University of Pardubice
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RFID system of active technologies for increasing safety in specific types of transport

Dissertation thesis

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Technika a technologie v dopravě a komunikacích

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ANOTACE

Cílem disertační práce je vytvoření funkčního modelu systému využívajících technologie lokalizace objektů v reálném čase RTLS pro zvýšení bezpečnosti ve specifických druzích dopravy. Specifickými druhy dopravy se rozumí provozy, kde není možné využít standardě dostupné technologie, případně infrastrukturu jako jsou sítě GPS, GSM atd. Pro návrh takového systému jsou využity technologie, založené především na principu Aktivní rádiové komunikace a identifikace A-RFID. Práce je založena také na dlouholetých zkušenostech s vývojem a nasazováním obdobných aplikací v reálném prostředí.

KLÍČOVÁ SLOVA

Lokalizace, RFID, bezpečnost, UWB

TITLE

Possibilities of removing barriers in rail freight transport through data sharing

ANNOTATION

The aim of the dissertation is to create a functional model of a system using RTLS real-time object localization technologies to increase safety in specific types of transport. Specific modes of transport are understood as operations where it is not possible to use standard available technologies, or infrastructure such as GPS, GSM networks, etc. For the design of such a system, technologies based primarily on the principle of Active radio communication and A-RFID identification are used. The work is also based on many years of experience with the development and deployment of similar applications in a real environment.

KEYWORDS

Location, RFID, safety, UWB

Content

INTRODUCTION

The use of RFID in various industrial areas, in transport and logistics is a modern trend and is clearly on the rise. However, the main motives for using RFID technologies are, in general, mostly economic, focusing on streamlining logistics and transport processes, eliminating human work and thus the possibility of errors. However, it is an indisputable fact that there is also an ever-increasing pressure to increase safety, and this also applies to transport and logistics.

The dissertation analyzes both the general principles and functions of RFID, as well as specific applications. A model is proposed that can be applied, for example, in mining and quarrying operations.

These operations have a number of specifics that make them critical from the point of view of worker safety. This is due to several basic factors, which, in addition to the generally difficult conditions, are also a considerable movement of personnel, material, handling and transport means. A significant number of occupational accidents occur in connection with the transport of people or material. Even in these operations, more and more emphasis is placed on safety, in contrast to "normal" operations, in this environment there are a number of technical and legislative obstacles to the deployment of new technologies.

In practice, it is common that what can be used completely naturally in surface operations simply cannot be used in the deep environment, e.g. because communication infrastructure based on new technologies is not available in the given environment. Other limitations are the technical-legislative requirements for the operation of the equipment, especially the standards associated with the European ATEX Directive (2014/34/EU) [1], which considerably complicates the deployment of new technologies.

The topic of the thesis is the use of modern technologies from the field of RFID in solving traffic safety, transport and logistics issues in demanding operations.

1 Overview of the state of the art in active RFID systems

The chapter deals with the current situation in the given area, the possibilities of use in transport and logistics. The chapter also includes a general description of technologies, their distribution and description of basic methods for identification and localization.

1.1 Current state of research and sources of information

Since the main topic is solving issues of safety in mining and other heavy operations, the topic can be broadly divided into two areas - the area of the mining and mining industry and the area of RFID and IT technologies.

The first area is in a relatively stable state from the point of view of the issues being addressed. Being a traditional industry, there is a very large knowledge base available.

The second area is the field of RFID and related IT technologies. Given that the subject of the dissertation is primarily a very specific subfield of active RFID, which - unlike passive RFID - is in rapid development, this subfield is quite dynamic from the point of view of information sources. Depending on the specific technology, most sources are dependent on the manufacturers of specific components, without which the information base would be highly theoretical. Specific relevant information can then be drawn mostly from materials published by manufacturers or companies that have created specific applications and deployed them in real operation.

As part of the analysis of the current state of information, a number of sources from the professional literature were studied. On a general level, the development of RFID systems from the beginning, through the current state to the prediction of RFID development in the future is described in [2]. But the document is mainly devoted to the development of RFID as such with a small overlap into RTLS applications. Nevertheless, the document is relevant for the given issue.

They describe the design of a typical application with a given solution to a given problem CAVUR, Mahmut a DEMIR, Ebubekir v [3]. But the output is an indoor localization system based on Active RFID technology with a location prediction algorithm based on RSSI analysis. This is a known and functional system so far, but the authors' claim that the required localization accuracy can be achieved with the required reliability and under the given conditions cannot be accepted in general. For a system based on RSSI processing, some of the intended applications of the system cannot be built, such as anti collision system.

The use of new technologies, including RFID in mining operations is also described in the work dealing with E-UTM [4]. Here, however, it is primarily about increasing the efficiency of production in general, and also about increasing the safety of replacing workers with inanimate labor.

Ways of deploying Industry 4.0 in the mining industry, which principally use RFID technology, i.e. RTLS, describes Lööw, Joel; ABRAHAMSSON, Lena and JOHANSSON [5]. But again, this is work focused on operations, which does not deal with the safety of workers in detail.

SALIM, Omar; DEY, Shuvashis; MASOUMI, Hossein and KARMAKAR, Nemai Chandra then describe an application to increase safety in the mining industry in the area of transport using belt conveyors [6]. It is a work that introduces the old-new topic of the safety of transportation by means of persons. In the Czech Republic, the transport of people using belt conveyors, which are also used for the transport of material, was essentially prohibited. But in a number of countries, this method is widely used to transport workers to and from the workplace, even over relatively long distances. Therefore, this work can be partly based on the topic being addressed.

ZARE, Masoud; BATTULWAR, Rushikesh; SEAMONS, Joseph and SATTARVAND, Javad then describe a whole range of communication technologies, more or less usable in the target environment [7]. In general, however, these are rather larger and more expensive systems.

For the sake of comprehensiveness, an analysis of the current state of information in various areas of RFID use was performed with regard to the environment [23], [24], the method of data processing and localization algorithms [18], [20], [25].

1.2 Analysis of RFID technology

RFID technology can be divided into passive and active. There are also categories on the border of these two basic ones, such as semi-active or semi-passive, but these will not be included in the description due to the fact that the work is basically dealing with the active category.

1.2.1 Passive RFID

Passive RFID is a category that is characterized primarily by the fact that the identification tag does not include a power source in its design (e.g. primary cell or accumulator). Powering the tag is then implemented by wireless transmission of electrical energy behind the reading device (hereinafter referred to as readers) to the tag, mainly by induction or radio frequency coupling.

Power supply by inductive coupling is implemented mainly in systems operating in the frequency bands of 125 kHz or 13.5 MHz [8]. Systems of this category are characterized by their simplicity, which is why they are widely used. However, they provide a relatively small reading distance, tens of centimeters at most. The most common uses for these systems are various kinds of access and identification systems, and nowadays also payment systems.

Powering the tag through high-frequency radio transmission is implemented with UHF systems operating in the 868 MHz band (region I) [9]. These systems are structurally more complex on the part of the readers, but they provide a significantly greater reading distance, practically up to a few tens of meters. The use of this technology is currently mainly in industry, transport and logistics, especially in the automation of object identification processes.

Some systems in this category are not described in this work because they do not touch the problem being addressed.

The common feature of passive systems from the point of view of the problem being solved is that they are not suitable for applications dealing with people's safety. The fundamental reason is that for a reliable function it is necessary to create or actively modify the conditions.

This fact can also be described in the way that for the proper functioning of, for example, a payment or access system, a person must have the will to use it. If a person wants to go through the door, he makes an effort to use the system and adjusts the conditions (for example, he brings the card closer to the reader, possibly changes the angle, takes the card out of the wallet). On the contrary, in the case of a security and monitoring system, functionality must be guaranteed even on the assumption that a person makes a certain amount of effort to make the system not functional.

The above shows the unsuitability of passive RFID technology for security applications, as it is very easy to change conditions so that the system does not work reliably, either intentionally or unintentionally.

Another critical shortcoming of passive technologies is the limited or no ability to determine the position of the tag relative to the reader other than by simply detecting the presence of the tag in the reading area. Due to the disadvantages and shortcomings described, other features of these systems, such as tag memory capacity, etc., are not relevant to this work.

1.2.2 Active RFID

Active RFID systems are characterized primarily by the fact that tags include a power source in their design. The sources can be of many types, the critical feature for this work is that the tag can work regardless of the presence or absence of the reader. It can thus perform a wide range of activities regardless of whether or not it is in range of the infrastructure.

Tags of the active system can transmit data bilaterally in the sense of communication with the reader, they can also communicate with each other. These are critical features for the intended model.

Active RFID systems are designed for a whole range of radio frequency bands. From very low frequencies in the range of kHz units, which are used e.g. in systems for the detection of people overwhelmed by an avalanche or rock, to systems working at very high frequencies in the GHz range with a very wide spectrum.

Systems operating in the 868 MHz band are important for the dissertation, because this is the band used in the widely spread ISI system - the system [10], which is used, among other things, by OKD to monitor the location of workers and means of transport in threatened areas. In some parameters, this system corresponds to the expected properties of the model being created, however, it uses a method based on RSSI for object localization. This is a very fit-for-purpose method, but it falls far short of the desired results for use in a transport safety enhancement system model.

1.3 Legislative framework for the use of RFID

In general, the use of RFID is governed by legislation and regulation on several levels. These are primarily technical solutions and properties governed by national standards, which differ according to individual regions and are standardized within the EU, then by licensing agreements that address the use of the radio spectrum, and then by the purpose and use of the technology, where the legislation primarily addresses how data from RFID systems will be processed and used and what rights and obligations result from this for all involved.

1.3.1 Technical standards

From the point of view of the basic technical characteristics of each product placed on the market within the EU, each product must be equipped with a so-called declaration of conformity and marked with the CE mark. This label proves that the product has been assessed before being placed on the market of the European Economic Area, whether it meets all the legislative requirements imposed on it [11]. Other world regions are approaching this in a similar way, albeit with their own specifics.

Within the EU, the basic document for assessing the technical properties of a product, or a group of products assembled into a functional unit (system), is a European harmonized standard. In the case of some standards, declarations of conformity of the parameters with this standard must be issued only on the basis of an examination and the issued protocol of the so-called notified person. In the case of RFID, this concerns primarily in context with the parameters of the high frequency and radio parts of the system. Then in the area of mutual interactions and EMC [12], [30], [31], [33], [34], [35], [37], [38].

In the case of a system or product in an environment with the possibility of the presence of an explosive atmosphere, it is also necessary to demonstrate compliance with the requirements of the ATEX directive. Here, assessment (certification) by a notified person and strict compliance with all related regulations at all levels, from the manufacturer to the user of the system or product, is absolutely necessary, with full criminal legal responsibility.

In the field of wireless radio communication, it is necessary to respect the technical standards regarding the use of the radio spectrum [43], and also chapter 1.3.2.

Since these are electrotechnical devices, a number of technical standards addressing the safety of electrical systems must be respected [32], [39], [40]. However, the issue of safety of electrical equipment is much more complex.

In addition to purely technical standards, a number of European and national directives must also be taken into account [41], [42].

1.3.2 Use of the frequency spectrum

This part of the legislative framework is mainly based on national standards and regulations. On a general level, however, the world can be divided into several regions (the most common division is Region 1 to 3) from the point of view of the use of the frequency spectrum. However, this division is essential especially for the UHF band, i.e. the 800 MHz - 900 MHz area. Within the EU, this is primarily defined by the ETSI EN 300 220 [13] standard, which regulates the operation of RFID and SRD devices. For UWB, it is primarily the ETSI EN 302 065 set of standards [14], for the 2.4 GHz frequency band then [29] for the broadband technologies used for localization.

It should be emphasized that within the framework of these standards, these are primarily technical specifications of equipment using given parts of the frequency spectrum, describing technical requirements and methodologies and performing testing of these technical parameters. Within our region, and especially the EU, the situation can be considered relatively clear and harmonized within individual countries. above this technical part lie the licensing conditions for the use of the given frequency bands and these are governed by national legislation. As part of that, a national regulator is designated, which oversees the operation of the systems within the given country over this legislation.

In the case of the Czech Republic, the national regulator is ČTÚ. Fundamental for RFID and RTLS systems (in general) is the general authorization no. VO-R/10/03.2021-4 [15], which regulates the operation of SRD within the Czech Republic. This is a measure that regulates the rights and obligations of the operators of individual systems in such a way that their rights to this operation are guaranteed, but at the same time, the CTÚ performs practical supervision of compliance with obligations within the scope of this authorization and compliance with the technical parameters of equipment and systems according to the relevant technical standards. The critical factors in this supervision are mutual collisions of systems using the same frequency sections and then collisions with other systems and services.

1.4 Using RFID for security

The use of RFDI for security applications can be divided into several fundamental levels. These planes, which will be briefly described, are not related to the technical design or solution, and the similarity or commonality of the terms used is counterproductive at this point, but it cannot be completely avoided. Therefore, the issue of the terminology used is one of the important aspects when building a new model.

The following subsections outline layout individual levels in the field of security applications. The division into these planes then overlaps in certain areas.

1.4.1 Legislative

At this level, legislation on the use of RFID is addressed. For some specific cases, there is legislation that clearly defines the use of technical means for safety management. In such cases, the use of RFID is a direct consequence of the existence of such legislation. These are mainly areas where it is required by legislation

- Restrictions - above all, restrictive control of access to potentially dangerous areas
- Control – cases where control of access or presence of persons, objects or resources is necessary
- Records – for legislative reasons, records and archiving of movements and events are essential

1.4.2 Prevention

At this level, the use of RFID is rather passive in nature (it has no connection with passive RFID technology). The goal of using RFID in application security is primarily to prevent the occurrence of harmful events.

The critical elements of such an application are, above all,

- Records - records of events
- Analysis – analytical processes over the obtained data set and measures created on the basis of these analyses
- Management – implementation and control of the implementation of the created measures

1.4.3 Active process control

This is the level where risk reduction occurs through automatic interventions in processes. Such examples can be limiting the access of unwanted persons or objects, preventing the entry of a vehicle or warning of an upcoming collision. It is therefore a use where the process is directly affected so that a harmful event does not occur.

1.4.4 Crisis management

This is the level that defines (or influences) the procedures at the moment when the critical event has already occurred. These are, for example, the possibility of managing emergency services based on information obtained before the occurrence of a critical event, or the use of information for managing emergency services in real time, if the system is still functional even after the occurrence of a critical situation [26].

1.5 Applications using active RFID in the issue

In the thesis, data from applications that are already in operation in a real environment are used to build a new model of experience. It should be noted that the experiences described are for the most part based on the author's experience, or the experience of the teams he was a part of, and due to their extensiveness, they can be considered completely relevant.

1.5.1 Experience in operation from the Czech Republic

The author's experience from operations in the Czech Republic can be divided into two industrial operations. Mining and automotive industry. In the case of the mining industry, this is experience with the development, deployment and operation of an ISI system within an industrial mining enterprise.

The ISI system is a system developed and manufactured in the Czech Republic and operated in OKD company mines. The following year, the ISI system (or its technical equivalents) became legislatively necessary for the operation of mine shafts in areas of the 3rd degree of risk of mine landslides. The system was or is being operated at the ČSA mines, Darkov, 9. měve, Lázy, ČSM north and south, Paskov. Its operation is required and controlled by BÚ.

It is an RTLS system based on the principle of RSSI measurement in the 868 MHz band. The system supervises the location of workers in critical areas, while mainly ensuring the registration of the movement of specific people in the given zones, their number in these zones and the authorization to move in these zones.

In operational mode, it also provides dispatch control of worker movement as an added value to this otherwise safe system. Considering that basically any object can be tracked using this system, this system is also used secondarily to track objects dealing with subsurface logistics. Even though it is a robust and widespread system, the localization principle used allows only limited application in issues of worker safety in subsurface transport and logistics. This is mainly due to the resolution and accuracy of localization. In general, the system achieves a relative resolution of positioning in the region of ±5 m, and the accuracy is given in the region of ±10 m. This is certainly sufficient to address safety issues in the event of mining accidents.

However, a significant number of injuries to mine workers are directly related to subsurface transport. When it comes to incidents associated with dangerous approach or dangerous movement of workers in the working zones of work or transport equipment, a number of experiments were carried out in real operation, which aimed to solve the possibilities of increasing the safety of both underground and surface transport with the help of this system.

1.5.2 Experience of operations abroad

These experiences can be divided into two basic groups. In the first case, it is an experience where the author participated directly, in the second case, it is not a direct experience, but a mediated experience.

Real-world experience was gained with the deployment and operation of the ISI system in Turkey and Poland. There are approximately 40 installations of this system in operation in Turkey, but the experience of the Imbat mine, which is one of the largest operations of this system ever, will be used in the dissertation. Given the level of security management in this country, and especially some tragic events in the recent past, there is considerable scope for creating measures that would lead to increased security. In this mine alone, there are tens of kilometers of mine shafts, where several hundred pieces of means of transport and logistics and in the order of a thousand people move in real operation. This, combined with very complex and challenging conditions, creates a high probability of accidents.

Another source of information and experience will be experiments with the deployment of a system based on UWB technology. The purpose of this system is to eliminate the dangerous approach of workers. The experiments were carried out in a real operation at the Russian iron ore mine of KMA Ruda during 2019.

Further experience comes from the deployment of the ISI system in Iran, India, Zimbabwe. Although these experiences are mediated, they broaden the view of a different perception of traffic safety issues and the possibility of using the created model on a wider global scale.

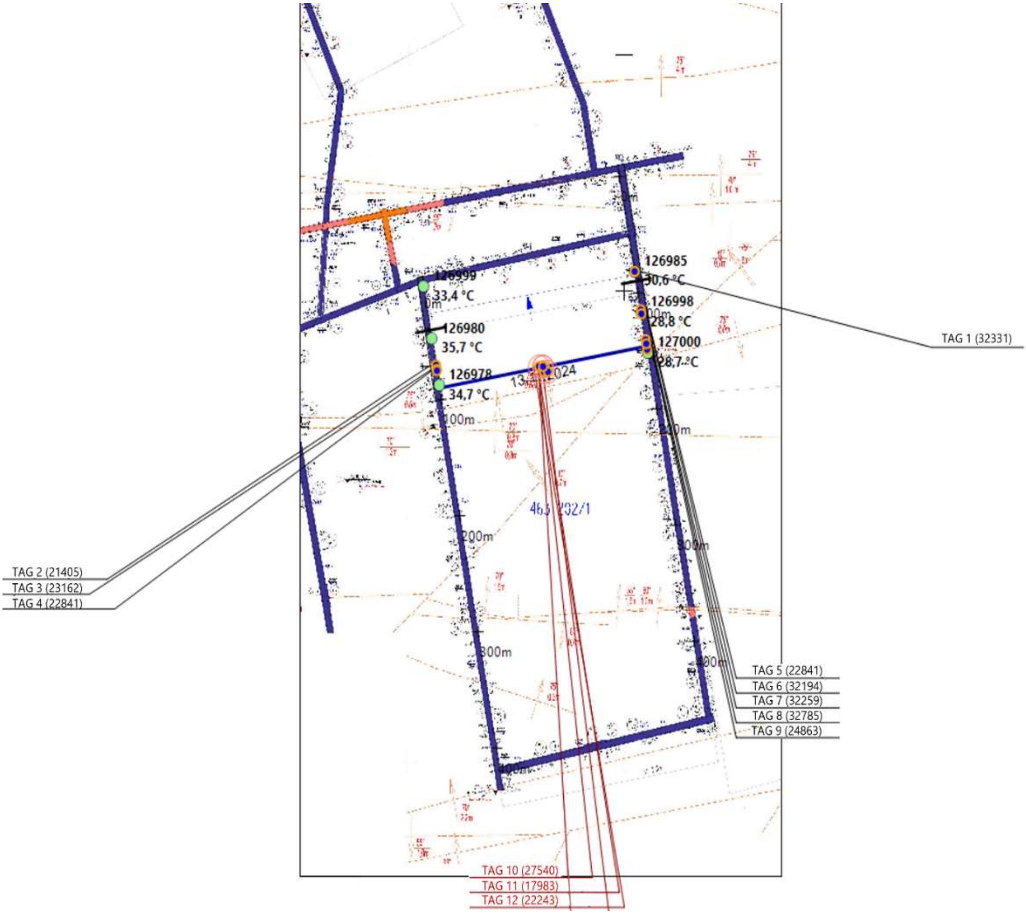
1.6 Analysis summary

Based on the analysis, it can be claimed that the issue of using RFID and RTLS systems to increase safety in mining operations is being solved in our country and in the world. However, both the available materials and publications and the author's own experience show that this is only a marginal topic. It is very difficult to find comprehensive information about how such solutions affect security as such.

The vast majority of available materials deal more with the technical properties of the commercial product, or vice versa, with the properties of the technologies used. In the case of real deployment, the internal documentation of companies deals primarily with limited cases and, on a general level, primarily with ensuring that legislative and security requirements are formally met by deploying such a system.

Another aspect is that it is difficult to promote new technologies in mining operations within the framework of very strict technical and legislative requirements. In practice, it is so common that those systems that do not have a direct and easily measurable positive effect on production are left behind, and the pressure for innovation is either purely formal or comes only with the arrival of critical or fatal situations [16].

It follows from the above that a justification can be found for the creation of a dissertation. Both from the point of view of the need to describe the current state and its evaluation, and from the point of view of the need for technical progress in the given field.



Picture 1. Typical view of the monitored mine working

2 The aim of the dissertation

The aim of the thesis is to create a model and its description, which, with the use of active RFID technology, positively influences the safety of workers in underground transport. The model is built on the basis of experience gained from real operations and from experience from experiments with new technologies in the field of active RFID. The core of the experiments is based on tests of active RFID technologies, especially those based on UWB principles in the complex conditions of subsurface transport and logistics, especially in the mining industry. The model is structured into several levels. The first level includes the physical layer of the radio system itself. Appropriate technology is defined here for the reliable radio identification of all included objects, such as fixed infrastructure, means of movement, handling and transport, and monitored persons. The second layer of the model determines the propagation of the obtained information across the individual elements of the system. As a model with decentralized data processing and evaluation is assumed, this is a key part. For the output, it is assumed that the acquired data is primarily processed in the central node and propagated in a dispatching manner, while it is but certain critical functions implemented at the end points of the system and evaluated in real time without the need for an established connection with a central node. This situation can best be demonstrated using the example of signaling the dangerous approach of a worker to a means of transport, or the dangerous mutual approach of two means of transport. The third layer handles data processing at the central node. This includes the processing of records of individual identified objects, their localization in real time, the dissemination of information in dispatching workplaces and the subsequent archiving of this data. In essence, this is an input analysis for the creation of the IT infrastructure necessary for the operation of such a system in real operation. The fourth layer describes the integration of the proposed model into the real organizational structure. As already mentioned, due to the experience gained, there is a low readiness of the organizational structure for the introduction of new measures and a high level of natural resistance of all affected workers. Therefore, the analysis of the procedure for the implementation of these measures in real operation is critical and absolutely necessary.

3 solution concept

A critical consideration to achieve the stated goal is to design a security system model and all its essential components using active RFID technology in combination with RTLS system using UWB technology. In order to achieve the set goals, the basic frameworks for the individual stages were established.

3.1 Analysis of the current state

To create a working model, the current situation must first be analyzed. It needs to be evaluated on many levels:

- Current legislative framework
- Actual status in individual operations
- Requirements and comments of affected workers
- Requirements and comments of middle management

Based on this analysis, a framework of requirements for the resulting model can be compiled. Based on these requirements, the most suitable technology is selected for the implementation of a system that would fulfill these requirements. Then a set of requirements is drawn up, on the basis of which a local investigation and experimental verification of the usability and suitability of the selected technology is carried out.

From the point of view of conducting experiments and observing in real operation, the legislative and operational conditions for these steps need to be analyzed. Given the chosen target environment, careful consideration should be given to what kind of experimentation and testing is even possible to do in that environment. To demonstrate such a limitation, an example can be given when an electronic measuring device (e.g. a measuring radio receiver) and the necessary IT equipment (e.g. a computer or tablet) will need to be put into real operation. If the experiment with such equipment is carried out underground in an environment not defined as an environment with the possibility of an explosive atmosphere, there are no obstacles to this. But if such an experiment has to be carried out in, for example, a black coal deep mine - and this is also the target environment - then a critical problem arises. Coal mines are in principle classified as an environment with the possibility of an explosive atmosphere and generally the importation of any electrical equipment, with the exception of equipment meeting the ATEX directives, is prohibited. Such devices are, on the one hand, very expensive and in some cases not even realistically available - e.g. mentioned measuring devices.

In such a case, it was necessary to formally request short-term permission to bring equipment into this environment from the mine management, which must ensure the necessary conditions for such an experiment or measurement. These measures must include sufficient staffing, continuous monitoring of the state of the local atmosphere and the concentration of individual gas components, and the possible participation of rescue system components. This entails a significant organizational and financial burden.

In the event of the need for long-term placement of such equipment, all operational and safety issues must be processed and permission must be sought from a higher authority, in the case of the Czech Mining Authority. This is absolutely critical to designing experiments and measurements in a real environment so that they can be implemented.

3.2 Conducting experiments and measurements in real operation

The prerequisite for the next procedure is the selection and verification of the functionality of all selected components of the future system and verification of their functionality in a real environment. Unlike, for example, IT systems, where easily available tools can be used to create a model, the hardware part, especially the high-frequency components, can only be simulated or modeled with great difficulty, and everything must be verified by real experiments.

For the vast majority of experiments, the workplaces of the OKD company were selected, where electronic systems ensuring the monitoring of people and means of transport are currently in operation using a system based on active RFID, but on RTLS technology, which is a generation older than the technology selected for the built model of the system, namely a technology based on RSSI measurement.

3.3 Model design

The model of the considered system is a complete design and description of all its components based on both the requirements and the results of experiments and measurements. Suitable and available tools, especially UML, are selected to create the model.

3.4 Partial conclusions

In the course of the analysis, experiments and model design, the outputs of the individual stages were discussed with the affected workers, members of the mine management and development workers from the affected fields. On the basis of these discussions, partial conclusions are also created, which are crucial in deciding on the key features of the model. As such, the model must be a usable basis for the subsequent development and implementation of a system to increase safety.

4 An overview of the methods used to achieve the objective of the work

Technologies and systems using elements of active RFID can subsequently be used for application in the operation model of one of the selected mines. In the system of localization of people and means of transport, emphasis is placed on solving the safety of people within the framework of transport and logistics processes. This results in the necessity of carrying out research work in the field in very difficult conditions and with limited possibilities of data collection. This is primarily due to the environment in which the affected operations exist, where the use of electronic systems and equipment is greatly restricted for security reasons. This greatly affects the choice of methods that can be used to achieve the goal of the dissertation, and to a large extent empirical methods will be used and modified in combination with other methods of applied research.

Paired logical methods of scientific work are used to process the results and create a model [17].

4.1 Empirical methods

In order to achieve the goal of the dissertation, a large amount of observation of the actual situation was needed. In the given environment and within the investigated processes, not everything is easily described and quantified. In addition, some circumstances and properties of the system emerged during the investigation, which could not be predicted well enough at the initial stage of the research.

4.2 Applied research

The goal is to increase the level of security of certain processes. The basis of application research is determining the use of the relevant technology and in what ways it is possible to use it in the given environment and processes, given their limitations so that the model works properly.

4.3 Action research

It was necessary to find out how the processes created from their use of the selected technology can be ensured organizationally. From experience and experiments, it can be said with a high degree of certainty that the introduction of measures that should ensure an increase in the level of safety is necessarily related to the natural reluctance of the affected workers and organizational units to accept these measures.

4.4 Logical methods

4.4.1 Abstraction - concretization

These methods are mainly used to create a mental model of the system, to separate its essential properties and to separate them from those that are consequently not fundamental and essential.

4.4.2 Analysis - synthesis

The method of analysis was used for the analysis and distribution of the obtained knowledge, both from the study of available materials and scientific works, and obtained by other scientific methods. The synthesis method is then used to combine this knowledge and information into partial functional units and, as a result, the model itself.

4.4.3 Induction - deduction

Induction is one of the logical methods and is used to create one's own view of the given system on the basis of the obtained data and information for creating sub-hypotheses. These hypotheses arose mainly when creating questions about the properties and behavior of the observed system.

It can be stated that deduction is the opposite of induction. In the dissertation, deduction is used in the processing of results and verification of individual hypotheses.

4.5 Modeling

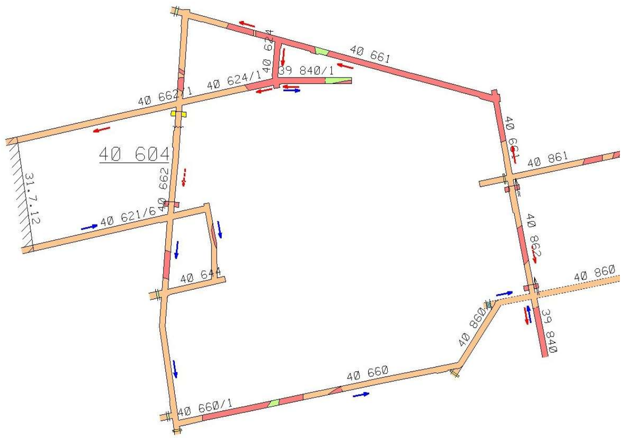
The aim of the work is to create a functional model in practice of a usable system. For modeling purposes, modern means are used, in this case the UML language.

UML (Unified Modeling Language) is essentially a graphical language used to easily visualize, specify, design and document software and information systems. [44], [45] UML defines standards for the structure of diagrams and its uniformity, thus it is possible to implement various diagrams across processes. The proposed model is a simplification of reality, where it focuses on important factors from different perspectives of settings and complex systems can be designed for them, which is also usable for mining operations and increasing safety in them. One of the most widespread uses of UML is to model object-oriented systems.

4.6 Graph theory

Graph theory algorithms are useful in both logistics and transportation. The methods have an apparatus with which it is relatively easy to express mutual "distances" of individual pairs of vertices embodied in a real network model. Subsequently, various tasks must be performed on the networks, in particular calculations of the search for the shortest routes, the capacity of the routes. The created models are used to create software.

As can be seen from the figure, these are classic graph structures on which relevant tasks can be performed respecting the specific environment of mining operations. It is possible to define edges and vertices in a standard way, as is clear from the following picture, and convert them into matrix notations with the appropriate parameters and incorporate them into the designed algorithms that are part of the designed model and its transcription into the Software/information system.



Picture 2. Use of graph theory for definitions of possible paths and movement of objects in mining operations

4.7 Simulation

To verify the functionality and usability, simulation methods are used to verify the validity of the model. However, the choice of simulation tools and the assumption of their use is primarily that simulation should be used in cases where it was not possible to use experiments. A typical example of the possibility or necessity of using simulation is the time use of the radio band when there is an excessive spatial concentration of transmitters, for example when people and means of transport accumulate in a small space when critical situations arise.

The parameters of such a state cannot be verified by experiment within the framework of the dissertation, due to the prohibitive cost of such an experiment (both financial, organizational, time, etc.). However, it was advantageous to use simulation methods that were able to provide information on the boundary parameters. Their comparison with the results of the analysis of the current state was then used to advantage in choosing the appropriate approach to solving the given problem and included these results in the built model.

A computer program is a model for computer simulation, where the goal is to simulate an abstract model of a certain system and find out its behavior. The aim of the simulation program is not to optimize processes, but to find out the expected results for different settings of input data and characteristics. It can then be used to adjust to obtain optimal or suboptimal solutions to a problem.[46]

5 Own contribution

5.1 Definition of cases of using Active RFID technologies for increasing security

Within the framework of the analysis, several general tasks and options were determined to increase primarily the safety of transport workers in specific operations using RFID. As mentioned above, passive RFID is not generally suitable for security applications. The use of active technologies then depends on the needs of specific operations.

In general, 3 areas were chosen for the work, where increasing safety is offered and these are:

- mining operations
- heavy industrial operations
- internal logistics.

5.2 Experiments

The experimental part took place throughout the entire period, but it is partly also based on the experiments that the author carried out even before starting work on the dissertation. Most of the experiments are focused on heavy industrial environments, especially the mining industry. As evidenced by the ongoing simulation results, simulation methods are only a very limited means for these environments. Unfortunately, a positive simulation result usually only indicates the possibility of a successful solution, but not with a high probability of success.

For these reasons, the scientific methods used make the experiment seem absolutely necessary and essential. The following chapters describe in more detail three real systems that are already in operation in practice and of which the author of the dissertation is the author from the position of a development worker or from the position of the creator of the concept of these systems and the leader of the development team. On the basis of these experiences, both the concept of the assignment and the description of the model of the actual goal of the dissertation were compiled.

5.3 Localization in a mine environment using RSSI measurement technology in a mine environment

5.3.1 Information system for identification - ISI

The ISI system is the author's development project, which is primarily intended for the electronic registration of persons in endangered areas of mining operations. In the first stage of the system's development, the task was only to identify individual workers in zones that are marked as endangered and to check both their identity and the number in these zones for registration according to the applicable legislation and regulations of the mining office.

But as it turned out over time, this brief request and assignment formulated by the Mining Authority was not sufficient from the point of view of normal operation. After a successful pilot operation, a series of accidents occurred at the ČSA mine of OKD, a.s. to the rapid deployment of this system in such a form that every worker in the underground operation had to be equipped with an identifier compatible with the ISI system. Within OKD, this requirement was implemented in such a way that every "farrier", regardless of his classification and function, is always equipped with a mine portable lamp with an integrated RFID transponder A-RFID of the ISI system. This requirement was and is still implemented with the help of the Main Báňské Záchranné Station, which manages the operation of mine personal lighting.

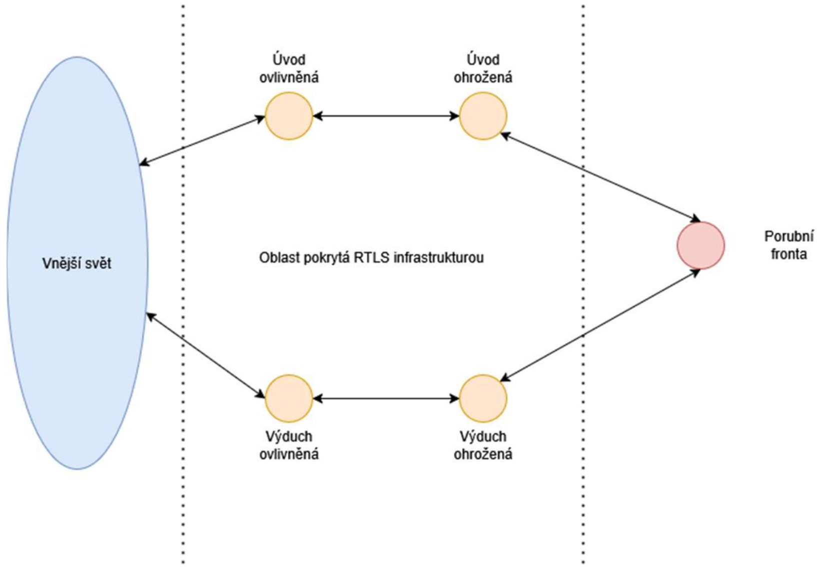
The system was initially conceived as a purely zonal one, i.e. did not address the real location of the miner in the map system, however, over time this simplified system - although fully compliant with the formal requirements - proved to be unsuitable from the point of view of normal operation. Above all, it was not suitable from the point of view of operational dispatch control and, despite the relatively significant technological shift, it did not provide sufficient resources for the crisis management system in case of crisis situations. Therefore, this system was gradually supplemented with additional functions and extensions, which, in addition to purely formal requirements, also met the requirements of the real environment.

Although it was originally a system for the automatic registration of people transported only by human walking, quite naturally it gradually began to intervene in the field of mechanized transport of both people and material. Even if it is no longer a purely safety application from the point of view of legislation and regulations of the Mining Office, on a general level the requirements are mainly subordinated to safety in the transport of workers. From this point of view, the ISI system and its real-world applications served to perform a number of experiments.

At the time of the greatest expansion of this system, 7 large deep mines and approximately 15,000 moving objects, mainly mine workers, were served by the ISI system within the framework of mine works in the Czech Republic. Another 50 mines are served by this system abroad, mainly in Turkey.

5.3.2 Zonal localization

As already mentioned, the primary purpose for the ISI system was zonal localization. This is primarily aimed at controlling the number of specific persons in the hazardous areas of mining operations, which are generally considered closed systems - that is, within these systems there is only a limited and strictly defined list of entry and exit zones. This task can be demonstrated on the map in the following image. Shown here is a map of a standard embankment, which consists of an embankment front and on it two threatened areas (zones) located on the breather and lead grade, terminated by entry-exit zones - in this case, affected zones.



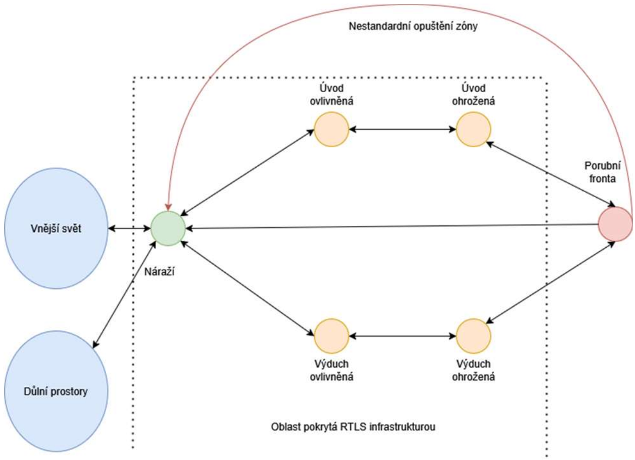
Picture 3. Locating persons within the mining face - representation using a network diagram

In the following case, there was a logical modification of the model where to the model represented by the graph in the following figure. In this model, the individual edges are weighted according to the values of the set hysteresis loop of the received signal strength (RSSI), where the new top of the graph represents the zone(s) that the worker must pass through in order to leave the monitored area with a very high probability.

In this case, it is also about the creation of a new oriented edge of the graph, which describes the one-way possibility of the worker to leave the monitored space, which is not expected, but a real assumption exists here. This edge of the graph is oriented (unlike the rest) for two fundamental reasons:

1. The use of this edge clearly indicates that the system as such has become inconsistent - either due to a change in the real environment that was not included in the model or due to the non-functionality of some of the system's parts
2. If there is any path (graph edge) that is the link between the top of the face and the mine spaces (without RTLS infrastructure coverage), there is no way to detect the use of this path and the whole system has to adapt to this possibility - in that case by

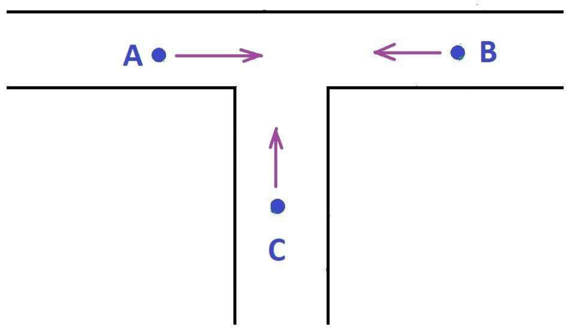
completely different means, outside of the localization system, but by completely different means, such as physically blocking the passage, etc. Another option is to extend the system with infrastructure in a form that removes these edges.



Picture 4. Adjustment of system access – the possibility of one-way transfer of a person to a completely separate zone

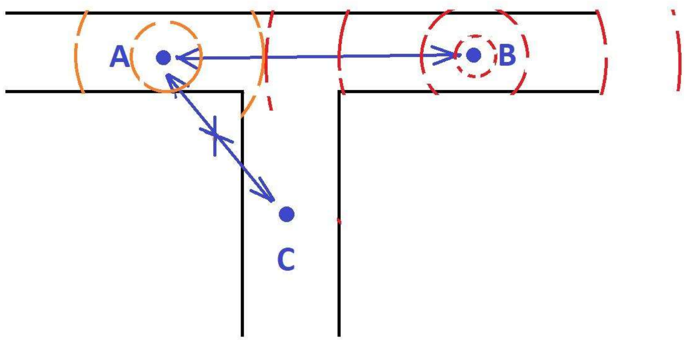
5.4 Definition of the basic task – the general principle of the solution

From the mentioned experiments in the dissertation and above all from the local investigation and discussion with the management of several key enterprises, a general description of the basic task was created, which is currently not sufficiently solved. This is an issue of worker safety and transport safety in difficult industrial conditions. As part of the experimental part of the work, individual methods and requirements were evaluated, and it emerged from them that it is necessary to solve the general situation in intra-company transport, which is modeled schematically in the following figure.



Picture 4. Schematic representation of the default situation

The diagram shown shows 3 moving objects in a single "T" intersection system. In a real environment, it can be assumed that from a radio communication point of view objects A and B are in line of sight, while object C is not in line of sight with other objects. Given the indicated motion vector of all objects, any combination of them is at risk of collision. The basic task of the proposed system is prediction, or active intervention in this situation in order to prevent such a collision.



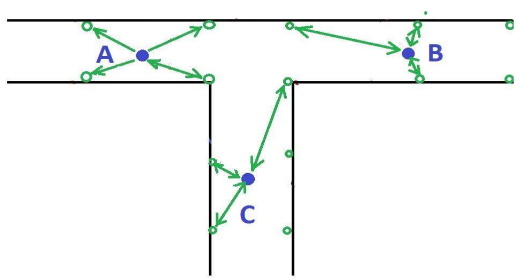
Picture 5. Schematic representation of the initial situation - solution using UWB technology - ranging

Within this model, a direct distance measurement system using UWB technology and the ranging method is used for the given situation. The big advantage of such a solution is that no stable infrastructure is used here. However, as can be seen from the schematic representation, in the case of object C, it is not possible to predict a potential collision with objects A and B in most common situations.

The mutual collision of objects A and B is then predictable with regard to the mutual speed of both objects and with regard to determining the safety limits of the system. But what is one of the fundamental problems is the speed relative to the frame of reference, which in this case is the environment in which the objects are moving. If the speed of both objects is the same, but the vectors are just opposite (the objects are approaching each other), the braking distance requirements for both objects are the same.

But if it is a case where the relative speed is the same as in the previous case, but one object is standing still and the other is moving at twice the speed, the stationary object cannot prevent a possible collision in any way, on the contrary, the second, moving object must have at least twice the braking distance.

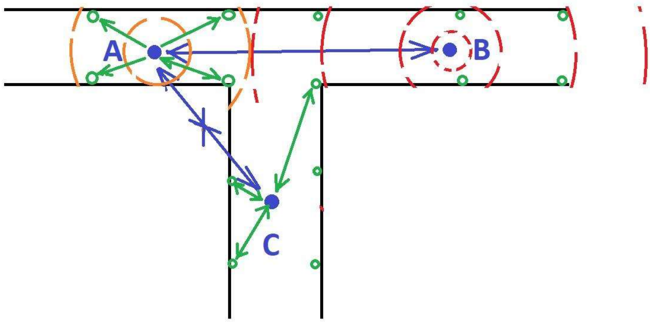
This, at first glance, banal problem fundamentally affects the design of a solution to such a situation. One of the possibilities is to increase the safety zones, which greatly affects the efficiency of operation, and the second is to supplement the decision-making algorithm with another input quantity, such as the speed of the object relative to the reference system - in the case of means of transport, for example, using odometry. However, even this additional information does not solve the model situation of object C.



Picture 6. Schematic representation of the initial situation - solution using UWB technology - RTLS method

The previous figure shows the default model situation solved using RTLS UWB spatial localization. This method seems to solve all the problems described above. All the necessary information about the situation is available and therefore it is possible to predict most potential collision situations. However, considering the practical experiments carried out, this solution is also not completely satisfactory as a general one.

The first critical problem with such a solution is the very necessity of a solid infrastructure. Fixed infrastructure is both a technical and above all an economic problem. This is because a system conceived in this way requires coverage by fixed infrastructure in all spaces, including open and extensive ones, where the presence of such a system is not possible.



Picture 7. Schematic representation of the initial situation - solution using UWB technology - RTLS/ranging

As part of the experiments and analyses, a combination of the two previous solutions was proposed as the most suitable method for solving general collision situations in transport in the final solution. The basis of such a solution must then be:

- the possibility of solving the anti-collision system in open spaces even without the need for the presence of fixed infrastructure,
- the possibility of localization and thus prediction of a potential collision in complicated environments - i.e. especially intersection prediction.

This combination, which is present in available solutions, has not been used anywhere. The advantage is that it solves most of the defined requirements and is a new approach to the problem and eliminates the problems of the currently used approaches from the pictures of the previous principles of possible solutions.

5.5 Assignment of an experimental task and verification of assumptions

As already mentioned, a simulation in a given task so that its results could be considered complex and weighted enough to design a system model based on it would be very difficult to implement in the current conditions and with the available resources. Therefore, experimental verification in a real environment was chosen as the main method of verifying the correctness of the proposed solution. The target environment should primarily be heavy and mining operations. Due to the complexity of the target environment, the experimental task was gradually divided into several consecutive stages.

1. Validation of the applicability of UWB technology in a mining environment
2. Verification of the functional properties of the WAS unit in a non-explosive mining environment (without the need to use ATEX certified equipment)
3. Testing in a typical industrial environment with equivalent functional requirements

CONCLUSION

The content of the dissertation is an analysis of basic theoretical areas and an assessment of the current state of knowledge in the field of radio identification and localization technologies with a focus on active RFID technologies and the associated design of an information system to increase safety in specific types of transport and related operations. This is a relatively young and highly progressive industry, which also deserves appropriate attention and development in the future with the aim of increasing the safety of transport in mining operations and increasing the safety of workers moving in these operations.

The main motive of the work was to develop the possibilities of introducing new technologies in areas where there is a high level of risk to human health and life, and these new technologies have a great potential to reduce these risks. One of the basic motives of the dissertation was the effort to develop traffic management dispatch methods in subsurface operations, which are quite standard in surface operations nowadays, but their introduction in subsurface operations is complicated by the absence of otherwise common communication and localization infrastructure, which is a big problem and brought with it many obstacles that had to be overcome so that the proposals were not just a theory without the possibility of application in practice.

The dissertation takes into account the author's many years of practical experience from mining operations, theoretical knowledge and the use of appropriate methods, which were supplemented by many experiments confirming that they respect the relevant strict industry standards, as well as the real suitability of the methods used respecting the specific environment that mining operations undoubtedly are.

In the dissertation, a model is proposed, described by UML diagrams with function explanations. It can be stated that the goal of the dissertation was fulfilled and this statement is also supported by practical tests and implementation

From a practical point of view, the possibility of real deployment of the proposed solution can be highlighted not only in the domestic environment, but also abroad, since the conditions are similar.

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