the components of the platform. Figure 3 shows an overview of the NEXUS architecture. All components will be described in more detail in the following chapters but the focus lies on the positioning techniques and the methods for data management.

In order to guarantee that the platform can provide the capabilities mentioned above, several requirements have to be fulfilled. First of all, the data safety and the confidentiality of personal data must be ensured. Otherwise, an acceptance by the user could not be expected. Furthermore, an adequate response time can only be achieved by a scalable infrastructure. To prevent the system from breakdown, parameter changes have to be handled appropriately. Of course, the interoperability of different NEXUS-based applications as well as different Augmented Area Models is another crucial prerequisite.

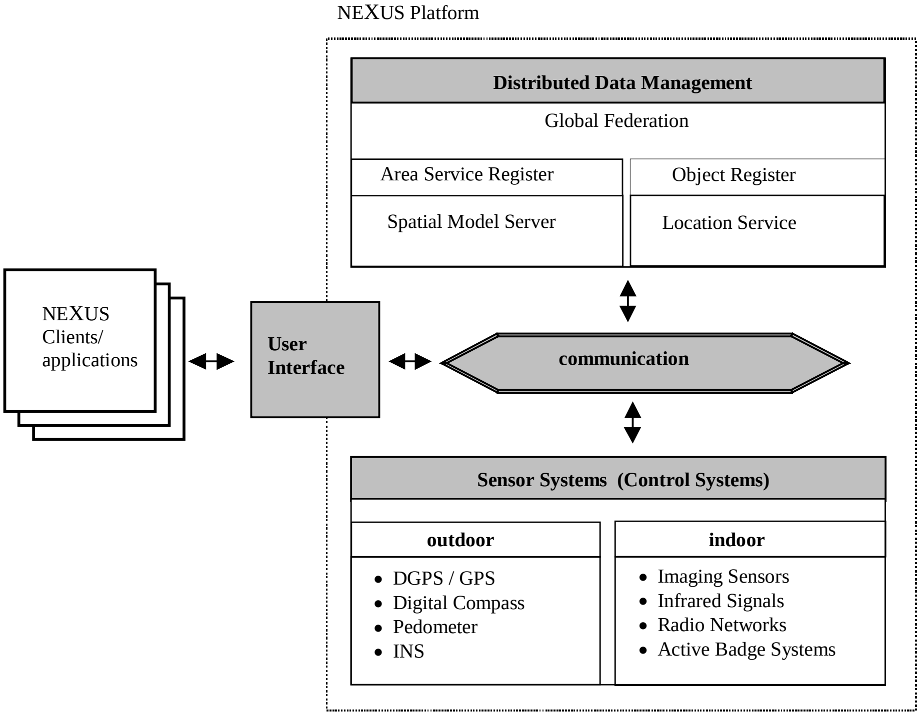

Figure 3: Architecture of the NEXUS Platform

3.1 User Interface

The User Interface support is running on the mobile device carried by the user and contains basic functionality, which is required for interacting with the NEXUS platform and for displaying and navigating through the model. It also provides support for adapting to devices with different levels of computing power, different amounts of memory, different levels of network connection or different displays. A PDA will e.g. require a completely different user interface than a Wearable Computer. The user interface should allow an easy communication between client and platform. Moreover, the performance of queries has to function in a straightforward manner, without having any specific knowledge about information systems.

3.2 Communication environment

We assume that NEXUS provides information for location aware applications. The user who wants to access the platform is equipped with some kind of mobile computing device. To get the necessary information, this device needs to be able to connect to the information source, e.g. the Internet, using wireless communication. For a wide area network (WAN) it can use the data service of a mobile telephone system like GSM (< 64 KBit/s) (EBERSPÄCHER & VÖGEL 1998) or of future systems which will be more suitable for data transmission like GPRS or UMTS (max. 2 MBit/s). Inside of buildings it can use a Wireless LAN, e.g. bluetooth (approx. 700 KBit/s), IrDA (IrDA 1.0: approx. 7 KByte/s; Very Fast IR: 16MBit/s), according to the 802.11 standard. The communication network structure that NEXUS must use at present is heterogeneous. And also in the future there will not be a migration to one single network. This fact means for NEXUS that it has to use different networks. The major task is the decision for network components that will fulfil the work best. This result is an antagonism between the decision for the best network and the available network components which NEXUS must be able to deal with. To bridge the difference between the NEXUS communication layer and the existing heterogeneous networks, a middleware layer must exist (see Figure 4). This layer acts as a broker.

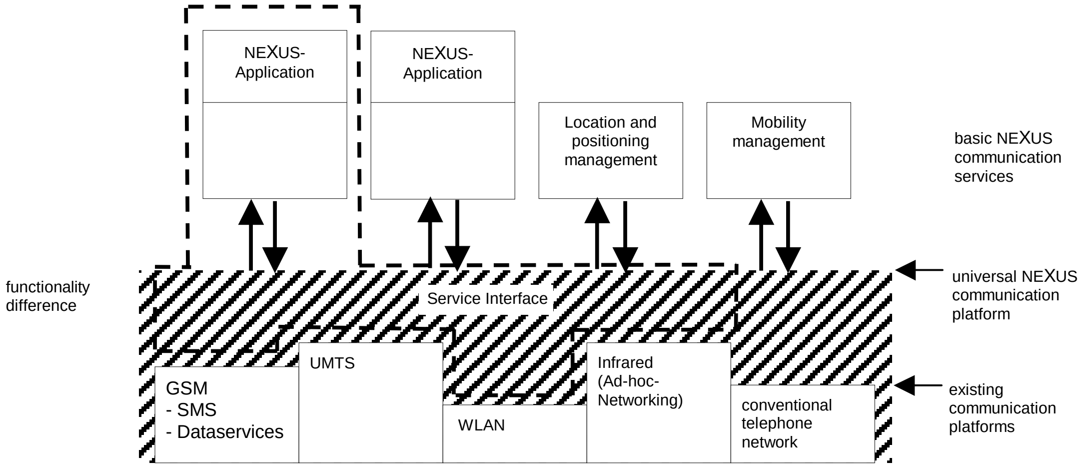

Figure 4: Functionality difference between NEXUS communication and existing communication platforms

3.3 Components for positioning

Spatially aware applications need location information in real time. For example, it is possible to use differential GPS. In combination with GIS, it is necessary to consider which model is representing the environment at the moment. In general, this could be subdivided in the outdoor and indoor area. If these two locations are considered, it is clear that it will be difficult to use only one sensor for positioning in both environments. In fact, there is a need of a multi-sensor tool. To create such, it is important to decide which sensors fit best for this purpose. Research results have shown, that it is important to combine tools based on different principles. Therefore, absolute sensors, relative sensors and also imaging sensors can be chosen. Imaging sensors do not provide direct position information. To extract location information from them, it is necessary to use image interpretation methods.

The method of using more than one positioning sensor also has a further advantage. To increase the absolute accuracy it is possible to combine two or more measurements delivered by different sensors. Kalman filtering is one method to overcome this problem, but also simpler techniques are possible. At this point it is necessary to rethink about the two areas where position information will be required: indoor and outdoor. As already mentioned the sensors for positioning in these two regions are completely different, because outdoor sensors in general fail in indoor. For indoor areas, Active Badge systems can be used. A disadvantage of using “Active-Badge” systems for locating a user is the precondition that all rooms have to be equipped with this technology. The use of imaging sensors is one way to solve this problem. The keynote here is to extract prominent points and lines with image interpretation as “tie points”. In combination with models of the indoor regions and additional algorithms it is possible to detect the position of the camera.

To give an overview of the positioning components, each of them will be described in detail.

3.3.1 Differential GPS

The main positioning sensor for the outdoor area is differential GPS. This sensor offers the possibility to determine the position with an accuracy of a few meters. This accuracy is needed to provide NEXUS specific services.

In the NEXUS project a standard Garmin LP25 GPS receiver is utilized. This is able to work in differential mode as well as in normal mode. In combination with the ALF service (**A**ccurate Positioning by **L**ow **F**requency) which the “Deutsche Telekom” provides permanently, the differential mode is realized. A correction signal is sent every 3 seconds via long wave from the transmitter station in Mainflingen (Frankfurt), and is available all around in Germany (see Figure 5).

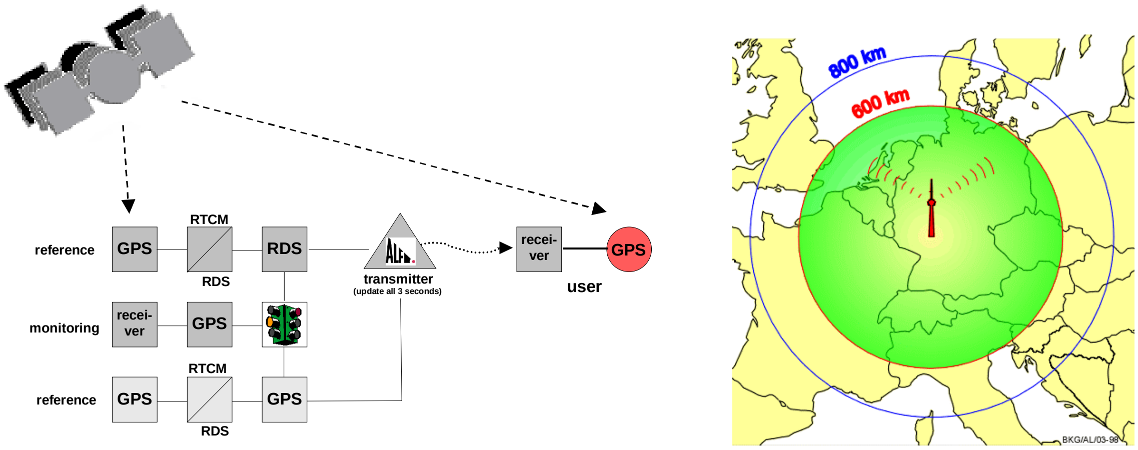

Figure 5: DGPS using the ALF service of the “Deutsche Telekom”

The accuracy of such systems depends on the distance of the reference station and the GPS receiver position of the mobile user (see Figure 6). The error budget is linear, but there are also additional random errors depending on satellite constellation and other phenomena like multipath, interference, etc. Research results show, that the necessary accuracies could be achieved and that the results are very positive. In the test area “Bohnenviertel (Stuttgart city center)” (see Fig. 7a) an accuracy of about 3 meters was achieved and maximum errors of about 10 meters occurred in some points (see Figure 7b). This accuracy is sufficient to use this sensor for location aware applications in outdoor and city areas.

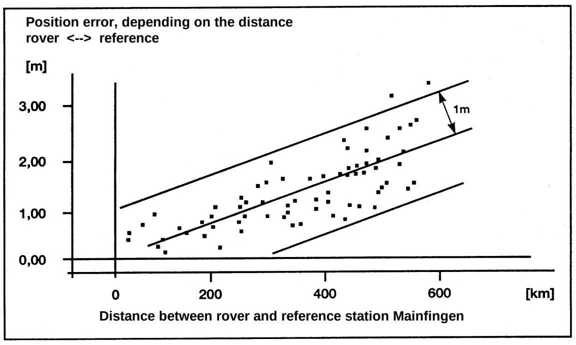

Figure 6: Accuracy depending on the distance of the rover station to the reference station (courtesy: Bundesamt für Kartographie und Geodäsie - bkg)

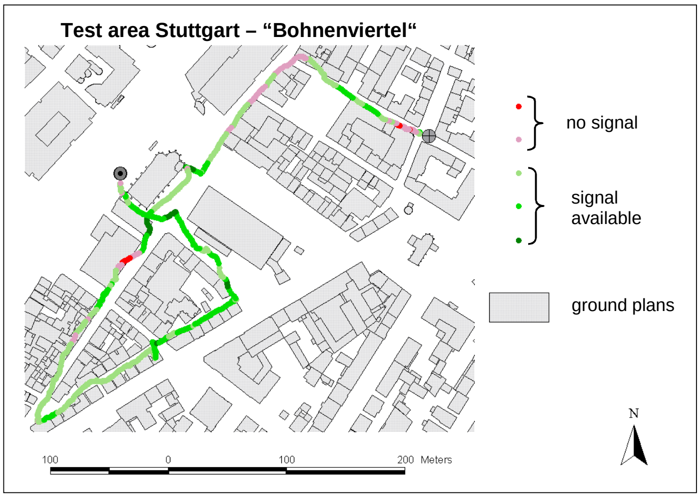

Figure 7a: Real-time DGPS Test – Stuttgart

Accuracy	
σ pos (Stuttgart-Bohnenviertel)	± 3 m
GDOP	3,2
max. deviation of desired trajectory	10 m

Figure 7b: Achieved accuracy in the test area “Bohnenviertel”

3.3.2 Digital Compass and Pedometer

As mentioned above, the main outdoor positioning sensor will be GPS. As well-known GPS fails in some cases, especially if the satellite signals cannot be received. For such situations additional sensors are necessary. One of them is a digital compass module. This can provide orientation information, so it is possible to detect the azimuth and tilt information without any metric component. To conclude to a location information a supplementary sensor is required. A pedometer is able to provide the missing metric information. The combination of these two tools leads to an additional measurement device for positioning.

3.3.3 Map Matching

A further method to provide position information is to use map matching. This tool provides the possibility to conclude to a position if other online measurements exist. In this case these are distance and orientation information (digital compass, pedometer). For car navigation applications, map matching techniques are utilized for a long time to increase the position accuracy (CZOMMER 1999). For vehicles it is easier to reconstruct the position. For pedestrian use it is more difficult, because the reference frame is not easy to fix to the body of the pedestrian. But this is a necessary prerequisite to assign the measurements uniquely. If this problem is solved, the measurements herein mentioned before can be used for the map matching process. Research results have shown, that curvature based map matching algorithms are qualified for solving this task (BERNECKER 1999).

3.3.4 Imaging Sensors

Inverse navigation using image sequences, in combination with image interpretation, is a method for indoor positioning (also in outdoor). For this purpose, digital cameras are required as imaging sensors.

The principle for location determination is to use objects extracted from the images. If this is completed, the position and orientation can be determined by spatial resection. The object recognition often is subdivided into data collection, preprocessing, segmentation, modeling (shaping) and matching. The segmentation process identifies and prepares points, lines and areas for the matching. The model contains a representation of each object by using its features. It is also possible to extract features from the input data. In a correlation process the correspondence between features of the scene and the object model is assigned. Within this process of identification and location the result is the position information of the imaging module. At first, a simple strategy is to use coded targets or signals (representing the objects which are to detect) for the location process (AHN & SCHULTES 1997). Finally, features from real objects serve as "tie points" to realize the positioning.

3.3.5 Active Badge Systems

The "Active Badge" (AB) system also represents an indoor positioning tool. At Olivetti Research Ltd. a system was developed, which provides the location of persons – equipped with a badge – within buildings (WANT ET. AL. 1991). Using this technology, each person must wear a badge with an unique ID. If a person is moving through the building, the AB Location Service is able to detect his position. The idea of this system is very simple, there is only the need of an AB location network and each user must wear a unique badge. In case of NEXUS it is doubtful if this will solve our indoor positioning problem, because the costs for realization will increase very soon, and NEXUS should be a low-cost and easy to use tool. So only for several indoor areas it seems reasonable to use this system, e.g. for airports, fairs, museums, etc..

3.4 Data management

The main component of the NEXUS platform is responsible for the data management. For this reason, models of the real world are stored, queries are processed and updates pertained. Since huge amounts of data and multiple users have to be handled simultaneously, a centralized solution is inadequate and this data management must take place in a distributed environment. According to the demands of different location aware applications, spatial data have to be offered in multiple representations. Hence, appropriate algorithms to deduce all the necessary levels of detail have to be implemented into the platform. In order to guarantee the interoperability, relationships between different Augmented Area Models must be defined and data formats must be exchangeable. All the different aspects concerning the management of data within NEXUS are reflected upon in the following sections.

3.4.1 Federation of spatial data

The requirement to distribute the data across many servers leads to the necessity to establish a Global Federation. Since the management of mobile objects demands for other optimization procedures than the management of rather static objects (as they are usually dealt with in GIS), the storage and processing of NEXUS-related data has to be divided into two separate parts. With regard to mobile objects, user specifications (like name, user profile, access rights) will be handled within an Object Register, whereas user positions are administered by a Location Service. On the other hand, a so-called Area Service Register is responsible for the assignment of the more static Augmented Area Models to the Spatial Model Servers. The Spatial Model Servers themselves store and manage the various computer models (including the virtual objects and their connections to external information spaces) and provide the necessary GIS functionalities.

Any query or update request that is posed on the NEXUS platform is first sent to the Global Federation component. The Federation then informs itself using the Object Register and the Location Service about the specifications and the current position of the client. Subsequently, it queries the Area Service Register in order to find out, which Augmented Area Models or Spatial Model Servers, respectively, have to be involved in the processing of the demanded task. After having carried out the required steps, the selected SMS instances yield their partial results back to the Federation which aggregates them to one solution and finally forwards it to the client.

Through the Global Federation, the applications are perceiving the combination of different Augmented Area Models as one big single model. In order to guarantee this interoperability between the various spatial models, not only their data formats have to be exchangeable, but also the relationships between them must be defined. Only then the Area Service Register disposes of the capability to find out, which Augmented Area Models can work together at all. According to EGENHOFER (1991), topological relations will be defined on the basis of intersections (overlapping, adjoining, inclusion, etc.), whereas the semantic correlations are determined in terms of refinement or reduction, e.g. with respect to geometry, attributes, etc.

3.4.2 Multiple representations within NEXUS

The Augmented World Model has to represent all the features of the physical world that could be of importance for any location aware application. Thus, the datasets have to be as detailed as possible. On the other hand, not each application needs data of high resolution, but rather prefers coarser representations. In consideration of efficient data analysis and visualization as well as low data transmission rates, it is very important to be able to provide the adequate level of detail for each application task. For this reason, it is a vital prerequisite for the spatial models that they can manage multiple representations. In order to achieve this goal, two different approaches have to be pursued: if data from multiple sources are used, the corresponding objects of the variously detailed datasets have to be identified by conflation procedures (WALTER 1997). Otherwise, if one disposes of a highly detailed dataset, the appropriate representations can be derived by knowledge based systems (ANDERS & SESTER 1997), (MACKANESS ET AL. 1997) or machine learning techniques (SESTER 1998). For TINs, geometric simplification can be realized by means of triangulation methods (DE FLORIANI & PUPPO 1995, SCHMALSTIEG 1997).

So far, three levels of detail for building geometries of a test area of Stuttgart have been derived on the basis of the municipal building information system. Figure 8 shows a scene of the virtual city model, displaying the level with the highest resolution (partially textured). This dataset has been collated by an automated method of HAALA & BRENNER (1999) which combines digital ground plans with height information from laser scanning data.

Figure 8: Highly detailed scene of the virtual city model of Stuttgart

3.4.3 Properties of Spatial Model Servers (SMS)

For the management of the various Augmented Area Models, special servers have to be established that support the storage and processing of spatial data. Typically, object relational DBMS like Oracle, DB2 or Informix in combination with spatial data blades like the Spatial Database Engine by ESRI are used for that purpose. Although SQL meanwhile allows geographical queries, it does not cover the complete functionalities of a GIS. Thus, geographic information systems will have to be integrated into the SMS as well.

Generally, the Spatial Model Servers should consider that different clients with varying computing power are accessing the platform and so an interface must be provided for each of them. Mighty clients only need the feasibility to receive complete spatial models and process the data on their own. Usually, the different kinds of location aware applications employ a user API that is located on the client side and makes the GIS functionalities of the server available. Until now, a Java library has been developed (SCHÜTZNER 1999) that uses ArcView to carry out spatial selections (*objectsInArea, closestObjects*, etc.), navigation tasks (*findShortestPath*), attributive queries (*getAttribute*) and graphical presentations (*getCurrentView*). Furthermore, also simple clients have to be supported by an HTML or WAP based interface. For system administrators, a management API has to be prepared.

As another requirement, an SMS has to accomplish an optimized distribution of the workload between client and server to reduce data transmission and response time. Of course, the platform independence of clients has to be guaranteed as well.

4 Conclusion and Outlook

The general concept of NEXUS aims at the development of a generic platform for location aware applications. The most important task of the platform consists of the management of Augmented Area Models within distributed spatial servers. Until now, a first prototype for such a Spatial Model Server has been developed on the basis of ArcView GIS to investigate the requirements that the platform has to accomplish. The focus has been put on the development of a Java library that allows the access of the functionalities that the geographical information system provides. These services have been implemented into a sample application.

In the future, the federation component has to be integrated into the system as well, so that the distribution of spatial queries can be realized. Furthermore, the data must be stored within large spatial databases to be capable of handling huge data amounts. Therefore, the functionalities of object-relational databases will also be investigated.

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