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Optimization of people evacuation plans on the basis of wireless sensor networks

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Abstract: This paper introduces the optimization process for people salvation in critical situations by organizing their evacuation plan from enclosed areas using modern approaches of data acquisition on the basis of wireless sensor networks. The proposed technology allows the ability to gather information about people density on the surveyed area by the usage of wireless sensor networks, consistently covering the enclosed territory. It enables the update of the evacuation plan on the basis of people density information inside the enclosed areas online. It is proposed to use common video surveillance cameras as sensors. The advantage of visual surveillance using cameras is that it does not require additional technological equipment for the area and much more important does not impose rules and restriction on the surveillance objects (people in this case). Next tasks are to be solved: creation of mathematical model of optimal enclosed area surveillance by wireless sensors, database and data interrogation modelling of wireless sensor network, creation of algorithmic model for automated people counting using video signal for the covering area; creation of dynamic people evacuation model on the basis of maximum flow problem [1, 2].

Keywords: Evacuation plan; wireless sensor network; light control; maximum flow problem

1 Introduction

The construction of buildings that are designated for intensive people flow like hotels, malls, universities, hospitals should concern the questions of life safety. Constriction should comply with existing regulations, policies and standards for people evacuation in the critical situations when such a construction is planned. The building should have the necessary minimum number of exits and ways to leave it. It is also in most cases required that every autonomous part of the building should have an evacuation plan depicted and mounted on the wall and easily visible This plan should have a path to leave the building and all exits marked. For each autonomous part of the building an individual evacuation plan is created according to the physical construction details, closest exits and throughput of the building sections. The problem of such plans is that they are static, and they don't reflect the current situation, density of people on each floor, density of people in each section of building. Because they have been planned during the architect and design processes of building construction, and not during the exploitation. They just suppose that people will be distributed across the building by normal distribution law. But the absence of real data, that is in most cases does not have a normal distribution, may lead to a situation when all people will be guided to one place through one section which cannot provide for the required throughput.

Thus the paper describes the problem – how can we optimize the people evacuation process using the actual information about people flow density in each section of building. It is obvious, that if building has a complicated architecture and not normal distribution of people density inside it – the problem takes a very classic maximum flow form, that can be solved using Graf theory. And the solution of this problem – is to gather information about people density by using wireless sensor networks, analyze the information and interpret it for further decision making system to actualize evacuation plan and influence people flow by informing them about optimal evacuation paths using LED indicators. The problem also concerns the topics of effective disposition of wireless sensor network nodes according to maximum coverage and minimal resource allocation [3]. The paper is a logical continuation of research, that was made in the area of attendance control optimization process in universities [4]. But the methods that have been implemented in previous paper [4] cannot be applied to a wide range of buildings and areas like cine-

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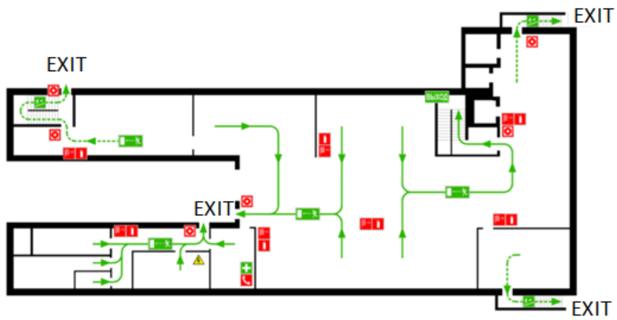

Figure 1: Evacuation plan.

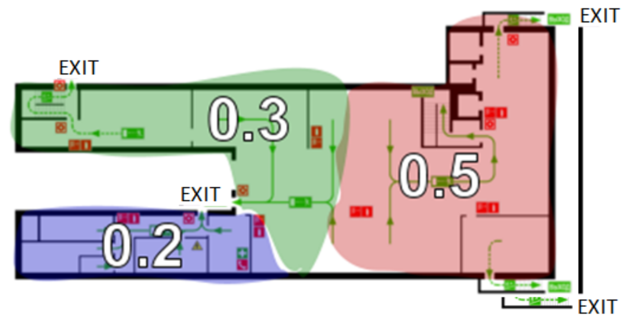

Figure 2: People density inside building area.

mas, hotels, malls, because the paper used a local information infrastructure of university that allows the imposition of rules on students and requires them to bring their proximity cards with them when visiting university. Thus this paper proposes the model of data acquisition with the help of video camera monitoring systems and computer vision algorithms [5] without interactive data interrogation with observable objects.

2 Formulation of the problem

Optimization of the dynamic evacuation plan problem consists of the following tasks that have to be solved:

1. Development of people flow density computational model;
2. Development of optimal wireless sensor network coverage density computational model development;
3. Development of maximum flow computational model integrated application.

Figure 1 depicts a typical evacuation plan from an enclosed area on the basis of 1 floor building.

Figure 1. shows the green arrows of an evacuation path according to the architectural design and the number of exit doors. Here we can see 4 exit doors to which green lines narrowed. Such an evacuation model was developed and approved during the construction of building. And in most cases it was never updated. The problem of such plans, is that they do not reflect the real situation – real people density inside the building in real time. Figure 2 illustrates the case where the density of people inside the area of the building does not have a normal distribution. The Density (D) of people for the whole building will be taken as 1. And for demonstration 3 areas of density are marked: 0.2 – blue, 0.5 – red, 0.3 – green.

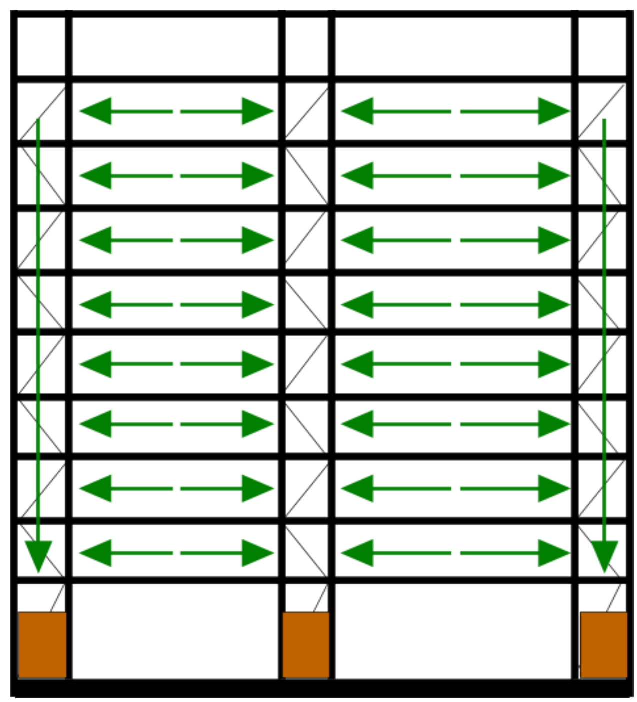

Figure 3: Evacuation plan from multiple floor building.

Here we can see, that if the throughput of each exit door is equal to each other, the optimal evacuation plan will not meet the plan designed during construction of building. The Figure 3 demonstrates another schema, that shows an evacuation model for a multiple floor building.

We can see here that that evacuation paths were designed according to the number of exit doors and architecture of building. And it is not very difficult to demonstrate a situation, when such a plan will not meet the optimal evacuation strategy. Figure 4 depicts the density of people on each floor in natural numbers.

Red arrows show the evacuation plan changes according to the stairways throughput and people density on each floor. As we can see – dynamic evacuation planning on the basis of real data provides increased speed of people evacuation. Also Figure 4 shows the static model cap-

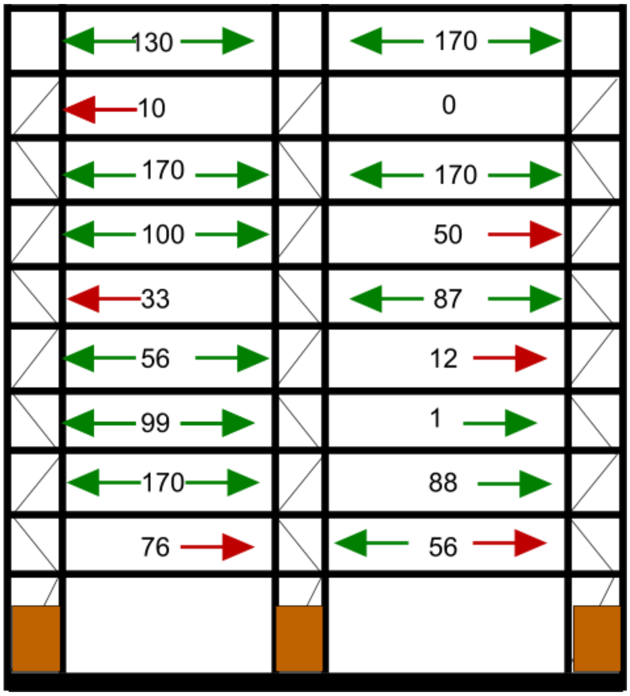

Figure 4: Dynamic evacuation model on the basis of people density information on each floor.

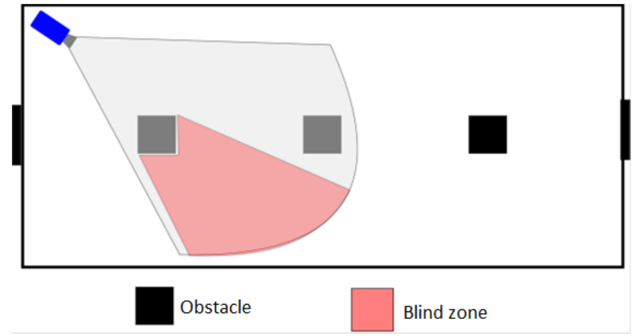

Figure 5: Example of obstacle presence in the field of camera view.

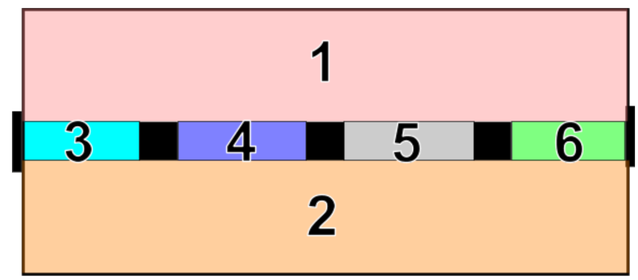

Figure 6: Division of whole are by rectangular subareas.

tured in time, calculated by only using the number of people on the floors, that does not consider a situation such as a people traffic jam that may happen in stairways during panic periods. For diminishing of such risk it is important to provide system feedback to inform people where to go to safely leave the building. And for this we propose the LED indicator lines mounted to each separate corridor of the building connecting one sector to another that allows for each individual sector to indicate the optimal path to follow.

3 Model Design

Model design consists of implementation of interconnected solutions, that provide the proper work of full system:

1. Optimal wireless sensor network coverage solution, where the sensor is a high definition camera;
2. Development of density calculation model using sensors data as video camera signals;
3. Development of maximum flow solution on the basis of data acquired from all sensors;
4. Development of integrated system to automate dynamic evacuation plan business process.

4 Wireless sensor network optimal coverage problem

Optimal coverage by the wireless sensor network is a common task to be solved to minimize resource allocation and expenditure. It concerns not only the dynamic evacuation modelling problem, but also regular video security surveillance. This is often a problem of irregular space structure in which there may be obstacles in the form of the supporting towers, beams, columns, limiting the field of view of surveillance cameras, as shown in Figure 5.

It is obvious that such an area can be subdivided by rectangular sectors without obstacles as we can see in Figure 6. It is possible to find a mathematical model, to attain 100% coverage by using different kinds of sensor properties – by angle of view, by distance [6]. But the less heterogeneous video surveillance system should be taken into consideration -which will be cheaper in configuration, installation and maintenance in the future.

Thus the solution of the problem in its classical form is inappropriate, as this will lead to a misallocation of resources and complicate the layout of sensors in the entire area of the premises. So to solve a problem we set limiting conditions – only 1 type of camera and permitted blind area for sector up to 20% of the total area covered.

Figure 7: Example of video camera snapshot in the mall.

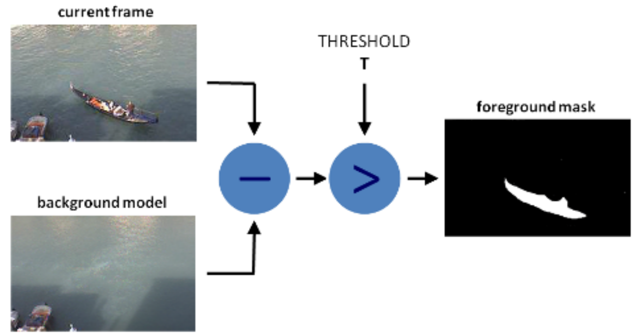

Figure 8: Image subtraction to produce differences matrix.

Figure 9: Contours detection.

5 People density calculation

To calculate the density of people in the surveyed area computer vision algorithms were incorporated. Particularly – the problem of image segmentation and person contour detection. Figure 7 demonstrates the snapshot of people captured inside the mall, with selected persons on it by contours.

Yellow contours in the image are marked closed fragments that were identified as a result of image segmentation. By counting these fragments in the image we can provide an approximate number of people inside the surveyed area.

6 Algorithm

For calculation of the number of people in the area using video signals two algorithms were implemented:

1. Change Detection – where from the base image of area in time (t0) we subtract image, that is taken in time (t+1) to produce differences matrix, where changes will be characterized by each pixel value.
2. Blob Detection – where differences matrix, obtained on the previous stage is analyzed for detecting the continuous outlines which we were to count.

The difference of images has long been used to monitor the dynamic objects in the scene. And the algorithm is well documented in numerous publications [7–9]. Figure 8 depicts the model of image subtraction from each other.

As a result of such subtraction we produce a binary matrix, where the areas, where difference does not exceed predefined threshold are marked as zero values, and areas where difference exceeds threshold – are marked as 1. After that, the resulting binary image is transferred to the second stage of processing - the selection of closed circuit boundaries [10]. Figure 9 depicts selected contours of the detected object in the image.

Thus, selecting all outline contours in the image we can filter them by the size, that are not appropriate to the size of human shape in the sitting and standing positions. The shapes that are greater than a human shape in dimensions are interpreted as more than one human in place. And such shape produces the value that is equal to total area divided by human shape area in standing position.

7 Maximum flow problem

Data acquired from all cameras inside building, that covers almost whole territory is being processed to obtain the number of people inside each sector. The number of people is an integer value that is assigned to each corresponding sector and interpreted as oriented graphs vertex, where edges between vertices represent the ability to transfer people from one sector to another and is measured as throughput value. Where throughput value is calculated by the length of segment in meters and number of people that can be moved through this sector per minute. The Figure 10 depicts a Graph, where S – is starting point – from where people start their evacuation, and T – is exit point from building where people end their path.

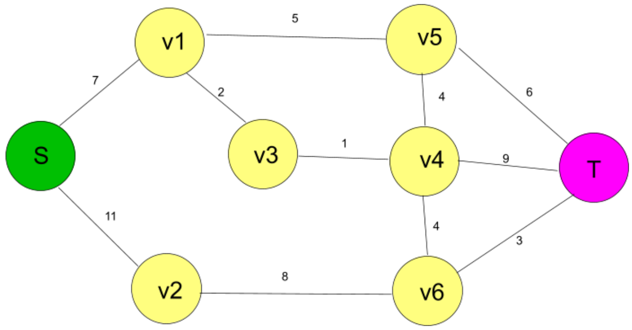

Figure 10: Graph, representing the building sectors as vertices and corridors between sectors as edges.

Figure 11: LED strip.

On the Figure 10 we can see that each vertex has a rating in the form of the real number of people in the sector. In contrast to the classical formulation of the problem, to assess the movement price from starting vertex to ending vertex, we also add the information about the number of people at the ending vertex. Thus, our task is to find such flow that the flow rate is Maximal (and flow price is Minimal). To solve this problem, we used the Ford-Fulkers on algorithm [11].

8 Evacuation direction broadcast system

Obtaining information at the command post is often important in the post-evacuation period, when it is important to organize search and rescue activities to save people lives. However, a much more important process is the notification of people and sending them signals to move in the right direction at the time of emergency. To solve this problem, we have applied LED strips mounted along the passages controlled by a digital controller, connected to the centralized LAN infrastructure. Figure 11 shows an example of such a LED strip.

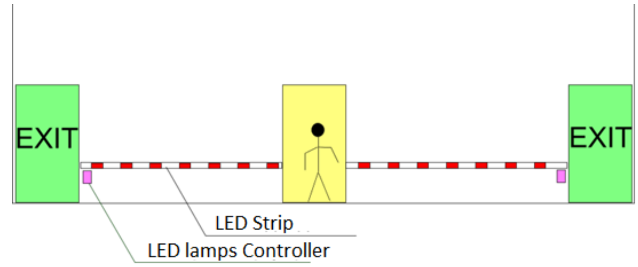

Figure 12: LED strip integration schema.

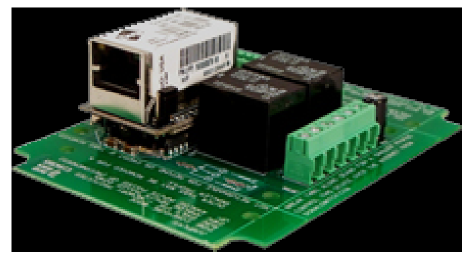

Figure 13: 2 Relay web controller.

Physical parameters such tapes make it easy to integrate it to the technological scheme of evacuation and connect to the power management controller to indicate the sequence of switching on and off of each light element tape. Figure 12 shows a diagram of LED strip integration along an extended section.

As seen in the figure, by using a controller we can manage the state of each lamp to inform people of the preferred direction of travel in case of an evacuation. To implement the effect of the direction of motion with the help of LED lamps, we used a simple scheme of changing the state of the lamps at every 4-th iteratively [12]. Thus, each controller will have to contain two power relay switches (the direction of the light pointer from A to B and from B to A) and the network communications interface. An example of such a relay is displayed in Figure 13. LED strip should be sufficiently low and can even be integrated into the floor. This increases the probability of its visibility in case of smoke.

9 System Design

System architecture involves the use of a service-oriented approach to software design that allows flexible horizontal and vertical scalability.

Implementation of the model requires the following components of the software package:

- Software for video-data processing server;

- Web relay management system;
- Server data base and application for processing and analyzing the video signals.

The SOA is preferred to make system ready to incorporate with existing information infrastructure as video surveillance system and further developments to make itbe not only a consumer but also a producer of data.

10 Mechanism of System

The building is equipped with a video camera surveillance system, exercising a uniform coverage of the entire territory. For each camera the monitoring area is selected using a polygon drawing instrument, because there can be overlapping areas of two or more cameras just like figure 7 depicts, where surveillance area of camera is more than necessary and overlaps the zone of responsibility of another camera mounted on different floor. All cameras are statically mounted, so the selection of responsibility zone for each camera is very simple in this case. After all areas are selected and assigned to the cameras there should be made initial configuration to the state Zero – where there is no people inside the building to make up the base image from which will be subtracted all following.

After initial configuration the system will be in a working state, where all data acquired by all cameras is centralized and the process of people counting is made continuously. Data of people counting is stored inside a database in a timely manner, assigning the numbers of people to each sector along with recording the time of the state.

At each time point, we may get the density of people inside each sector of the building. When an emergency occurs, the evacuation module is switched on, and starts to inform people about the preferred safe evacuation path, by sending control signals to the LED strips controller. The signals sent to controller depend on actual computation of solution for maximum flow problem according to mean time situation of people density in each sector of the building and may guide to move from point A to B or vice versa by turning on/off relay 1 or 2 for the same LED strip.

11 Software Design

Relational database management system is selected as a backing storage system for the results of video signals analysis and image segmentation. The relational model is easy to interpret and also integrate to different information

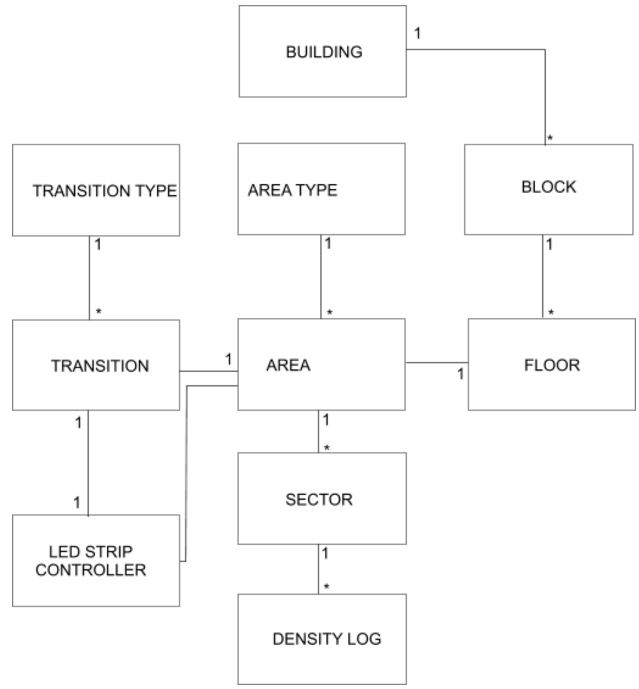

Figure 14: ER diagram for dynamic evacuation system.

systems as most commonly used DBMS architectures. Figure 12 depicts entities relationship designed for the current model. The schema consists of the following entity: building, as main element of dynamic evacuation plan modelling concept. This entity has the information about object passport and other meta information. Each building may have several interconnected or not connected blocks. Each block may contain a number of floors, where each floor consists of areas (corridors, rooms, halls) list. Each area should be one of 3 types – two-way, one-way and exit. Every area may be subdivided by sectors covered by video camera surveillance system. All areas are connected with each other by transition of two types – unidirectional and bidirectional. All the LED strip controllers are stored in a database also with information in which the transition LED strip is mounted. Allanalyzed data that is produced by module of processing and image segmentation module is stored in table of density log with conjunction to the mean time and sector assigned.

The data streams coming from all cameras to the central unit of analysis will depend on the complexity of the building and the number and technical characteristics of the cameras. It is necessary to take into account the situation of the camera or even an entire network segment failure. To transmit video signals defined UDP - as it is the most productive in terms of one-way transmission of large amounts of data. UDP - does not require acknowledgment of receipt of each data packet, making it very beneficial in terms of transmission and amount of information in the transmitted data rate. This protocol is also used to manage LED strip controllers. Each room sector is served by a single camera. Each LED strip controller is configured and stored in the data model with the following parameters - its IP address, its relationship with transition and two areas (area A and area B). We also store the command signals sent to the LED strip controllers in case of evacuation separately of ER database model to make post-evacuation analysis available and assessable. For such logs we use simple file storage system to reduce load to the main DBMS.

For the development of the application server for data storage and processing it is considered to use open source solutions and multiplatform programming languages, that allow the creation of multiplatform software independent from operation system platform. In this particular case it is supposed to use ASP .NET and C# language for server application to control dynamic evacuation process, and C++ programming language to process video signals. MySQL Community Edition as Relational Database Management System (RDBMS).

12 Discussion

The problem of saving lives in emergency situations will always be relevant. And the use of modern methods of improving the effectiveness of the process can increase the likelihood of saving lives. Evacuation plans, which are now available in all buildings need to be improved by using modern approaches of wireless sensor network integration to calculate people density. This allows not only to save lives, but also improve the safety rating of the building, which undoubtedly will provide the owner of a building additional benefit.

We did not discuss security issues of information flows in this article, however it is also a very critical nowadays. The purpose of this article is not to build a complete information system of evacuation, ready for replication, but introduce a new model and new vision to the problem of people evacuation. Of course it is very important not only to subsequently organize an effective evacuation model, but also to protect the system against false response and wrecking intervention in the process of evacuation. Also it should be possible to transmit information LED controller directing signals over wireless channels and use of autonomous batteries since they are more resistant to physical damage of the building.

It also requires further study into the ways to integrate people accountant modules into video cameras, for that would distribute the load on the data collection and analysis server. In cases where video data transfer is not required – the video traffic can be eliminated altogether, and the load on the network will be reduced up to 100 times.

One of the simplest algorithms was selected in order to solve the maximum flow problem. It is known that the algorithm can work only with integers that imposes certain limitations. When weights of edges in the form of real numbers, the algorithm may not come to an optimal solution. Also this algorithm has a great time complexity, and should be revised in favor of others.

13 Conclusions

The use of a dynamic model for solving the problem of maximum flow for evacuation was made possible with the use of wireless sensor technologies that allow you to take the data from the object of study by observation or in a non-contact manner. At the same time there are no requirements to the object of study and mode of operation. Wireless sensor networks have great commercial potential, which are currently being implemented by a variety of high-end solutions. Wide range of problems can be solved using wireless sensor networks from common navigation systems to the high precision technologies.

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