HADMÉRNÖK

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POSSIBLE USES OF GEOGRAPHICAL INFORMATION SYSTEMS IN WIRELESS NETWORK SYSTEMS OF FUTURE

Abstract

Geographical information systems just like wireless sensor networks showed a great development over the recent decades. These two fields are closely related, a wireless sensor network without a capable geographical information system that supports it is hardly feasible. The foreseeable development of such systems adumbrate much smaller and cheaper motes, which will present new possibilities and challenges in the use and the design of these systems. The paper at hand focuses on these matter from the aspect of the deployment of motes.

A térinformatika, csak úgy, mint a vezeték nélküli szenzorhálózatok nagyívű terjedése az elmúlt pár évtized vívmányainak eredménye. A kettő szorosan összefüggő terület, nehéz praktikus szenzorhálózatot elképzelni valamilyen térinformatikai kapcsolódás nélkül. A technológia fejlődése a mote-ok további méretcsökkenését hozza magával, amely új lehetőségeket és új kihívásokat jelent e rendszerek használata és tervezése kapcsán. Jelen cikk ezeket a kérdéseket teszi a mote-ok kijuttatásának tükrébe.

Keywords: *wireless sensor networks, geographical information systems, radio wave propagation ~ szenzorhálózatok, térinformatika, jelterjedés*

INTRODUCTION

Unattended Ground Sensor networks and Geographical Information Systems has been made feasible by the rapid technological development of the recent decades. Both of them heavily rely on the three great technological achievement that changed everyday civilian life as well as warfare: advanced mobile communication, global positioning systems and the power of Internet. UGS[1] and GIS[2] are two very closely related topic, better said, it is hard to imagine a sensor network in military use without a capable GIS that supports it.

Sensor motes[3] typically communicate over radio waves. Radio wave propagation is a very sensitive to the environment that radio waves pass through from the transmitter to the receiver. Geographical information systems can support the operation of wireless sensor networks from this aspect as well.

GEOGRAPHICAL INFORMATION SYSTEMS

Knowing the environment has been a vital skill for surviving since the beginning of the history of the human race. The method has changed throughout the centuries naturally, but the process itself for achieving geographical knowledge can be divided into four main phases regardless of the era under examination[1]: gathering data from the environment (input), record it somehow (management), making analysis on them and finally present the results in a well usable form. In the recent past these activities served to provide different kinds of paper maps, and processes for using them, but with the ambitious evolving of technology, all four outlined steps became heavily technology dependent. Paper maps are exchanged to digital maps, one can say, which is somewhat oversimplifying the question. A digital map is only one part of a huge interconnection of systems that is called a geographical information systems.

Geoinformation is in its broadest sense means storing and managing data that has geographical aspect. Geoinformation systems are all the processes and equipments which are involved during the above mentioned activities as [1]:

- input
- management
- analysis
- presentation

The input activities cover all the processes and systems which provide the data the system will use and rely on. These are typically (but not exclusively) information regarding the surface of the Earth: altitude points, rivers, forests, cities, road-networks etc. The data can be obtained either by digitizing already existing paper maps or by using modern data acquisition technologies like GPS positions or satellite photography. These are the so called static data, which don't change over time, or at least not rapidly. Data on the other hand that changes with time is equally important, like the position of the own and of the enemy forces, position of vehicles, weather conditions or changes in the static data (collapsed bridge, blocked road). These are called dynamic data.[2]

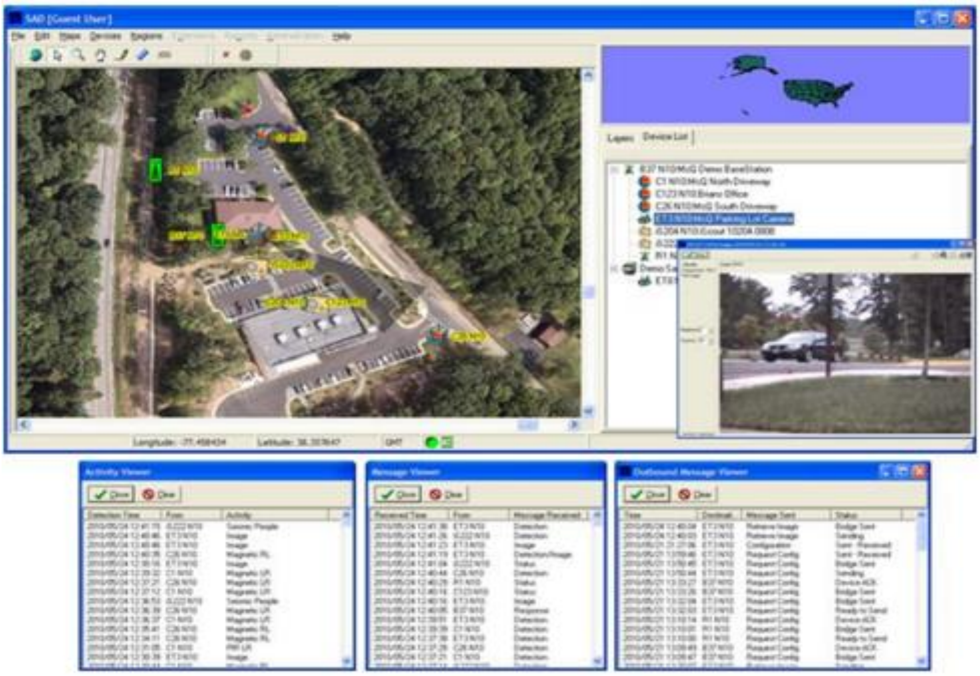
The management of all the static and dynamic data is done by DBMS[4] which are able to store and provide this data for analysis. Storing and providing it for analysis requires to build up a model based on the input data, which in turn can be converted into a format that a DBMS system will effectively handle. These systems must be capable of handling huge amount of data,

[1] UGS: Unattended Ground Sensor
[2] GIS: Geographical Information Systems
[3] mote: An elementary part of a sensor network, which can actually sense its environment. A node with sensor.
[4] DBMS: Database management systems

moreover the required storage place is not the only bottleneck. Much data means many interconnections. Interconnections typically not linear with the number of items but shows exponential relation, which means computational power is also a serious concern at handling of huge amount of data. [1]

Analysis is the process which aims to answer questions like: What is at a particular position? Where is a particular object? Is there anything has changed? How can the troops get from A to B fastest? What would happen if... ? Geoinformation systems should be capable to answer these kind of questions, and by that help the soldier who uses it. The analysis can be divided into operative, decision-supporting and strategical parts. The algorithms behind the application which delivers answers for these questions must not only quick and very ergonomic in design, but unquestionably reliable too. If the system supplies the commander with false or misguiding information, the systems is not a benefit but a disadvantage in warfare, which is obviously something inadmissible.[3]

The geographical information data, be it static or dynamic, shall be displayed for the users in a well understandable and convenient form. This is called the presentation. The characteristic of such a systems must be very ergonomic and easy to use. Ergonomy is not a question of luxury here but the question of smooth interaction between the system and the soldiers who are using it. With today's technology the presentation of geographical data is far more than a digital version of a 2D map. Data can be visualized in 3D virtual space, simulations and “what if” scenarios can be made. This means the 2D computer screen not only has to display a 3D environment in a well oversee-able and navigable manner, but even by reaching into a fourth dimension, has to run simulations to predict possible scenarios of the future. Moving from the command center to the battlefield, augmented reality[5] techniques can help the war fighters, where information can be projected onto the real world in real time, with the suitable HMD[6]. In Illustration 1. below McQ's presentation application is shown. On the top-down view map the sensors location is depicted, with the angle-of-view of the camera mote. The activity log of each mote can be queried and the image the camera mote sees as well. [4]



1. Figure. McQ's application for supervising the sensor network. [4]

[5] Augmented reality: A visual presentation technology, where virtual objects can be placed into 3D space as if they were actually parts of reality by a suitable display and a computer program.

[6] HUD: Head Mounted Display, a small screen coupled with the suitable optics mounted on the soldier's helmet.

For a better overview on geographical information systems four fundamental division can be created regarding their components [1]:

- hardware and networks
- software
- data
- user

Hardware serves the purposes of inputting data, such as GPS receivers, digitizer devices, measurement devices and all the sensors which gather data or contribute with data to the system. Another level of hardware the actual IT equipment, infrastructure and network that serves the management, transport and analysis of the gathered data. A final layer of the hardware devices are the ones that are responsible the presentation and input. Today, when information technology has a never-seen upstream from the commercial fields, it is not surprising to see that military in many cases uses exactly the same technology, moreover the same products as civilian life. Of course all these equipments must be tailored for the rough use that can be expected in the military.[1]

Software is naturally all the program which make the system work. Geoinformation systems rely heavily on databases that can reliably store data and make them easily accessible by the upper layers of the system.[5] Again, military does not need to develop their own systems if proven solutions can be found in civilian life. This is only true for only to the layer where civilian and military usage does not differ much. DBMS systems should be usable in military life, but the analysis and especially the presentation layers might be quite different.

Raw input data must be carefully and systematically prepared for storage. First a model shall be defined which describes reality: keeps all parameters which is important for the perspective of the application and excludes all that is not important. This model shall then deliver entities, which has a class, attributes and connections. These entities will be the base for creating a logical model, in order to interconnect geographical data and other data. These objects then can be stored in and actual DBMS system in a way which is optimized for access from an IT point of view. [2]

Finally, when one focuses on the users of these system, one shall focus not only on the commander who oversees the battlefield on a neat 3D visualization of the operation or the soldier in the field who uses geographical data displayed on his battlefield-capable tablet. Users in a wider picture are the developers and the professional geoinformation engineers who facilitate the smooth operation of the whole system.

As we can see modern warfare is unimaginable without powerful geoinformation systems, in fact the significance of them will continue to grow in the future. Due to the huge amount of data that can be and is being acquired from the environment the gap between modeling reality and reality itself will decrease. As it was written, the input sources for these systems are numerous and expanding. Wireless sensor networks contribute to the inputs, and the foreseeable future of them just make this statement even more substantial.

SENSOR NETWORKS IN MILITARY USE

Wireless sensor networks are relatively new achievements of technology just as geographical information systems. The purpose of their existence on the military field is also very similar to the one of geographical information systems: dominate the environment. They can be found in many applications today in civilian life as well, and some of them are very similar to military use. A mote senses physical variables from its environment like: pressure, temperature, sound, seismic waves, radio magnetic waves in various frequency ranges, light and even shorter wavelengths. These data then might or might not be preprocessed and sent out to other motes in the network. The motes form an interconnected network, which is typically connected to the out world by a special kind of element, known as the gateway. The motes have a built in radio system, which makes it possible for them to communicate with each other and with the gateway. The gateway is communicating with a remote network, where the operator is able to supervise the whole network with a special purpose application.

There are plenty of companies which are developing such systems with the intent of selling their products to the military as well. This means it is easy to survey the state-of-the-art of this field, since it's not in the interest of these companies to hide the technical specification of their systems, as it might be the case with pure military developments.

A system called MicroObserver by Textron Systems[6] depicted on Illustration 2. is quite typical for today's unattended sensor networks. The system utilizes two different kind of seismic motes. A long-term sensor which is capable to operate for two years with the built in battery, and a smaller one, intended for tactical purposes with 30 days of battery life. These shall be buried into the ground, set into operation and camouflaged. These motes then can collect seismic data, and by analyzing this seismic data the mote can tell if someone or a group of people are walking in its vicinity or a vehicle might have entered into the circle of supervision. The system also contains a camera mote, which can take pictures in the infrared range. The motes after deployment form a mesh network automatically, which is also self-healing. This means the network will operate with optimal message paths, and will automatically reconfigure itself if one mote fails. The system gives another fine example of what an unattended sensor network is capable of: The infrared camera is far more power-demanding than the seismic motes, it would not able to maintain as long operation times as the seismic motes with a reasonable sized battery back. That's why it is in a sleeping state and only wakes up if the seismic motes tell it to do so[6].

2. Figure. Components of MicroObserver [6]

The motes connect to a gateway which should be in a several kilometer range. All the motes have GPS receiver built into them, which make them aware of their own location. After deployment without further adjustments the operator will be able to supervise the network from a suitable notebook computer.

The presentation application will conveniently show all the motes on a map. The sensor network itself will log events, so the operator is informed not only the activities of the present but of the past too. Similar systems are provided by other companies as well. Scorpion II by Northrop Group[7], iScout from McQ[4], Lockheed Martin and its SPAN system[8] or RDC by Digital Barriers[9] only a few of the many. Apart from military application they can be used for border control or proprietary defense by any company or individual who might need them.

These devices are deployed by the infantry at carefully designed strategical positions, where they are camouflaged and set into operation. After this initial setup the sensor network does not require maintenance, hence the name UGS.

RADIOWAVE PROPAGATION

Sensor networks typically communicate over radio waves. This is true for inter-mote communication and for mote-to-gateway communications as well. If communication doesn't work the sensor network is rendered useless. Since the motes should be operable without human interaction it is very important for them to recognize present and foreseeable problems with communication and apply remedy if possible.

The environment plays a big role how radio waves propagate, and GIS has knowledge of the environment. This means relying on data from the GIS, the mote might be able to acquire data regarding the environment, which in turn can help to adjust the communication. Electromagnetic radiation can be reflected, refracted, diffracted and absorbed during transmission. Radio waves are electromagnetic radiation, from the one millimeter up to one hundred kilometer wavelength range. All these phenomena have a huge effect on the quality of the communication. Let's recap the four basic phenomena.[10]

Reflection of radio waves can be imagined just like the reflection of the light by a mirror. As the wavefront hits a surface with an angle of α it continues its way with the angle of $(180° - \alpha)$. After reflection the phase of radio wave might be altered in some cases.

Refraction of radio waves occur when the wave front reaches a boundary between two environment where the velocity of wave propagation is different for some reason. As a result the radio wave will changes its direction. The change of direction is always toward the medium that has the lower velocity of propagation. If the changes are gradual, the effect is more like a bending and not an abrupt change in direction.

If a radio wave meets an obstacle, it has a natural tendency to bend around it. This is called diffraction. This phenomena makes it possible for the radio wave to reach regions behind an object that would normally be in the shadows.

If a radio wave's energy is transmitted entirely to a particle or an object increasing the internal energy of that particular particle or object, the radio wave is absorbed and ceases to exist.

These four basic phenomena explains all the effect that happen with a radio wave during transmission. When the radio wave meets a mountain, a tree, a concrete wall, a raindrop, foggy air, or ionized particles in the higher parts of the atmosphere it will be effected by these phenomena. In most of the cases these effects are bad from the quality of the communication. But in some other cases these effects actually makes over the line of side radio transmissions possible. The effects of these phenomenas highly depend on the wavelength of the transmission which is being used. The VLF band for example is known for being a very good in following the Earth's surface. These signals if transmitted by high enough power capable go overseas and mountains, following the Earth's curvature. On the other hand decreasing wavelengths in the microwave domain will become more and more sensitive for water in the air for example. At smaller frequencies only rain (drops) will affect the communication, but if even higher frequencies would be used simple water vapor or fog would significantly weakens the quality of the communication. The combination of wavelength, the properties of the matter the wavefront hits, the angle of inclination, and those four basic phenomena will determine the quality of communication that a mote can maintain.[10]

This means the communication quality between the motes, which equally means the benefit of the network, highly depends on the environment, better said, the position of the motes, the transmission mode they use and the characteristics of the environment. As wavelength plays a big role in how these phenomenas affect wave propagation, for different environments different wavelengths would be optimal. The question is not only whether a particular mote is able to operate after deployment, but more like whether it is able to communicate or not. It plays a big part whether a mote is able to adjust its transmission characteristics to the environment or not. A non-communicating mote is virtually non-existent and shall be considered as lost.

GIS IN SENSOR NETWORKS

In military application the shoe-box sized, infantry deployed devices are dominant today. Depending on the purpose of the mote, they can reach down to matchbox size, but sizes below that are quite experimental yet. By studying today's technological possibilities one can conclude that sensor networks on the battlefield have a much greater potential.[11] A well positioned network can substitute an outpost or a patrol squad, and moreover by using them the direct threat for the soldiers can be greatly reduced. It also fits well in the theory of today's warfare where the impact factor of information tends to overcome brute force.[12] It speeds up the decision cycle and lowers own casualties. One particular example of them is REMBASS[7] [13] as depicted on Illustration 3.

3. Figure. Components of REMBASS system a military UGS [14]

The present of these networks can be summed as: maximum several tens of matchbox to shoe box sized, too-expensive-to-loose motes. But technology is evolving, size of every gadget decreases while the computational power increases. What does this mean from the aspect of sensor network? It means sooner or later these systems will entirely fulfill the definition of sensor networks as it is stated by a Hungarian recursive acronym: SOK (sok - many, olcsó - cheap, kicsi - small).[15]

We don't have to look into the future too far to see the real power of sensor networks where hundreds or thousands of very small and cheap, sub-matchbox-sized motes are deployed to the battlefield or to any area where sensor networks might be useful. If technology reaches this phase - and we have every reason to make this supposition - sensor networks will give the military a whole new potential as well, as new challenges for the algorithms which makes a mote running and the protocols which made them communicate. One of the main challenges

[7] REMBASS: Remote Battlefield Sensor System

for sensor networks which meet the SOK definition will come from the way of their deployment. Today typical are REMBASS sized systems, but there are already somewhat smaller units available. One example is SPAN's sensor, which is depicted on Illustration 4.

4. Figure. SPAN has surprisingly small sensors [8]

At this stage at least two categories can be made regarding the deployment of sensor network motes:

- systematic deployment
- chaotic deployment

Systematic deployment is how motes are deployed today. The soldier puts the mote according his orders to a well selected place, does the required initial settings in positioning and setting up the device, camouflages it, ensures if the installation was successful and then leaves it behind. This gives guaranties and knowledge of the motes initial working conditions.

Chaotic deployment on the other hand practically eliminates these fundamental working conditions. Motes can be deployed from containers attached to manned aircrafts or UAVs[8], can be scattered from ground vehicles or even can be shot to the target area by the artillery. All these methods provide some statistical distribution of the motes in a specific area, but no guarantees whatsoever regarding the actual position of one mote.

As it was written above, in today's military sensor networks systematic deployment is dominant. However, by following the viable vision of cheaper, smaller and more capable motes of the future, chaotic deployment techniques are expected to be the main method. This requires significantly different approach in the design of these systems.

What a mote does and how it communicates highly depends on where it is. Is it on a plain surface? Is it in a forest, hanging on a tree? Is it submerged in some pond or river? Is it on the roof of a house? Is it in the hands of the enemy? Yes, a mote might have a GPS receiver and it could be able to pinpoint its location, but without a database that would connect geographical and other type of data to the location, the location itself doesn't serve too much sense. In order for making a mote's operation efficient, the mote must know where it happened to get.

Altering a mote's operation in a geographically sensitive way might be carried out at least two ways:

- supply each and every mote with some level of the necessary geographical data
- create the network in a way which makes bi-directional communication possible between the motes and some data center in order to supply the motes with geographical data in exchange for their coordinates.

Both methods have their pros and cons. Supplying the motes with predefined geographical data has the huge benefit that the sensor network does not need to communicate to a data center to obtain geographical data. Motes are typically short on resources, and such communications

[8] UAV: Unmanned Aerial Vehicle

can be very demanding, especially in terms of battery capacity. Wireless communication is unpredictable due to the environment. Initially supplying the motes with information brings the huge benefit of these information is there, no matter what the circumstances are with the communication.

Network-based geographical information supply on the other hand beneficial where the geographical data can be time-variant and the mote's ROM is more limited. Connecting to a live geographical information database a mote can not only determine whether its location is in a forest, in a pond or on the plains etc, but also can use dynamic data such as weather conditions. This second approach is the way today's sensor networks work. The drawback of this, that receiving geographical data already assumes a working connection.

A chaotic deployed sensor network raises the importance of a potent geographical information system to a new level. The motes upon sending their current location to the GIS will receive the orders what is suitable to that particular geographic location. These orders among other things can aim on how the mote communicates over the radio. As it was described above, the quality of a connection between two motes can depend on many things, and most of these factors are given if we have at least rough knowledge regarding the environment where the mote is.

Depending on the actual geolocation the transmission characteristics might be adjusted. More than that, if the GIS is informed on changes in dynamic data it can supply this data to the affected motes in order to have them change its transmission characteristics again. The possibilities become especially interesting with motes using multi-band radio[9] techniques, but this is an especially problematic field in the small size a mote provides.

SUMMARY

Further shrinking of motes in wireless sensor networks can be expected in the future due to the fact, this is a field under serious attention by the military and by civil companies as well. Integrated circuitry and all components that a mote is made of are also known for decrease in size while increase in capacity as technology advances. I classified the deployment of sensor networks as systematic (as they are deployed today) and chaotic (as they might be deployed if they will go under a certain size and cost). The chaotic deployment will raise new possibilities and challenges, and will bond the link between geographical information systems and sensor networks even stronger. Chaotic deployment yields the actual position of a mote is only determinable after deployment, and after it managed to communicate. The operation mode of the mote depends on what environment it happened to get, and this is especially true for the way it uses the radio. The quality of a radio connection highly depends on the characteristics of the environment because of the characteristics of wave propagation in different environments, thus the selected transmission mode. If a chaotic deployed mote communicates to a geographical information system, and receives data from it regarding the environment provided by that geographical information system, then the mote is able to tune it operation mode to the environment better. The operation mode doesn't only limited to the initial conditions, but by relying on dynamic GIS data, can be altered in accordance with the changes of the environment.

[9] multi-band radio: a radio system which is capable to communicate on significantly different frequencies

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