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ON THE DESIGN OF A MONITORING AND ALARMING SYSTEM FOR HAZARDOUS GOODS TRANSPORTATION BY SHIPS

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Abstract:*Various hazardous goods and materials are now transported all over the world in ships and vessels. In order to minimize the high risks posed to the people and environment, the recipients containing flammable substances, toxic or nuclear wastes should be tracked and monitored in every transport phase: loading on the ship, storage during the haulage on the sea and unloading at destination. An innovative system that is able to respond to these requests is presented in this paper. The proposed solution core is an innovative RFID tag with a special memory structure. The system integrates automated location devices (GPS / Glonass), data recorders, specially created intelligent RFID readers and a central monitoring station that is able to communicate with governmental authorities (emergency services, environment protection organizations) in order to alert in case of dangerous and emergency situations.*
Keywords: *hazardous substances tracking, RFID, transportation safety, monitoring ship load*

INTRODUCTION

Transportation of various goods on large distances, sometimes between continents, is done frequently over seas, using various types of containers and ships. Sea transportation was the most used carrier of freight in the history. Even if air cargo is faster, ship transportation is cheaper and can be used for carrying larger quantities of various goods, except the ones that are perishable (time-critical).

There are many types of ships that are currently used for goods transportation. The main types of vessels used for cargo purposes are:

- container ships, that transport stacked containers on the deck;
- bulk carriers, that are used for transportation of unpackaged goods such as cereals or coal;
- tankers, that carries liquids in bulk, such as oil or petrochemical substances;
- general cargo ships, that can carry both packaged (containers) and unpackaged goods.

The vessels operates in two modes:

- liner ships, that follows a fixed route on a well-defined schedule.
- charter, that transport goods between two ports, based on the client requirements.

The liner vessels use standardized routes. In Europe there are routes that links to the Far East, passing through the Suez Canal and Malacca Straits. Eastern coasts of United States of America and Canada are linked to Western Europe by the North Atlantic route. Apart from these well-established directions there are many routes linking main ports. If the direct link between sender and destination is not available the cargo will be transferred to another local vessel. It is obvious that all the containers should be carefully tracked. [4]

Almost all the ships nowadays are equipped with GPS/Glonass navigation and radio transponders. Some them have GSM/GPRS modems for real time data transmission, but on their way on the sea they encounter frequently zones without GSM network coverage.

Moreover International Maritime Organization (IMO) has elaborated a series of regulations regarding the standard localization and communication systems that should be installed on vessels. Since 2004 IMO requires AIS – Automatic Identification Systems to be installed and operational on all ships of 300 gross tonnages, cargo ships of 500 gross tonnage and all passenger ships. IMO states that AIS is a supplementary identification measure to the classical marine radar, that continues to be the main method for collision avoidance. [4]

Automatic Identification System is an automatic tracking system used primary for locating and identifying ships by exchanging data with specially designed UHF beacons installed on shore or on other vessels. AIS information consists in identifier (call-sign), geographic position (latitude, longitude), course and speed. The AIS cannot provide detailed information about the transported goods, a critical information when hazardous substances are carried. The system proposed in this paper tries to solve this issue and to provide valuable information regarding the goods carried. [4]

In this paper the author present aninnovative system for monitoring the hazardous cargo transported on various vessels. The developed solution is independent from any systems such AIS or other internal ship safety equipment. A special active RFID tag is used in order to precisely identify each container and also to store information regarding the nature of the goods into it.

PROPOSED SYSTEM ARCHITECTURE

In order to provide powerful and precise identification, tracking and to be able to alert authorities in case of a dangerous situation the proposed system is complex and integrates four sub-systems as presented in figure 1.

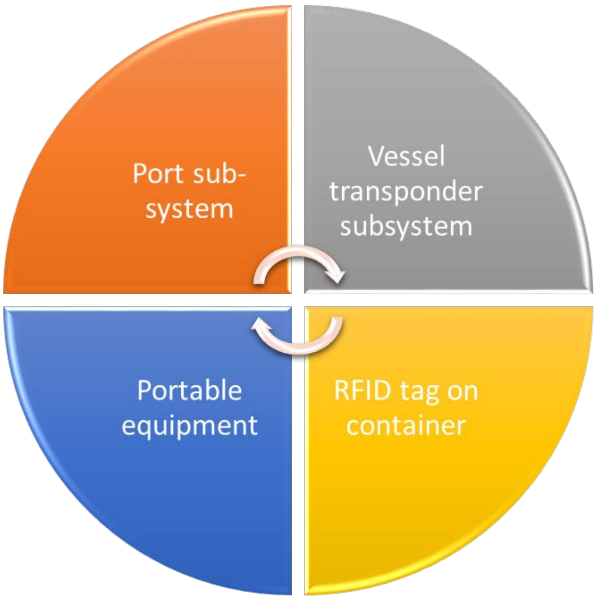

Figure 1 - Tracking system components

The system components are described in the following paragraph. The whole system will not interfere with existing tracking and identification devices installed on the vessel, having its own communication infrastructure and power supply. The author chosen this approach in order to eliminate any kind of restrictions, to assure the system flexibility and independence from the ship manufacturer.

1. The RFID tag is the system kernel as it is used to store critical data about the goods. The tags used are active tags operating on UHF frequency (860 MHz – 900 MHz). Tags are to be placed on any container that is loaded on the ship in order to be precisely identified and tracked. The memory structure of these tags is innovative and is described in the third section of this paper. Also each ship has its own RFID tag that precisely identifies it.

2. *Vessel transponder subsystem* is the system component that enables each ship to "know" information about the containers that are loaded and to share the data with authorized entities, such as naval or governmental authorities, emergency services. This component is also used to locate the ship and communicate with port subsystem via GSM/3G or ZigBee links.

3. *Port subsystem*is located in selected ports. The proposed system is a distributed monitoring system, each port subsystem being a local monitoring station. Each port substation communicates with vessel transponders located in its nearby by using ZigBee or GSM/GPRS technology.

4. *Portable equipment* consists of a portable RFID reader that can be used by authorized employees of the ship owner, naval or governmental and emergency services. The device can be used to retrieve container information and also to display details regarding the hazardous substances carried and the recommended way to action in case of emergency.

The RFID tag is the central element of this system, since this is the main element that is able to identify the ship and the containers contents. The RFID card memory structure is presented in the following section.

RFID TAGMEMORY STRUCTURE

In order to be identified correctly, each container should be marked with at least six active RFID tags. The tags can be attached to each of the six faces of the container in order to be read from almost any angle. The UHF RFID tags are not omnidirectional but there is an angle of about 30 degrees in which the reader can be placed.[1]

In order to be read from an appreciable distance of about 10 meters the tags should be active, so they integrate a little li-ion battery. The reading distance is depending also on reader performances and tag-reader alignment.

The RFID tag is not simple commercial tag that is available in the market; it has a special memory structure that is presented in the following paragraphs. Data availabliliy without any data link to Internet and databases is a critical element of the proposed solution.

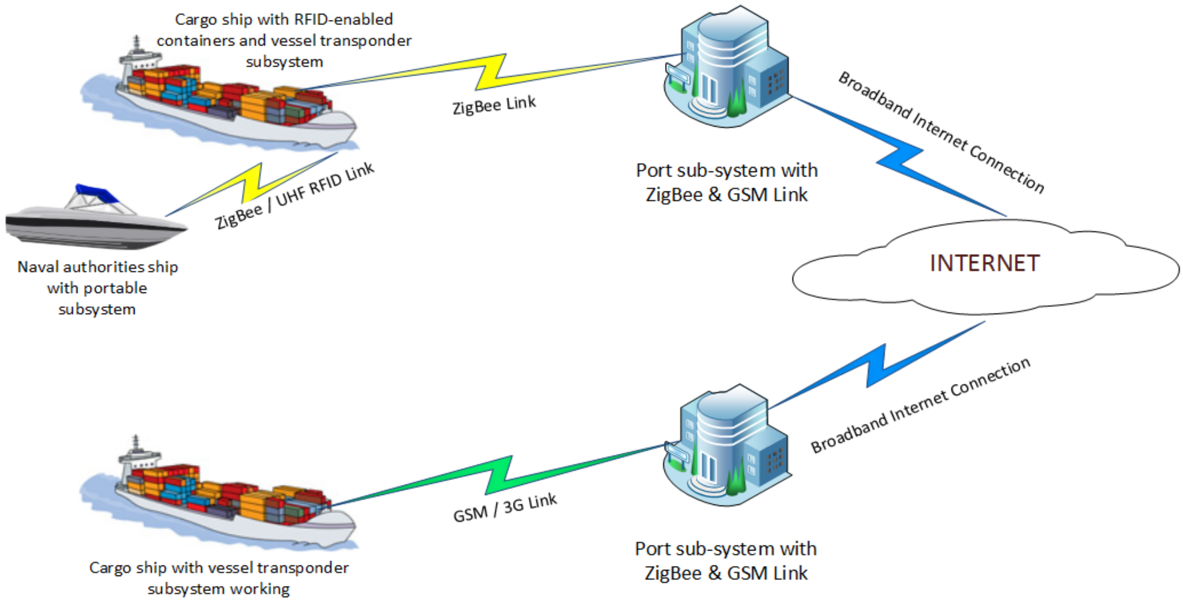

Figure 2 – Integrated system diagram

All the four subsystems mentioned above are working together in a complex and interconnected system. The integrated system diagram is presented in figure 2. The two cargo ships in the left side of the image are carrying various containers that have embedded RFID tags specially designed for the proposed system. Each cargo ship is equipped with the vessel transponder subsystem that can send data via GSM/3G links when network is available or via ZigBee. ZigBee communication can be used at a maximum distance of 1 – 1.5 km in line of sight.

When the 3G or GSM network is available the cargo ship can send information to port sub-system on a periodic basis or as a response to interrogation. When the ship is in the nearby of a port with a ZigBee beacon the communication is made using ZigBee link, in order to reduce costs associated with data transmission.

The port sub-systems are interconnected via broadband Internet connections in order to exchange data about shipped or received goods in real-time. Each port component has its own database that is synchronized with the other ports in the system. This component can also write RFID tags in order to store important information about the carried goods directly on the container.

The naval authorities and emergency services should have ships equipped with the portable subsystem. It comprises UHF RFID reader, in order to be able to read tags on the containers or the ship tag and also ZigBee link to download the data from vessel transponder subsystem.

The RFID tag that is placed on the container has a memory capacity of 2 KB and has the following structure:

- Card_ID, unique numeric tag identifier with the length of 8 bytes;
- Container_ID, unique numeric value used to identify the container with the length of 8 bytes;
- Sender – sender organization code, with a maximum length of 4 bytes;
- Sender_name – memory zone used to store the sender organization name as standard ASCII text. The length of this field is 100 bytes, allowing the storage of up to 50 characters.
- Expedition_date – field used to store the date when the container should be shipped. The length of this memory zone is 16 bytes. Date is stored in ddmmyyyy format, for example 1st May 2015 would be represented as 01052015.
- Expedition_hour–field used to store the hour when the container is to be shipped. The time is stored in format hhmm, taking 8 bytes of memory space.
- Perishable_goods – field used to indicate if the container has perishable goods that are time critical. This field has the length of 1 byte and with value 255 decimal, if the goods are perishable;
- Perishable_time – field used to indicate the maximum travel time for the goods, expressed in hours. The memory space allocated for this field is 6 bytes.

- Destination -destination organization code, with a maximum length of 4 bytes;
- Destination_name - memory zone used to store the destination organization name as standard ASCII text. The length of this field is 100 bytes, allowing the storage of up to 50 characters.
- Destination_port – field used to memorize the name of the destination port as ASCII characters. The field length is 100 bytes;
- Emergency_name - memory zone used to store the name of an emergency contact organization name standard ASCII text. The emergency organization can be contacted in case of an accident since it has all the knowledge about the transported goods. The length of this field is 100 bytes, allowing the storage of up to 50 characters.
- Emergency_phone–field used to store the contact phone number for emergency situations with the container. The number is stored as ASCII characters and the field length is of 26 bytes.
- Goods_id – unique code defining each transported substance. The system developer defines these codes. For example li-ion batteries have code 3D in hexadecimal. The memory zone allocated for this field is of 50 bytes.
- Ignition_point – ignition temperature of the transported substances, maximum length of 6 bytes;
- Self_ignition_point – self-ignition point of the transported substance, maximum length of 6 bytes;
- Boil_point – boiling point, maximum length of memory zone used to store the destination organization name as standard ASCII text. The length of this field is 100 bytes, allowing the storage of up to 50 characters.6 bytes;
- Melt_point – melting point, maximum length of 6 bytes;
- Imdg_codes– this field is used to store the IMDGInternational Maritime Dangerous Goods) Code for the dangerous loading. The length of this field is 24 bytes.
- Verified_date– memory zone used to store the last verification date of the container status. The length of this memory zone is 24 bytes. Date is stored in ddmmyyyyhhmm format, as ASCII text, for example 1st May 2015 12:34 would be represented as 010520151234.
- Verif_authority–field used to store the name of the authority that verified the container status. Total size of this memory space is 100 bytes.
- Extended-info – optional field containing various informations as ASCII text. The size of this field is 500 bytes
- Reserved_transfer – rewritable memory zone that store the ports code where transfers should take place. Total size of this zone is 100 bytes.
- CRC – this field contain a cyclic redundancy checksum, which validates the RFID tag memory contents. The CRC has a total size of 24 bytes.

The RFID card structure defined in this section allows the creation of a complete electronic record for each container. It can be used to identify the shipping information (sender, destination), contents and valuable data regarding the goods, especially if they are hazardous.

Each port subsystem can write and issue RFID tags compliant to the structure for any container that is delivered from its location.

PORT SUBSYTEM

The port subsystem is a complex entity, comprising a RFID tag issuing system, the communication infrastructure (GSM/3G and ZigBee links, Internet connection) and vessel loading/ unloading surveillance system. All those components are operated by specialized software with a powerful database system.

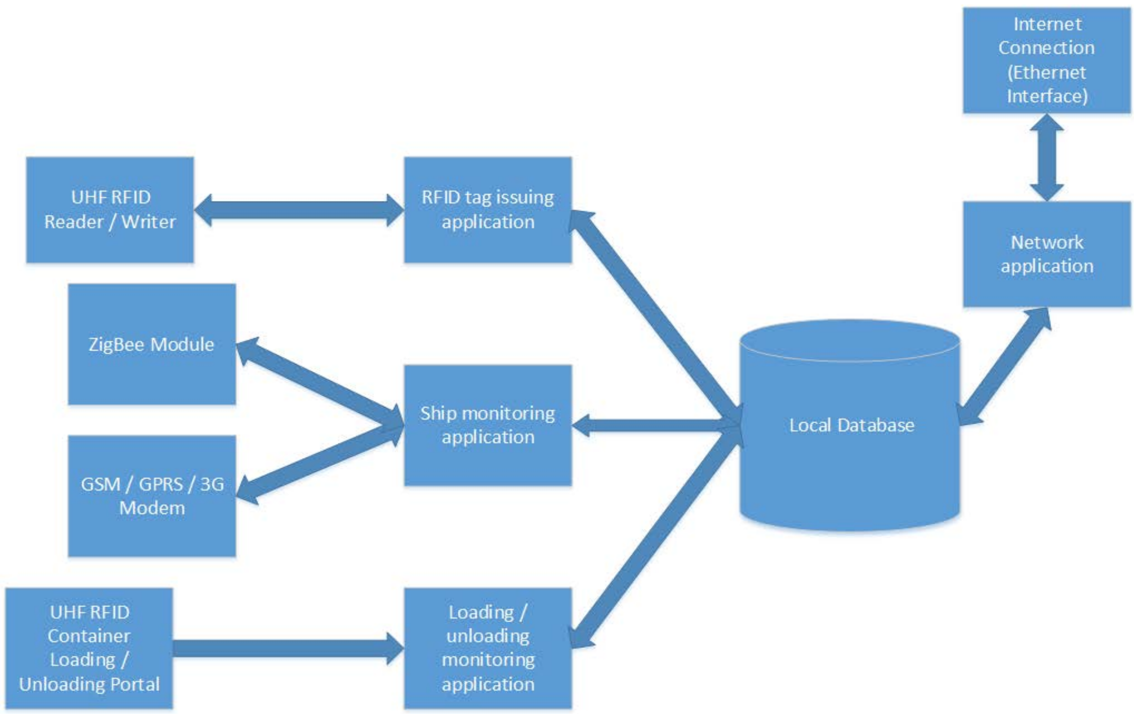

Figure 3 – Port subsystem block diagram

- Toxic_info – field used to show whether the substances carried are toxic for humans and environment. The field length is 1 byte and has the decimal value of 255 if the goods are toxic and 170 if the goods are non-toxic.

The software components of the system will not be described in this paper since here is presented only the system's conceptual design.

The ZigBee and GSM/3G modules presented in the Figure 3 are standard high-performance communication modules used

by the port subsystem to transmit and receive data from the vessel subsystem. The received data will be processed and displayed by the "SMA – Ship monitoring application" and then will be stored in the database for history purposes and for sharing with other port subsystems.
The UHF RFID reader/writer (Figure 4) is a standard hardware component used in order to issue RFID cards with the structure proposed in this paper.[5]

Figure 4 - UHF RFID Reader/Writer[5]

UHF RFID Container Loading / Unloading portal is the main component of the port subsystem. It contains a RFID reader with 4-6 antennas (Figure 6), that are able to detect and interrogate any active tag situated at around 10 meters distance.
The portal should be mounted in the loading / unloading area and all the containers with embedded RFID tags should pass through this portal in order to be registered in the system. The RFID reader is provided with anti-collision algorithm, allowing the sequential reading of at least six tags with high reliability[1].

The unloading operation must be done in the same way. The container should pass through the portal at the unloading port. If the data stored in the "Destination_name" or "Reserved_transfer" fields of the RFID card does not correspond to the one programmed in the reader memory, meaning that the container is unloaded at another port that the destination/ transfer points the system will alert its operator about the possible mistake.

Figure 6 - RFID Portal antenna installed in the laboratory

The network application and the Internet connection is used to synchronize the database content of the actual port subsystem with other port subsystems all over the world, in order to make a distributed monitoring system.

VESSEL TRANSPONDER SUBSYSTEM AND THE PORTABLE SYSTEM COMPONENTS

This integrated system component is a data recorder and a transmitter that is able to communicate with port subsystem equipment. The second function of the vessel transponder subsystem is to gather information about the containers, as they are loaded on the ship. The block diagram is presented in Figure 5.

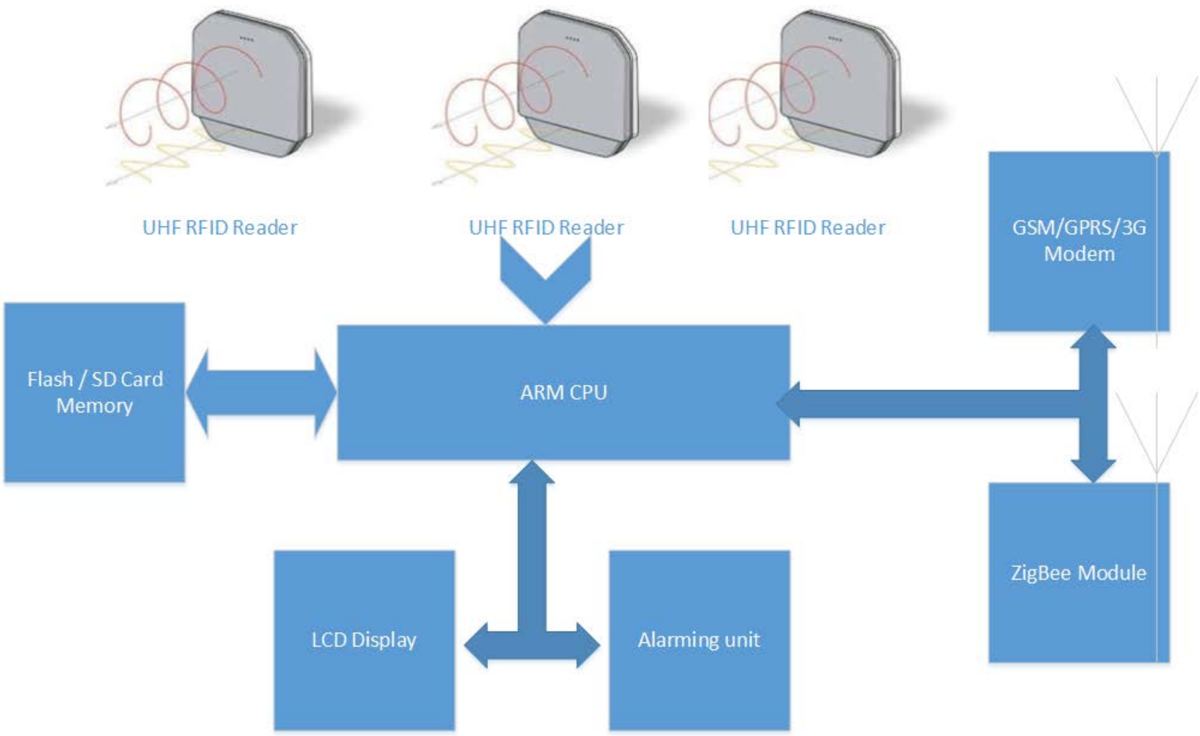

Figure 5 – Block diagram of vessel transponder subsystem

In order to monitor all the containers that are loaded on the ship the vessel transponder system should integrate a matrix of UHF long-range RFID readers. The number and placement of the readers is strictly dependent of the ship size. The system can function with only one RFID reader, but this approach is not practical, since all the containers should pass in front of this device. For gaining better performances there should be used at least six RFID reader, three on the right side and three on the left side of the ship in front, center and bottom regions.
The data from RFID readers is sent to the ARM CPU that coordinates the entire subsystem. The data is then stored in the Flash or SD card memory. In this memory there is also stored information regarding the ship, such as call sign, name, etc.
If needed the vessel transponder subsystem can integrate a GPS/Glonass receiver in order to determine accurately the ship geographical location. This module is not a critical one since exchanging data with the port subsystem identifies the destination and transfer nodes.
If ZigBee connection is availablethe ship will broadcast its call sign periodically. These signals are detected by the shore component of the system that starts communicating with the ship. If there is any container that should be unloaded the system will alert the operator by displaying all the required information on the LCD display and playing a pre-recorded audio message on the alarming unit.
The GSM/GPRS/3G module is used to communicate with the system when the GSM coverage is available. The system can be interrogated remotely in order to obtain information about the goods it is transporting.
The portable system is somewhat similar to the vessel-installed system. It integrates only one UHF RFID reader, an ARM processor, an LCD touch-screen display, flash storage and a power supply. The portable system can be used by naval authorities and emergency services to check the containers on a cargo ship.
When an RFID enabled container is verified all the information contained in the RFID memory is displayed in a user-friendly manner on the LCD screen. In this way an authorized user knows exactly what is the source and the destination of goods, what type of goods are transported, whether they are dangerous or perishable. The most important is the fact that the portable unit is able to present information in case of an emergency.
Reading of the RFID tag information is very quick (<1 sec.) and the portable equipment can provide information about the nature of the transported goods and the methods of intervention in case of an emergency.[1],[5] For example in case of a chemical substance that leaks from a container, the system will display all the necessary information in order to know how to neutralize the substance.

Conclusion

The system proposed in this paper is a complex system for monitoring the load/unload and storage of containers with dangerous goods shipped on cargo ships on the sea. The proposed solution integrates three subsystems: one component on the shore – port subsystem, one vessel transponder subsystem and a portable equipment for authorized users such as governmental authorities and emergency services.
The system concentrates around as specially designed UHF active RFID tag with a special memory structure described in the third section of this paper. The RFID card represent in the author view the electronic document that should fully describe the attributes of any container located on the ship. It contains information about the sender, destination, the nature of the transported goods and valuable information for intervention in case of an emergency (chemical composition of goods, ignition temperature, substances that should be used to neutralize the hazardous materials transported, etc.).
At the moment of writing this paper the integrated system is still in the design and concept phase. Discrete subsystems were assembled in a laboratory of Petroleum-Gas University of Ploiesti. The RFID portal presented in the paper was tested in laboratory with good results.

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