Abstract: In northern countries several freeze-thaw cycles may occur per day making it especially significant to monitor temperature and water content in road structures. The way to acquire this data in different layers of road structure is still costly, difficult and time consuming. The data is valuable as an input in choosing upon the suitable design technology. In this article an idea is presented and preliminary tests are carried out to use RFID tags with sensors in road structures to measure continuous data about significant parameters throughout the lifecycle. The results of these tests proved that RFID tags can be read through different layers and depths of road construction materials. The use of gathered data in road performance measurement systems is proposed.

Key words: RFID, road infrastructure, data collection.

1. INTRODUCTION

In all northern countries similar special problems with road deterioration due to cold climates occur but vary with variations in temperature, geology and other condition as traffic configuration, road design practices etc. The deterioration of roads can have serious consequences for the safety and comfort of road users and reconstructions cause extra need for financial assets.

In developed countries investments in transportation infrastructure account for a significant part of appropriations to the real sector and adequate data from performance measurement systems is required for making investment decisions and in monitoring executed projects. Radio Frequency Identification (RFID) technology is a relatively new technology in road construction field but has widely spread in Intelligent Transportation Systems (ITS). Because of its benefits construction and transportation industries are researching and implementing RFID technology to improve data storage applications and also to develop “smart RFID tags” that are able to sense, monitor, and adapt to their changing environment. RFID has been identified as one of the cornerstones of the upcoming Internet of Things (IoT) and the focus is moving from conventional RFID towards next generation pervasive networked and interconnected systems [14].

Currently pavement and road structure monitoring needs significant personnel time or the use of costly equipment but there is need for this data as an important input in choosing upon the suitable design technology for new projects and in measuring [6]. In this article an idea is presented to use passive and Battery Assisted Passive (BAP) RFIDs with sensors in road structures to measure continuous data about significant parameters throughout the lifecycle of the road. Previous research [8] has indicated readability problems with the use of RFIDs therefore the authors conducted preliminary tests to verify the suitability of the suggested technology.

The estimated lifetime and durability of suggested technologies are more close to lifetime of the road than other low-power wireless technologies such as Wireless Sensor Networks and Active RFID Sensor Tags and therefore do not require intrusion to road structures for data acquisition and maintenance reasons.
2. MOTIVATION OF THE RESEARCH

The climate of Estonia, comprising of several freeze-thaw cycles even per day in winter makes it particularly important from the sustainability point to have knowledge about temperature changes and the amount of water moving through pavement and in different layers of the embankment. Cracking of pavements related to low-temperature frost action and freeze-thaw cycles is a well-recognized problem in most northern countries. Premature deterioration of road pavements is related to high frequencies of freeze-thaw cycles, primarily where subgrades are composed of fine-grained, saturated material [5].

Once in a pavement or embankment water plays a primary role in giving shorter service life, service-ability and increasing the need of rehabilitation measures. In order for a road to be sustainable it is necessary to do the following: consolidate well the earthworks, have good sub-base drainage, keep the water-table low, preventing the moisture content of the sub grade increasing, avoid failures due to binder stripping, not to allow water to remain on top of the surface course weakening the surface due to hydraulic pressure. If improperly canalized, water can also cause soil erosion and a breakdown of pavement edges. With below 0 °C degrees and freezing the deteriorating effect is even much greater. Cold temperatures in winter are great concern for transportation agencies because due to frost action the phenomena called frost heave occurs, a road will actually "heave up", being the main deterioration of roads especially in case of insufficient drainage. Therefore it is essential to monitor the above mentioned causes of deterioration in order to avoid design failures and to give support to the road agencies to establish the best requirements for designing and constructing sustainable roads. Authors have chosen to suggest measuring water content and temperature simultaneously in road structures using passive and Battery Assisted Passive (BAP) RFIDs with sensors (see Fig. 1).

3. RFID TECHNOLOGY

RFID technology as we know it today dates back to 1970's when Mario Cardullo's and Charles Waltons devices were patented in 1973 succeeding with the marketing of first usable products in 1979. The RFID technology is a means of uniquely identifying an object with a wireless radio link, allowing data to be stored on an RFID tag and retrieved in remote application at a later point of time [1].

Wireless sensors incorporated in RFID systems are important in several industrial,
consumer and logistics applications. By extending RFID tags to sensing applications the products become smarter and RFID sensor network applications are emerging and moving towards commercialization [9]. Two RFID technologies are available: (SAW) and Integrated Circuit (IC) based Passive RFID sensor tags may be categorized as Surface Acoustic Wave (SAW), IC Passive and IC BAP. Multiple designs of adding sensors on passive RFID tag exist (see Fig. 2). These technologies have been successfully used in various applications amongst others also in the construction industry. Due to the progress in integrated circuit technology, it is expected that RFID will play an important role in the global circulation infrastructure. It is expected that more RFID tags will be used in the future as sensory functions come more common-place [12].

![Fig. 3. RFID system generic structure](image)

A typical RFID system includes three components: an antenna or coil, a transceiver (with decoder), and a transponder (RFID tag) electronically programmed with unique information, as illustrated in Fig. 3.

4. SYSTEM DESIGN

4.1 System Architecture

Authors have studied RFID tags with sensory functions because it is considered that the RFID tag can detect some conditions of structures and transfer its information through external reader [10]. With this in mind we are trying to develop a system ((see Fig. 4) to monitor the condition of road structure and establish the impact of water content and temperature change to road deterioration and with the use of RFID tags with sensory functions.

The device may be located in the moving vehicle or placed stationary on the road side. The RFID reading on motion will add certain requirements on the tag and reader antenna orientation, but at the same time reduces cost. Having many metering points with stationary readers will cost more than few, but often by-passing vehicles with the Interrogator on board [5], [8].

![Fig. 4. System architecture](image)

Interrogator processes and enriches the raw sensor tag data. It consists of a RFID reader together with an antenna and data processing system. It may contain the GPS module to add the location coordinates to the sensor reading event to allow reporting in deviations of stored data and field information. Interrogator contains additionally sensors for reading the air temperature, relative humidity, and speed of the Interrogator when in motion. The data from Interrogator towards the Backend server is transmitted over REST style HTTP(S) interface on top of TCP/IP network to avoid possible data communication network operator restrictions and makes the data transfer operator and media agnostic. For moving units, radio network is necessity. Stationary units may be connected to fixed communication line if available. Backend server keeps the inventory of installed sensors (location, installation date, depth, layer material) and collects the sensor data (interrogator identifier, sensor identifier, reading location, temperature and water content in road structures, signal strength,
temperature and relative humidity in Air) sent by interrogators. Road section inventory (section name and identifier, owner, maintaining organization, condition, and history) is kept in the same database to allow reporting based on the road sections. Backend keeps also road planning information (e.g. price by the road section) to be able to report on the deviations between the plans and current situation and do the cost calculations of the delta to assist decision modeling of upcoming road construction projects. The reports and online sensor data is displayed and rendered to the graphical format in frontend graphical user interface to be used by the stakeholders. Sensor data is made available to third-parties through public API (Application Programming Interface) using Open Data principles. Correction functions for sensor readings are applied in the backend during the data collection process.

4.2 Sensor applications

For IC tags normally sensor tag comprises four major blocks – an analogue sensor, analogue-to-digital converter (ADC), digital controller circuit and RF part with antenna. The BAP tag may contain optionally Non-volatile memory (e.g. FeRAM) for data storage, ultra long-life energy storage (e.g. lithium-polymer, thin film super-capacitor) and renewable power source (e.g. piezoelectric or photovoltaic generator).

It is known that low-cost Capacitive Soil Water Content sensors that are suitable for this type of application are sensitive to soil density, temperature, salinity, and supply voltage (RF signal strength) variations [2], [11]. The calibration method to correct the readings based on geostatistics, sensor clustering and information sharing has been proposed by Zhang [18].

The proportional-to-absolute temperature (PTAT) current generator, directly representing the temperature, delivers a PTAT current and a reference current, keeping the latter’s value constant over the temperature range of interest. In the RFID tag the ADC then processes both currents into the digital data stream, passes to the controller which encodes the result into the response [7], [13]. Also a design without ADC has been proposed by Shenghua [17] to even more reduce the power requirements of the sensor.

The capacitance and time domain reflectometry (TDR) method are two widely used electromagnetic (EM) techniques for soil water content estimation. Both methods make use of the strong dependence of EM signal properties on volumetric water content that stems from the high permittivity of water compared to mineral soil solids, and air. The basic principle of the capacitance method is to incorporate a dielectric medium (e.g. soil) as part of the dielectric of the sensor capacitor [2].

Temperature and Water Content measurement using SAW tags has been shown by L. Reindl [16]. The SAW RFID tag consists of an inter-digital transducer (IDT) and a series of acoustic reflector traps etched into a piezoelectric substrate. The tag reader emits a radio wave pulse to the IDT that is converted piezoelectrically into a nanoscale acoustic wave. The wave travels past the reflectors to produce a unique pattern of reflected pulses. These travel back to the IDT, where they are piezoelectrically converted into an encoded radio wave reply signal to the reader. The SAW chip operates in a purely passive mode and does not require supplementary DC power [15].

5. PRELIMINARY TESTS

Authors conducted a preliminary empirical and field study to check whether the UHF IC Passive tag transmittance in dry soil and road construction materials is similar to the expected.

For that we connected ThingMagic Vega UHF RFID reader to RHCP (Right Hand Circular Polarized), 7,5 dBiC Antenna and to a PC with software needed for reading. In another end authors used Confidex Ironside metallic, ALN-9629 “Square” Inlay and Avery Dennison AD-824 RFID tags.
Authors were aware of the fact that the metallic tag performance is suboptimal when placed on non-metallic surface, but we decided to test a tag with average performance in the air, which is approximately 4 meters in the combination with our reader. All the tests were executed in laboratory environment in room temperature. Second set of tests was conducted at a road construction site to get proof that the signal could be read through different materials used in road construction from the depths up to 2 metres. During the experiment we inserted the tag in various depths into the soil going up to 2 meters and took readings leaving the variable air gap between the soil and antenna so that the distance between the antenna and tag was never bigger than 3 meters. The success rate of the reading was as expected and we were able to get readings using all three types of RFID tags. The results provided solid ground on continuing with testing with varying materials to simulate actual conditions. In the preliminary field trials authors tested the Confidex Ironside metallic RFID tag in soils with various moisture, sand, and gravel. We placed the tags in depths up to 2 meters, leaving the gap between the antenna and the tag so that the distance between the antenna and tag was also never bigger than 3 meters. Authors were able to get readings through all tested materials and are confident to move to the next stage to start preparing field test in road construction site.

6. FURTHER RESEARCH

As the results of the preliminary tests that proved RFID tags suitability to get readings from the depth of up to 2 meters in the ground we are can continue with the research and field tests in actual conditions as follows.

- Theoretical and experimental study of radio wave propagation from the air through different layers of road construction materials and back taking into account the possible frequencies of suitable Passive or BAP RFID technologies, environment temperature and water content deviations.
- Evaluation of existing SAW, IC BAP and IC Passive sensor tags in soil.
- Study on energy harvesting and storage solutions suitable for BAP tags.
- Adding sensors to measure if salt used in winter maintenance percolates into road structures.
- Study alternative WSN approach using IEEE 802.15.4 (e.g. Zigbee or 6LoWPAN) based sensor mesh network to gather underground sensor data ignoring the current battery lifetime issue.
- Testing removing the battery altogether and storing energy solely in the super-capacitor, there is now a viable option for achieving long-life operation. By designing the node to operate on 50% energy capacity, the operational lifetime can be pushed out to 20 years [19].

7. CONCLUSIONS

Long term monitoring and feedback from sensor equipped RFID needs helps: reduce maintenance cost, improve longevity, enhance safety, and advance research in pavement design. Authors have conducted a series of tests in laboratory and field conditions and were able to confirm the RFID tag suitability and readability in different depths up to 2 meters of road structures. Literature review and preliminary tests prove that the technical solution presented in this article is perspective and ready to move to feasibility study phase.

8. REFERENCES


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