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Enhancing Large Dam Safety Using IoT Technologies: A Case of a Smart Dam

Rastko Martać
(Jaroslav Černi Water Institute, Belgrade, Serbia
mrastko@gmail.com)

Nikola Milivojević
(Jaroslav Černi Water Institute, Belgrade, Serbia
nikola.milivojevic@gmail.com)

Marijana Despotović-Zrakić
(Faculty of Organizational Sciences, University of Belgrade, Serbia
maja@elab.rs)

Zorica Bogdanović
(Faculty of Organizational Sciences, University of Belgrade, Serbia
zorica@elab.rs)

Dušan Barać
(Faculty of Organizational Sciences, University of Belgrade, Serbia
dusan@elab.rs)

Abstract: This paper investigates how to transform a manual monitoring system into a smart environment using IoT technologies. Large dams are of huge importance as water reservoirs and potential energy sources primarily because of their use for electric energy generation. Monitoring and predicting dams' behavior are quite challenging. Due to a variety of limitations, environmental obstacles and dam system complexity, the application of RFID, Bluetooth, and IoT technologies has proven to be an adequate, affordable and reliable dam safety solution. This paper introduces a comprehensive model of dam safety management and monitoring based on pervasive technologies. The model described in this work has been applied within the large dam "Iron Gate 1", on the river Danube in the Republic of Serbia. The results show that the use of new technologies in the dam monitoring process can reduce human error and improve overall process.

Keywords: Internet of Things; Dam Safety Management; Dam Monitoring; RFID; Bluetooth; Smart Dam
Categories: H.1.2

1 Introduction

Dams are infrastructure objects that by their nature carry a certain risk, a potential danger to the surrounding area. The risk can never be eliminated but could be significantly reduced. The issue of dam safety, as well as the safety of the associated facilities, is of great importance, especially in the case of large industrial dams. The security of a dam implies defending itself through the finding of a reservoir in which it can discharge all its design functions without adverse consequences for the people, the environment or physical property. Similar to other constructions, dams have a lifetime, too [Titova, Longobardi, Akhtyamov and Nasyrova 2017]. Over time, their condition should be kept up to date and, if necessary, preemptive reactions are needed in order to prevent the possibility of damage, collapse or uncontrolled discharge of water. However, the production conditions gradually alter the characteristics of the materials used to build a dam. The characteristics of the geotechnical environment are subject to change too. In addition, professional and social factors, as well as safety and risk criteria (hydrological, seismic-tectonic, etc.) are changing over time, accompanied by the occasional changes in standards and legal norms. Regardless of all mentioned variable elements, the safety of the dam is managed throughout the entire exploitation period.

The process of monitoring, collecting, and management of systems data is unquestionably important for engineering projects and structures, such as dams [H. Wang, Li, Jiao, Ge and Li 2014]. The collected data are used to predict the behavior of a dam and adequately control dam safety management (DSM). Dam safety and reliability of various parameter measuring devices are affecting the entire ecosystem of a dam [Sander-Kessels and Strasser 2017] [Martać, Milivojević, Milivojević, Ćirović and Barać 2016]. Since the risk of progressive dam damage becomes higher with any new damage, it is necessary to continuously improve the dam monitoring system. At selected measurement points on the dam, devices for monitoring were built-in at the time when the dam was erected. During the period of exploitation, a number of devices are being replaced by new devices based on new technologies. Since certain embedded devices cannot be replaced (strain gauge, pressure cell, concrete thermometer, etc.), the presence of human dam operators in the process of dam monitoring and collecting data is unavoidable when using these devices. In such a process of data reading and recording it is possible to encounter a human error.

The introduction of new technologies, such as radio-frequency identification technology (RFID), has brought new possibilities for more reliable data collection at dams, avoiding the costly installation of new complex devices. The applications of RFID can increase the efficiency of data collection processes at an affordable cost [Ko 2009]. In addition to the ROI argument ['Why RFID? | Confidex' n.d.], several authors have stressed that using RFID technology in an automated monitoring process can eliminate human error [Schnock, Biggs, Fladger, Bates and Rozenblum 2017] ['Using RFID technology to reduce medication errors - Hospital News' n.d.]. Additional benefits in remote dam monitoring can be achieved by using Internet of things (IoT) technologies, various sensors and actuators.

Literature analysis shows that papers dealing with dam safety management are mainly based on software advancements. In one of our previous papers [Martać et al. 2016], we presented conceptual designs that dealt with the hydro-information system of a river basin. In this paper, we try to further improve the system of dam monitoring using RFID and Bluetooth technology (BT) in the concrete example of the large dam Iron Gate 1 on the Danube River. This work is focused on replacing manual monitoring and data collection system, and the transformation of the legacy system into a smart automated system using available IoT technologies. The main idea is to employ RFID technologies in replacing manual data collection and so improve the overall dam monitoring and safety management ecosystem. We have developed a solution based on BT, which enables the automated process of dam data collection, thus eliminating the factor of human error. Through the implementation of the developed solution on one large dam in Serbia, this paper tries to address the following research questions:

1. Does the harnessing of RFID and BT in the manual technical monitoring (MTM) process improve the dam monitoring process?
2. Do RFID and BT in the dam monitoring process provide more reliable data than the manual reading of data?
3. What information, collected by RFID and BT, can be used to control the quality of technical data?
4. How does the use of RFID and BT influence the effectiveness and productivity of dam employees (emp.)?

The research was conducted at the dam Iron Gate 1. The dam is the largest hydrotechnical structure on the Danube and is managed half by the Republic of Serbia and half by the Republic of Romania.

2 Literature Review

2.1 Dam Safety Management

Dams must be permanently maintained in a proper manner because of extreme consequences that may occur in case of a failure. Maintenance refers to monitoring the condition of a dam and its belonging facilities, which implies identification and undertaking of all necessary measures for ensuring safety and functionality of the facilities in a timely manner [Milivojević, Grujović, Divac, Milivojević and Martać 2014]. Table 1 shows the relevant projects that deal with DSM.

Literature/Project	Relevant findings
[Jeon, Lee, Shin and Park 2009] KWATER	- managing 30 large dams in Korea; DSM system KDSMS
[Bao, Gu and Zhang 2006] Fujian	- managing 27 large dams in China; development of a remote safety monitoring management system; process, analyze and evaluate data to judge the state of the dam
[Huai-Zhi and Zhi-Ping 2005] IEWSDS	- implement real-time diagnosis and reasonable evaluation for dam safety; intelligent early-warning systems of dam safety
[Milivojević et al. 2014] DSM	- safety of dams in the state of Serbia; developed and implemented on Prvonek dam; improve the maintenance system, safety, and functionality of the existing dams
[Yang, Bao, Liang, Mi and Yang 2009] DSMMIS	- development in the management information system for dam safety monitoring; based on Browser/Server; Bi Kou
[Sun, Zhang and Li 2012] TDMPAS	- tailing dam monitoring and pre-alarm system ; based on IoT and cloud computing; applied in several mines
[Ding et al. 2013]	- real-time safety early warning system; based on the (IoT); combination of the sensor system and RFID; Applied in Yangtze Riverbed Metro Tunnel

Table 1: Review of DSM implementations

2.2 Application of RFID Technologies in Industry

Smart technologies have found applications in various fields, such as logistics, industrial objects, large constructions, energy sector, etc. One example of good use of smart technologies is the application of RFID in monitoring. RFID is the most common technique for identifying and localizing objects from a distance [Fardoun, Altalhi, Villanueva, Tesoriero and Gallud n.d.]. This automatic identification (auto-ID) is an important basis for many of today's applications of ubiquitous computing [Friedewald and Raabe 2011]. RFID consists of two elements: a reader and a tag, which can be passive, semi-passive and active. Active tags use a variety of power sources and constantly emit a signal, semi-passive use power but do not emit a constant signal, while passive ones activate after receiving a signal and use only signal energy.

Literature/Project	Relevant findings
[Pursula, Marttila, Nummila and Seppa 2013]	• development of passive HF and UHF RFID • humidity and temperature monitoring • demonstrated in concrete casts
[Li, Calis and Becerik-Gerber 2012] HVAC	• RFID based occupancy detection systems in heating, ventilation, and air conditioning • demand-driven HVAC operations
[Chu et al. 2013] PPS-RFID	• a design for a self-powered RFID tag • piezoelectric power supply (PPS) • portable remote temperature monitoring
[Katayama, Nakada, Hayashi and Shimizu 2012]	• active RFID is more advantageous than passive RFID and enables higher data reading performance • tracking ocean/air container transportation using active RFID systems
[Ibrahimy and Motakabber 2015]	• the system of RFID tags implemented in bridge monitoring • passive RFID tags • the RFID reader can directly detect the absence of the tags as well as the amount of the scouring
[Chen, Chen, Sawaya, Oouchida and Hirano 2015]	• RFID tag technology applied in monitoring of vehicles on roads and tunnels • Two scenarios: a gantry-based tag reading system and an in-road reader

Table 2: Review of RFID implementations

Depending on the frequency, tags are divided into low frequency (LF) with the range of 10cm, high frequency (HF) tags have a range of 10cm to 1m and ultra-high frequency (UHF) tags have a range up to 12m. UHF passive tags were used in this project because the tags needed to last as long as possible (no battery change) and because of terrain accessibility (range) [Daniel Hunt, Puglia and Puglia 2007]. Table 2 shows papers dealing with the applications of RFID.

2.3 Bluetooth

BT is a wireless technology that runs on most mobile devices. There are two types that differ in power consumption: Bluetooth Low Energy (BLE) and Bluetooth Classic. BLE is mainly used for sensors or for devices that require low energy consumption. There are 3 classes depending on range Class 1 range 100m, Class 2 range 10m and Class 3 range less than 10m. The most common is Class 2, used in [Akash 2018]. Table 3 shows various applications of BT.

Literature/Project	Relevant findings
[Shorey and Miller 2000]	• advantages and disadvantages of BT
[Jara et al. 2013]	• compare BLE and standard BT
[Zapata, Egeling and Schwanenberg 2018] FieldVisits	• digital data acquisition • used for dam monitoring and hydrology
[Köppe, Moldenhauer, Haamkens and Helmerich 2016]	• BLE technology in wireless sensor networks • WSN acts as early warning systems

Table 3: Review of BT implementations

The application of BT is versatile and is used for data exchange. BT has not been analyzed here in detail, as it has long been present with diverse fields of application and it is simple to use [‘Bluetooth Technology Website’ n.d.].

The analysis of the literature shows that the application of RFID technology is the most prevalent in the industry, but there are other areas of application. By reviewing a large number of scientific papers, the authors have not encountered the use of RFID and BT in dam monitoring. Most papers dealing with dam safety focus on the improvements or innovation of software and their implementation in combination with early-warning systems.

3 Design and Implementation

3.1 Model of Manual Technical Monitoring

Dam monitoring is significant in dam process management. It is very important because it affects not only the operation of the dam but also its safety. Dam monitoring includes numerous types of measuring devices performing different measurements (Table 4) [Chavan and Valunjkar 2015], and storing them in the database (DB). Data processing is also highly significant when it comes to the issue of dam safety. Processing data enables simulation models to perform prognoses of dam behavior, which largely helps the dam management process. Dam monitoring includes numerous types of measuring devices performing different measurements [Chavan and Valunjkar 2015]. The table below (Table 4) presents some of the most commonly used devices and their purpose.

Measure	Device
Underground water pressure	Piezometer with manometer
	Remote piezometer
Relative movement of the dam	Coordinometer
	Remote coordinometer
Change in dam gradient	Clinometer with the vertical base
	Clinometer with the horizontal base
	Remote clinometer
Operation of dilatation coupling	Deformeter Dilatometer
Air temperature	Air thermometer
Dilatation in concrete	Extensometers
Relative movement of the coupling	Displacements
Concrete temperature	Concrete thermometer
Water level	Water meter lath

Table 4: Measuring devices

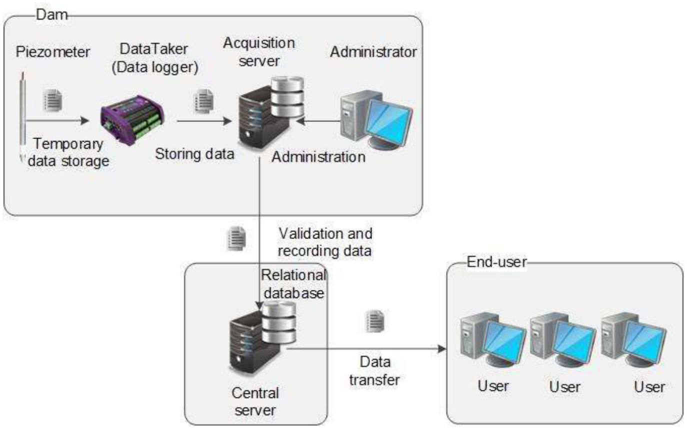

Figure 1: Automated data collection system diagram

There are three types of data collection on dams: automatic, semi-automatic and manual. The semi-automatic collection is used to check automatic data collection, while, obviously manual collection requires human presence. Figure 1 presents the piezometer function in the automatic process of data collection. Piezometer is the device that measures underground water pressure i.e. piezometer pressure. Data logger automatically collects data using embedded software. Acquisition server is a hardware-software component, aiming to collect, validate and prepare data. After the data was taken and validated by the acquisition server, the central server takes over validated data and stores them in a DB. The central server is a hardware-software component, aiming to coordinate, distribute, synchronize and store data, as well as to manage data access and service. The information-communication infrastructure system contains a central server and all other elements of the system are connected to it. DSM typically contains one central server.

3.2 Implementation of RFID Model in Manual Technical Monitoring

Manual technical dam monitoring represents one of the keyways of monitoring, where it is necessary to include people. It is costly to change measuring devices that people manually operate on. Also, in some places, it is impossible to replace the manual with an automatic device because the visual inspection is significant. To understand the results of the measurement, an expert should have an insight into the measurement location because the result which measurement device shows is not enough. Up to date devices are proven to be reliable and measurements are precise, which is why devices won't be changing anytime soon. Apart from financial restrictions, there are also restrictions related to the environment in which measurements are performed – humidity, temperature, light, etc. Therefore, it is necessary for devices to be highly resistant, reliable and cheap. The authors have chosen RFID technology because it is widely used in the industry for tagging, it is robust, up-to-date, fast-paced, and can meet demands at affordable costs.

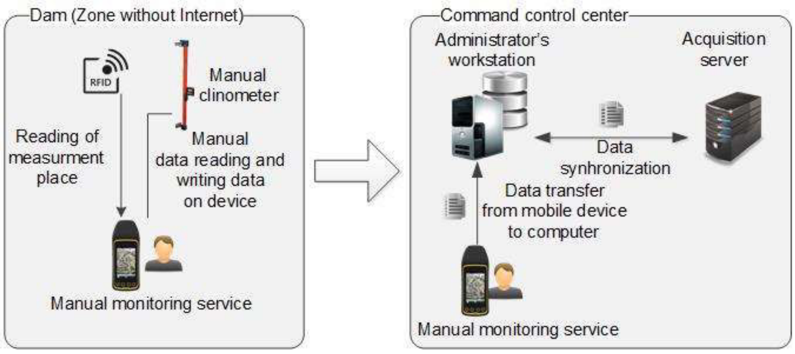

Figure 2: Manual dam monitoring system diagram

When MTM of the dam is performed, it is necessary that an employee enters the field, observes values on a device and records these data. Later, data is inserted into DB, because there is no network connection in the dam. Prior to the implementation of RFID technology, the employee read the data and recorded the measurements on the paper on which the tables with the measured values were printed. When an employee completes the readings of all measurements on various devices, he/she goes to the office and enters the data into the application connected to the Internet. Figure 2 shows the manual technical observation of the dam, where the following errors are quite common: unreadable label at the measuring location, wrong paper selected for entering data, the missing field for entering the measurement, incorrect data reading, incorrect data recording and incorrect data entry into the application.

The implementation of the new model of MTM consists of 3 phases. The first phase is the integration of RFID technology (device recognition), the second phase is the integration of BT (data transfer) and the third phase is the implementation of Beacons, as a special type of RFID active tags (with sensor for collecting data from the environment). The first two phases have been successfully implemented and are being used on the dam “Iron Gate 1”. Currently, the implementation of the previously mentioned model of manual technical observation is carried out on the dam “Iron Gate 2”. Figure 3 shows both the first and the second phase of the implementation of the improved model of the system of MTM (implemented solution on the dam “Iron Gate 1”). At the measuring point next to each device, a passive RFID tag is installed. Each tag has its own unique ID. The connection between the measuring point and the tag is written in the DB. Since the measuring device does not have BT, an external BT module is installed next to the device, which is connected to the measuring device. The module and measuring device communicate via an RS485 port.

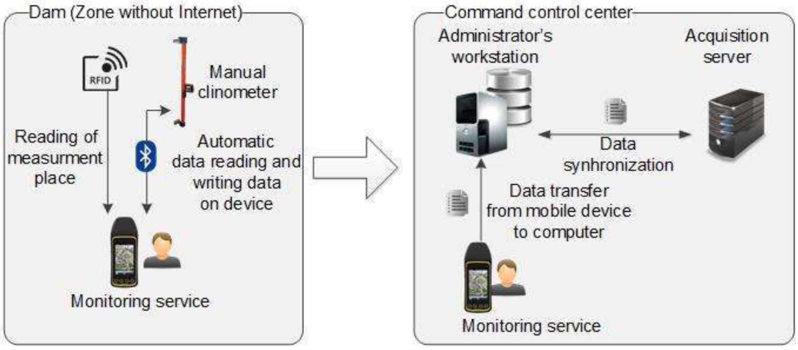

Figure 3: Model of the improved dam monitoring system

After reading the tag, the RFID reader (PDA) [L.-C. Wang 2008] starts an application with a mask (table) for data input. In the application, by clicking the button, the user has submitted a request for data transfer from a recognized measuring device. After that, a Bluetooth port opens and data transfer starts from a measuring device to a PDA. After the termination of the data transfer, the entered values are temporarily stored in the RFID reader memory. The procedure for downloading data from a measuring device is shown in Figure 4.

After monitoring all measuring devices, the user goes to the Command Control Centre (CCC) where he/she connects the RFID reader with the administrator workstation (cable or Wi-Fi). Windows Mobile Device Centre [‘Microsoft Windows Mobile Device Center 6.1’ n.d.] enables the user to install device drivers and transfers data from the RFID reader to a computer. After transferring data, synchronization between the computer and the acquisition server is performed. At this stage of implementation, this project is only for Windows devices, which can be cited as a disadvantage of this project.

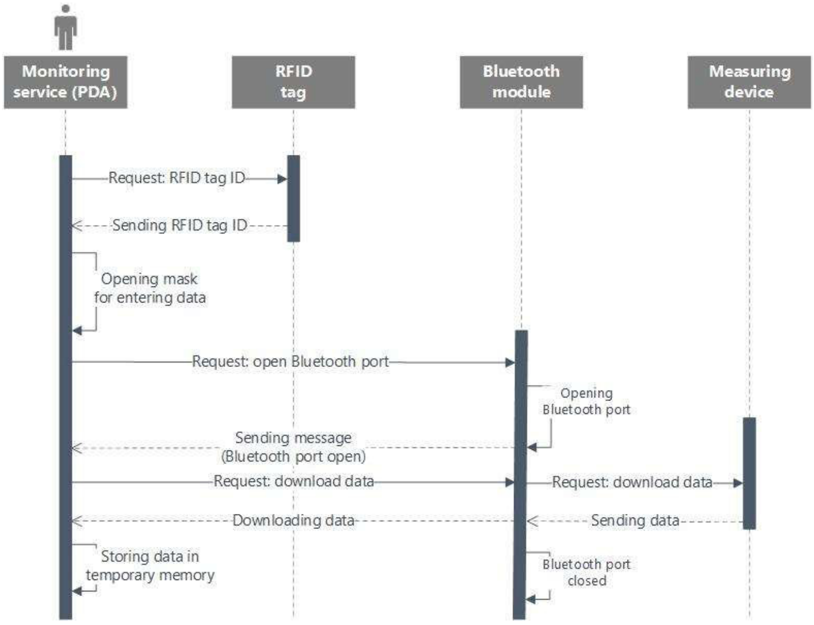

Figure 4: Time sequence diagram

Integration of the first and the second phase eliminates the possibility of a human error, making the error in data reading minimal. The observer on the measuring point no longer writes data on paper. Also, the observer in CCC does not overwrite the recorded data to the computer. This solution makes the data more authentic, and the process of MTM is faster. It can be said that there is no space for human factor error. With this upgrade, data becomes much more reliable, as the only error that can occur is a device malfunction. This type of error and the elimination of incorrect data will be explained in detail in the following chapters.

3.3 Further Improvements of RFID Model

The third phase of the process of improving the MTM will be concentrated on improving the assessment of the quality of the measured data. In the third phase, the installation of Beacons is planned. Beacons are active RFID tags that can read various environmental parameters. Environmental parameters such as air temperature, humidity, light level, etc. can greatly affect the increase in the human factor's error. Also, in addition to the environmental factors, Beacons would measure the time spent on a certain measuring device, as some measuring devices require that after connecting the device reader it is necessary to wait a while for the device to stabilize and start measuring the parameters of the dam. All measured values, i.e. metadata would be stored in the DB. The obtained measured values would pass through certain formulas and provide an assessment of the quality of the data (the measure of its usefulness). In the further development, there is also the possibility of employing AI in dam management for analyzing and evaluating data quality and using automatic machine learning (AutoML) [‘AutoML’ n.d.].

4 Evaluation of RFID Model Technology in Technical Monitoring of Dams

The evaluation of the model includes two main parts: testing the success of RFID technology implementation and employee surveys. Checking the success of RFID technology implementation is reflected in the analysis of the series of measured data. The series which are analyzed are the ones before and after the installation of RFID technology and are given a quality score. A comparative analysis of the number of errors determines whether the improved model is more efficient than the previous one. Employee surveys are carried out using specialized survey models, which enable a better understanding of the impact of RFID technologies on the work of employees.

4.1 Quality Control of Technical data Measurement

The Quality Control System for Measured Technical Data (QCMTD) is an important part of the overall Dam Management Information System (DMIS). QCMTD directly contributes to the reliability of the performed analyses based on the measured data. The QCMTD consists of two parts: validation of data and control of the technical quality of the measured technical data (Figure 5). Some of the basic assumptions of the QCMTD system are:

- Each data consists of the measured value and associated attributes including measurement, measurement point, and measuring device,
- After the implementation of QCMTD data are assigned the quality score (0-1),
- The QCMTD system is formed for each series individually and consists of the so-called formulas, which consist of a set of schemes,
- QCMTD methods represent methods for checking one aspect of the quality of data and are formed based on the experience,
- Each scheme must have at least one method that must be performed,
- The final assessment is formed by the aggregation of the estimates.

QCMTD process can be run both online and off-line automatically or by an expert. Quality control of measured technical data is carried out in two ways: Evaluation of data from acquisition (Online quality control of measured technical data) and Evaluation of archive data (Offline quality control of measured technical data).

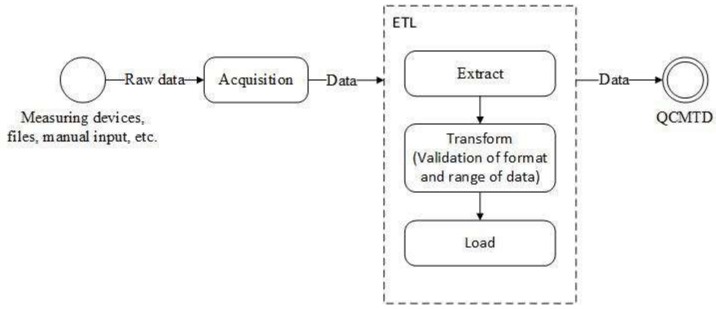

Figure 5: Validation of Data System
['Intégration projets data - Comparatif des outils ETL' 2018]

Online quality control of measured technical data is done after the data acquisition process (and the validation system) and before the data is entered in central DB with all associated attributes. Unlike online evaluation, when evaluating archival data, all other archival data are available, regardless of whether they are time-positioned before or after the observed measurement. This fact greatly enhances the possibilities of data quality assessment because data can be compared with one or more measurements, both from the past and the future, making the assessment more reliable. Another advantage of offline rating is the fact that there is no imperative for rapid data analysis during their arrival because a longer period is at disposal. Therefore, the set of methods for assessing the quality that can be applied is not limited to time-efficient methods that work in real-time, but it is also possible to use more demanding methods, which are carried out in a longer but reasonable period.

4.2 Data Quality Assessment

Measurement of deformations of high structures, dams, and hydroelectric power plants is done to ensure possible sudden and unpredictable phenomena (defects), aiming to protect the environment and the downstream area from damage and disasters. The collection of necessary data is carried out through geodetic-technical monitoring of the most precise geodetic measurements, for rational maintenance of large structures [Alba et al. 2008].

Geodetic displacement measurements include all measurements for determining the change of the shape of the structure or ground under the influence of external or internal forces. The object is idealized by a certain number of points, where the position is determined in relation to the reference or basic geodetic base outside the area of possible shifts [Moore 1992].

At the "Iron Gate 1" dam, RFID and BT were applied to three types of measuring devices: clinometers, deformeters, and dilatometers. The results of the dilatometer are also presented in the paper. The collected data must be processed by an expert to detect and mark the wrong data, remove them and replace them with interpolated data. In general, the first step in detecting the wrong, anomaly data is called the data quality assessment or data validation [Branisavljević, Prodanović and Pavlović 2010]. In the following examples, the data were evaluated manually (offline) based on historical data, observing a period of 10 years and more. The observed period in which data were analyzed and compared was for a period of 12 months (from July 1), as RFID and BT were installed in July 2018. Figure 6 shows the data measured by dilatometer D-31 of the Iron Gate 1 dam on the coupling-opening Jan-2010 to July-2019. Dilatometers measure the displacement of the couplings on the dam in three directions: up-and-down, back-and-forward and left-right.

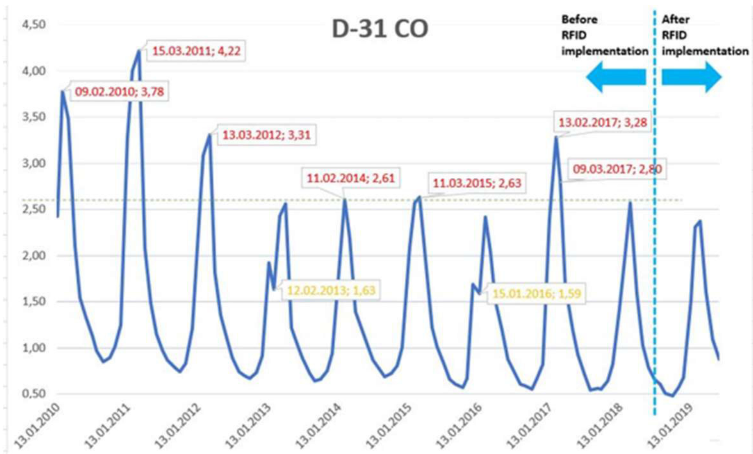

Figure 6: Historical data of dilatometer D-31 before and after implementation of the new model of monitoring

There are three types of data entering the DB: correct, acceptable and invalid data. Correct data are the ones that enter the predicted scope of measurement of a device. Acceptable data enter the predicted range of measurement of a device, with minor errors in reading or recording values (e.g. number permutation), so that the diagram has a slight leap or drop. Invalid or unacceptable data emerge outside the predicted measurement range (for example, a malfunctioning device). Invalid data will not be used in the analysis. Figure 6 shows the period before and after the implementation of RFID and BT. After the implementation of RFID and BT, there was no data registered as a minor error. It is also possible to see that the possibility of human error is minimized.

Table 5 shows the total number of measurements of 6 dilatometers grouped by year. Also, the table shows the number and percentage of data with a minor error.

$$Error\ rate = \frac{Number\ of\ minor\ errors}{Number\ of\ measurments\ for\ 6\ devices} * 100$$

Period of 12 months (from July 1)				
Device	***Period of measuring***	***Measurements for 6 devices***	***Minor errors***	***Error rate (%)***
Dilatometer	***2014 - 2015***	*214*	*8*	*3.7*
	2015 - 2016	*208*	*10*	*4.8*
	2016 - 2017	*210*	*9*	*4.3*
	2017 - 2018	*214*	*6*	*2.8*
	2018 - 2019	*214*	*1*	*0.47*

Table 5: Percentage of accuracy

Table 5 depicts that after the use of RFID and BT, the percentage of human errors (minor errors) has been significantly reduced. In the observed period from 2014 to 2018, the error rate was around 0.04, while from 2018, with the implementation of RFID and BT, this percentage was reduced to almost 0. The use of RFID and BT has reduced the possibility of human error to a low rate, as the process of data reading and recording has been improved.

4.3 Technology Acceptance Model of RFID Technology in Dam Monitoring

The survey was conducted on employees who use RFID and BT on daily basis. The survey results are evidence of satisfied workers and successful implementation of technology within the MTM. For the model to be accepted, it must be accepted by professionals who perform the measurements - technicians. A modified version of Technology Acceptance Model 2 (TAM2) will be used for this study, to structure the research process and to help enhance the understanding of the acceptance and use of RFID and BT in monitoring [Cowen 2009]. The modified TAM2 model uses technological aspects but excludes sociological aspects. Model measures 6 different aspects of the potential use of new technologically advanced products[Davis 1989]: Perceived usefulness (PU), Perceived ease of use (PEOU), Perceived behavioral control (PBC), Perceived voluntariness (PV), Scale for behavioral intention (PBI). Data collection was conducted through a survey containing all 5 aspects. This is a specific system used by a small number of experts (10 emp.). The survey was conducted on all professionals (experts) involved in the collection and processing of data. The survey was filled up by people from the dam monitoring department (2 emp.), data processing (3 emp.) and data analysis department (2 emp.), as well as a department for predicting the behavior of the dam (2 emp.). The dam monitoring department and the department for predicting the behavior of dam are located in the city of Kladovo, the data processing department is located in the city of Kragujevac and the data analysis department is located in the city of Belgrade.

Table 6 presents the average values and the standard deviation for each question of the survey. It is also possible to see the average values and standard deviations for each aspect of the survey. The average rating of most questions exceeds grade 4, which shows that RFID and BT users are satisfied with the improvement of the monitoring process on the dam.

Aspect	Question	Avg	SDev	Aspect Avg	Aspect dev
Perceived Usefulness	RFID and BT enable me to accomplish tasks more quickly	4.800	0.422	4.350	0.685
	RFID and BT have improved my quality of work.	4.400	0.516		
	RFID and BT make it easier to do my job.	4.500	0.527		
	RFID and BT have improved my productivity.	4.300	0.675		
	RFID and BT give me greater control over my job.	3.900	0.994		
	RFID and BT enhance my effectiveness on the job.	4.200	0.632		
Perceived Ease of Use	My interaction with RFID and BT has been clear and understandable.	4.400	0.699	4.283	0.804
	Overall, RFID and BT are easy to use.	4.500	0.527		
	Learning to operate RFID and BT were easy for me.	4.300	0.675		
	I rarely become confused when I use RFID and BT.	3.900	1.101		
	I rarely make errors when using RFID and BT.	4.500	0.707		
	I am rarely frustrated when using RFID and BT.	4.100	0.994		
Perceived Behavioral Control	I can confidently use RFID and BT.	4.700	0.483	4.460	0.646
	I have the knowledge to use RFID and BT.	4.500	0.527		
	I have the resources to use RFID and BT.	4.700	0.483		
	I can use RFID and BT.	4.400	0.699		
	I have control over using RFID and BT.	4.000	0.816		
Perceived Voluntariness	My use of RFID and BT is voluntary.	3.900	0.994	3.209	1.163
	My supervisor requires me to use RFID and BT.	2.900	0.994		
	Although it might be helpful, using RFID and BT is not compulsory in my job.	3.400	1.350		
Perceived Behavioral Intention	I intend to continue using RFID and BT to perform my job.	4.300	0.675	4.050	0.887
	I intend to frequently use RFID and BT to perform my job.	3.800	1.033		

Table 6: TAM of RFID technology in manual monitoring of the dam

Table 7 contains open-ended questions and employee's answers.

Question	Answers
Q1: Why RFID and BT make your business easier?	Most of the responses the employees have made to this question are that RFID and BT reduce the possibility of error. A1.1: It reduces the possibility of error, I'm less likely to make a mistake. A1.2: Less possibility for error. A1.3: The use of RFID and BT make it easy to carry out everyday tasks because it speeds up the activity by automating the identification of measuring points and reduces the possibility of error. A1.4: It makes it easier to read and enter data. A1.5: Control error measurement. It's easier to collect data.
Q2: What would make your work easier?	Most of the responses the employees have made to this question are that automation can make work easier. A2.1: There are more options for automation, e.g. automatic reading of a measuring device, etc. A2.2: Implementation of RFID and BT to more measuring points.
Q3: What should be improved to make data collection more efficient?	According to employee responses, higher automation is something that can improve data collection. A3.1: Higher automation. A3.2: Automatic identification of measuring device, automatic reading, etc. A3.3: It would be necessary to digitally collect data and reduce the occurrence of a measurement error.

Table 7: Suggestions and remarks from open-ended questions

5 Discussion

Dams are significantly sensitive to minimal shifts [Van Tien et al. 2018], so the minimization of human error in observation has a great impact on hazardous events (undermining the stability of the dam). Some of the dams where the failure happened are Way Ela [Pramono Yakti et al. 2019], Zhouqu [Cui, Zhou, Zhu and Zhang 2013], SE Brazil [Agurto - Detzel et al. 2016], etc. In [Mallakpour, AghaKouchak and Sadegh 2019] authors describe the situation in California, where most dams are older than 50 years old. The results show that the probability of failure is likely to increase for most dams in California by 2100. Therefore, it is necessary to constantly improve the observation system and increase the safety of dams. In Serbia, improving the security of the dams Iron Gate I and II is of great importance due to many settlements located in the lower Danube basin. Besides, Iron Gate I has a great significance for the energy system of Serbia and the region with an annual production of electric energy of 6.4 GWh ['HE Djerdap - Ispunjen godišnji plan proizvodnje' n.d.].

The key contribution of this paper is a detailed description of the application of RFID and BT in the process of MTM of dams. The authors conducted a survey among employees, who are using RFID and BT, using the TAM method. Also, data analysis was performed in order to compare errors in data monitoring before and after the implementation of RFID and BT. The results show that the use of RFID and BT in the process of MTM improves the overall process of monitoring, the data becomes more reliable, the process of manual data collection is more rapid, and employees are more satisfied because they spend less time in the body of the dam and feel less pressured not to make a mistake. With the use of RFID and BT, data becomes more credible, since the percentage of the error caused by the human factor is reduced to a low rate (Table 5). By reducing the number of errors, the Damage Prediction Model will give a more accurate picture of the state of the dam [Stojanovic, Milivojevic, Ivanovic, Milivojevic and Divac 2013].

The results of the survey show that the use of RFID and BT speeds up the process of MTM. By accelerating the process of MTM, employees spend less time in the body of the dam, i.e. in the rooms with moisture and poor lighting. Also, the use of RFID and BT reduces pressure on employees to make a mistake in reading or writing data and solves the problem of illumination and misreading of measurements, as this is done automatically. All the above-mentioned impacts the working conditions for employees and increases their satisfaction. The idea of using RFID and BT can be carried out at any other facility where MTM is done (buildings, bridges, etc.) because the principle of observation is similar. Table 8 provides a list of main implications and practical recommendations for different groups of stakeholders.

The main contribution of the work is reflected in the improvement of the dam monitoring system, using robust and inexpensive RFID technology, which leads to a reduction in the human error factor and directly affects the reliability of the data, resulting in a more realistic state of the dam. The paper brings new value to the existing literature through the original approach. In this paper, it is possible to see an approach to the improvement of dam safety from the technical side, i.e. the use of RFID and BT that provides more reliable data and makes it easier for employees dealing with MTM. This model of MTM using RFID and BT is designed for specific environmental conditions (indoors, moisture, etc.) dictated by high dams. The model has not been tested in conditions such as building or bridge observations, therefore, one of the constraints are different environmental conditions on other types of buildings.

The next phase of the implementation of the improved model of MTM is the improvement of the data quality assessment. An idea about the use of beacons and the collection of environmental data was developed (air humidity, temperature ...), which will be used as input parameters in the data evaluation functions. Formulas with new input parameters will upgrade existing formulas used to assess the quality of measured technical data and provide a better data evaluation. One of the following stages of improving MTM and quality assessment is the use of predictive analytics. Based on the existing examples and historical data, it is possible to create a database with cases of use.

Stakeholders	Implications (research questions)
Practitioners	The use of RFID and BT partially automated and digitized the process of MTM, which speeds up the observation and reduces the probability of human error. All this makes the employee more satisfied because he/she has less stress and ends his/her tasks faster. (RQ4) The evaluation of the model proves that RFID and BT could be used in the monitoring process when a data gathering and analysis expert is required.
Owners of dams	The use of RFID and BT improves the dam monitoring process, minimizing human error, which makes data more reliable. More reliable data ensures better dam maintenance. (RQ2) It is recommended to use as many passive RFID tags as possible, due to unification and financial constraints [Daniel Hunt et al. 2007], as well as due to effective replacement in the case of failure.
Government	Reliable data enables the normal maintenance of the dam, which affects the safety of the facility, which is directly related to the protection of the ecosystem located near the dam. (RQ1) The application of RFID and BT has many good effects e.g. preserving the social environment, reducing the costs of projects funded by governments, automating processes, etc. [Pala and Nihat 2008]. Research results point out that RFID and BT should be harnessed to a big extent when designing and implementing huge IT ecosystems or infrastructure projects.
Researchers	Time spent next to the device, lighting, humidity, temperature, etc. can affect the perception of employees. Such data can be collected using Beacons, which can be further used for the quality control of technical data. More reliable data collected by RFID and BT used in modeling dams makes it possible to give a more accurate picture of the dam state. The collected measurement data can also be used to establish a device reliability DB. (RQ3) Researchers should harness RFID and BT to a big extent and enable as much data to be collected as IoT evolves['The Growth in Connected IoT Devices' 2019]. Further, additional efforts should be invested in upgrading existing models with pervasive technologies (RFID, Beacons, AI, etc.)

Table 8: Key implications for main stakeholder groups

6 Concluding Remarks

This paper presents how the use of RFID and BT in manual dam monitoring helps to minimize the human error factor. This study was primarily designed with the aim of making a strong impact on practice. The results aim at helping stakeholders to the benefits of using RFID and BT. Specifically, practitioners involved in manual technical observation can benefit from the presented results. The research proves that it is possible to upgrade the existing monitoring system and obtain more quality data with minimal investment. The improved monitoring model was applied within the dam "Iron Gate 1", and since it has shown visible improvements, preparations are underway for implementation within the dam "Iron Gate 2".

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