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Modelling of an Accurate Positioning System Using RFID Technology for Enhanced Railway Track Maintenance

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Abstract

This paper focuses on modelling a new positioning system that aims to locate the Track Recording Vehicle (TRV), in reference to the locations of the switch and crossing (S&C) using RFID technology. The paper details the models of the three subsystems that constitute the whole proposed positioning system, developed using the Systems Modelling Language (SysML™), and their internal and external interactions as part of the railway network. The idea is to install two RFID tags for each switching and crossing node, one on the switch-toe sleeper and the second will be on the crossing-nose sleeper. Whereas the RFID reader is expected to be mounted underneath the TRV vehicle. Thus, the key features of the S&C, the switch toe and crossing nose, will be considered as a definitive reference point for the inspection vehicle's position. When the TRV passes over an S&C, the positioning system will provide information about the S&C's ID, which is stored inside the RFID tags and will indicate the S&C's GPS coordinates. The new methodology is expected to be adopted by a digital asset management system that locates faulty infrastructure, especially the S&C units, more accurately which allows for enhanced maintenance practice.

Keywords: Railway; track switch and crossing; RFID technology, positioning system.

1 Introduction

The work in this paper aims to introduce a graphical model for a new positioning system in order to know accurately the position of vehicles equipped with monitoring equipment, such as the Track Recording Vehicle (TRV), in reference to the locations of the switch and crossing (S&C). It is anticipated that high position accuracy might be achieved by using a modern wireless identification system such as the Radio Frequency Identification (RFID) technology. Currently, a few positioning systems are being used to localise a vehicle position along with the railway network, but with limited precision [1]. Also, previous research including In2Track [2], In2Smart [3] and TfL-London Underground AIT project [4] suggested that RFID technology can be a suitable candidate for train positioning. But, none of these suggestions have been developed further in any research work. Thus, the purpose of this work is to develop and demonstrate the feasibility of having an accurate RFID-based positioning system for a vehicle such as the TRV in relation to the S&C's location along with the network. The key features of the S&C system, the toe and nose, will be considered as a definitive reference point for the vehicle position. This will be achieved by testing and validating the possibility of using the most suitable RFID technology to better position the TRV when it is performing its different tasks including the ones related to inspection.

The modelling work presented in this paper is an initial step to develop a solution that is expected to enhance the positioning precision of the TRV. This paper details the whole system model, developed using the Systems Modelling Language (SysML™)[5], and its internal and external interactions as part of a wider system view. The SysML tool is a purpose graphical modelling language for specifying, analysing, designing, and verifying complex systems that may include hardware, software, information, personnel, and procedures. This work is the following of an early stage of research that has focussed on identifying the specification and requirements of the proposed positioning system. Those requirements have been identified in a technical stakeholder workshop where six experts from different disciplines in Network Rail (NR) have participated [6]. All participants were in the position of Principal Engineer and from six different departments within NR, including Intelligent Infrastructure, Safety Technical Engineering Directorate, Mobile Monitoring, Data Analysis, Technical Authority, and Asset Enhancement.

2 Methods

The S&C's toe and nose will be considered as a definitive reference point for the vehicle position. Thus, the idea is to install two RFID-tags, one on the switch and the second one will be on the crossing, with an RFID-reader that will be installed underneath the vehicle. When the TRV passes over an S&C, the reader will communicate with the tag(s) and read the S&C-ID that refers to its position within the rail network. Three subsystems can present the constitution of the positioning system (Figure 1); the On-board Subsystem, the Trackside RFID tags, and the Asset

Management Subsystem (AMS). The on-board subsystem refers to the equipment to be mounted on the TRV which consists of the RFID-reader, a controller, and a wireless module. This data communication platform is responsible for transferring the data recorded in the trackside RFID-tags subsystem to the AMS where the GPS coordinates, for each S&C, will be stored in the database. It will use Wifi, GSM or LTE technology, so, that the S&C-ID can be uploaded to the database.

The AMS, which consists of the database and the TRV position page, will act as a Digital Twin for the deployed assets. The database will hold information regarding each S&C-ID and its GPS coordinates. Consequently, the TRV position page will represent the previous TRV inspection journeys besides a live map view when the TRV is in operation.

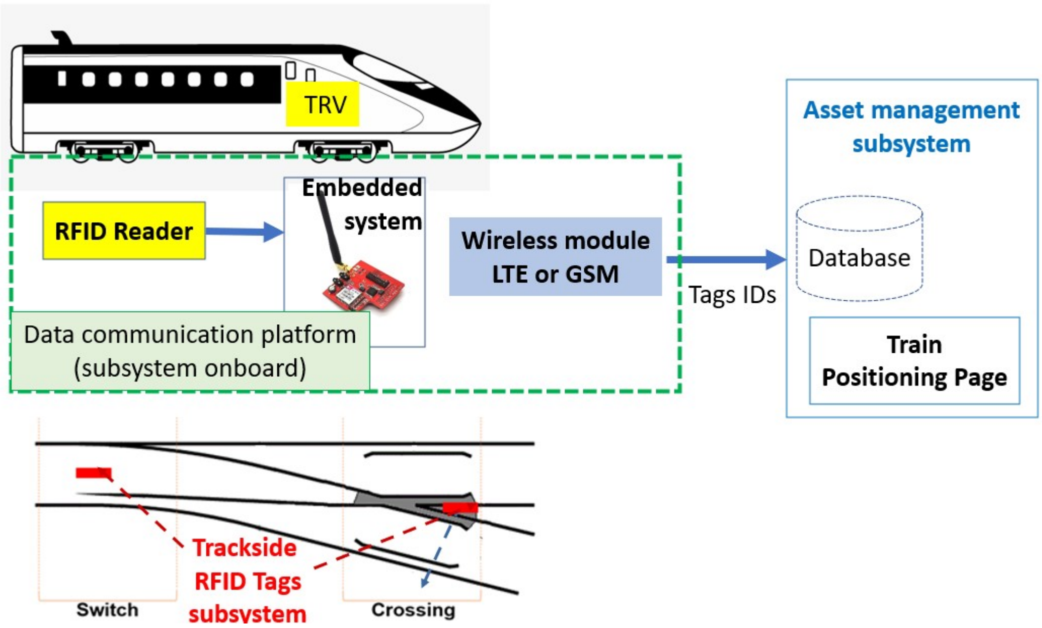


Figure 1: Layout of the proposed positioning system based on RFID technology.

The graphical model for the complete positioning system has been developed and presented mainly by two categories of diagrams that describe the system Structure and Behaviour as shown in Figure 2.

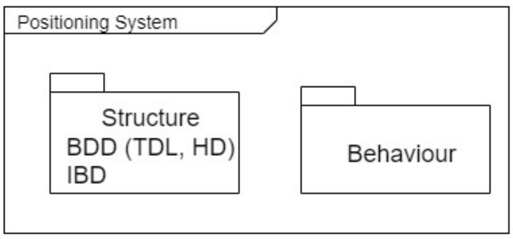


Figure 2: Package diagram for modelling of the positioning system.

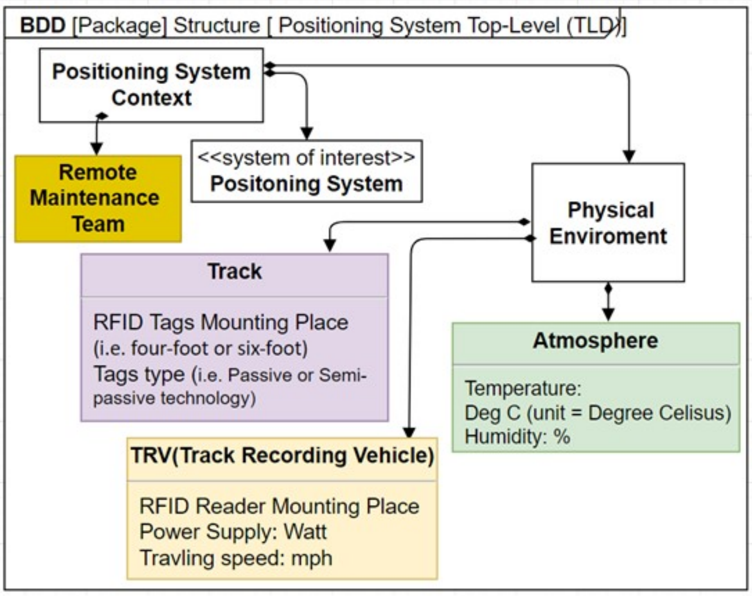
The system Structure has been represented using two diagrams: the Block Definition Diagram (BDD) and the Internal Block Diagram (IBD). In the model proposed, two BDD diagrams are represented; a Top-Level Diagram (TLD) and a hierarchy diagram (HD). Each diagram will present, in the next section, the different aspects of the positioning system describing, the dataflow and interactions between the various subsystem components. This approach provides a comprehensive view of the system model and also shows the possibility of integrating the positioning system with the latest development of a digital twin to provide a comprehensive representation of the deployed assets.

3 Results

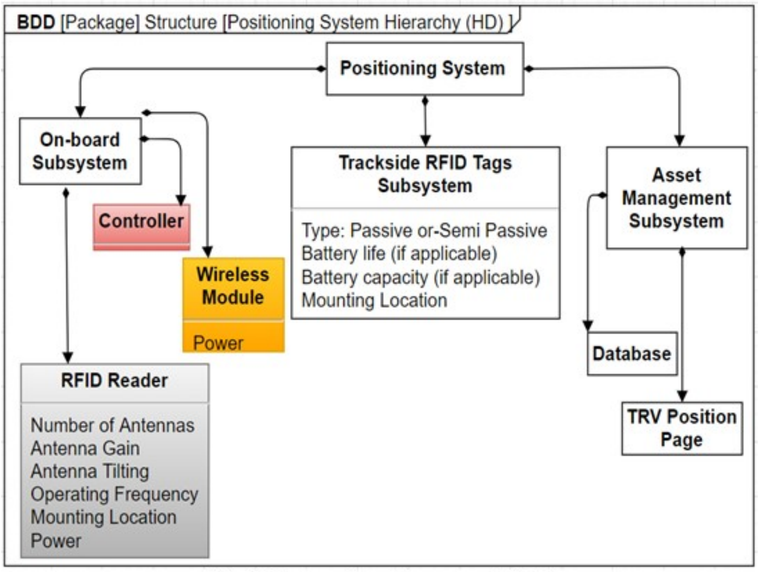
The TLD diagram, Figure 3(a), describes the context for the positioning system as the system of interest and its physical environment which consists of the Track, the TRV, and the Atmosphere. The TRV is key to the positioning system as this vehicle will host the RFID reader and supply the needed power for it to operate. Other TRV attributes such as its operational speed can also impact the performance of the mounted reader. The track infrastructure determines the optimal locations of the two RFID-tags to be mounted for each S&C. Furthermore, the operating weather conditions such as temperature and humidity could impact the whole system performance.

Figure 3(b) presents the three subsystems and their connections; the RFID reader has a set of different attributes related to its antennas (number, gain, tilting, transmitting power, and the operating frequency). The controller can be either an Arduino or a Raspberry-Pi that stores the S&C-ID and broadcasts it to the wireless module that will transmit it to the remote ASM. The attributes associated with trackside RFID tags are the type, the battery capacity & life, and the size of internal memory.

The second diagram in the system "Structure" is the IBD (Figure 4). IBD demonstrates the internal and external interconnection and the dataflow between the positioning system itself and its environment. The notable in IBD is that the wireless module will transfer the S&C-ID to the remote database to fill the TRV Position Page. This data will be accessible to the maintenance teams through the defined interfaces.



(a): Top-level overview, TLD diagram.



(b): Hierarchy diagram (HD)

Figure 3: Two diagrams represent the Block Definition Diagram (BDD) of the system model

The second main container of the whole system's model is the "Behaviour" block. Figure 5 shows this activity diagram in terms of the order in which actions are executed based on the availability of their inputs, outputs, and control. The process is divided into five simple steps, the first is for the RFID reader to read the tag-ID, while the 2^{nd} & 3^{rd} steps are for the controller and integrated wireless module to transmit the ID recorded to a database. Consequently, in the 4^{th} & 5^{th} steps, this database will use the received data to find out the corresponding S&C GPS coordinates which are needed to build the TRV position page.

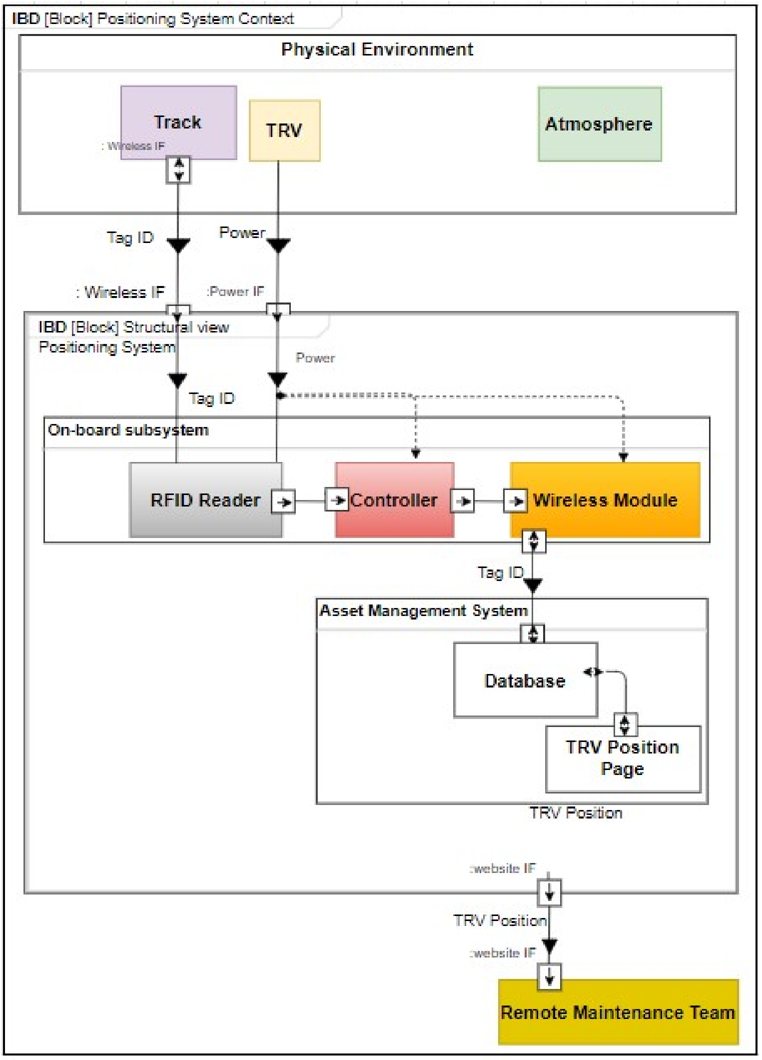


Figure 4: Internal Block Diagram (IBD) and its interaction with the physical environment

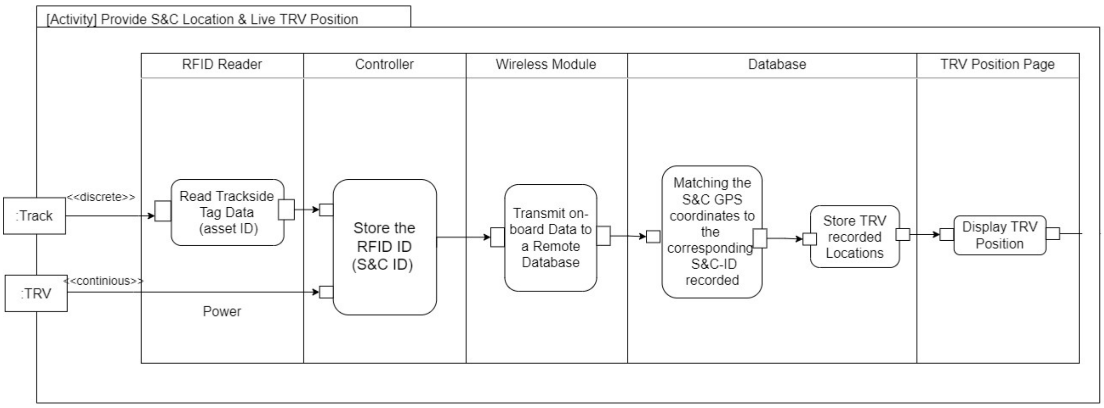


Figure 5: Activity diagram for S&C location and live TRV position

4 Conclusions and Contributions

In this paper, the positioning system model has been developed using the Systems Modelling Language (SysML). The model has been used to assess the operation of the whole system with a specific focus on data feeds between the RFID tag and the reader. Also, the model has shown the interaction between the different three subsystems of the whole proposed RFID-based positioning system.

The main focus of this work is to identify the position of the TRV on the track in reference to the S&C asset. This will be achieved using an RFID tag(s), which will ideally be harmonised across all Network Rail databases to use such tags as the definitive position identifier for the S&C units. The output of the work will help also to identify more accurately faults within S&C. This will be done by pinpointing the exact location of the geometry defect, measured by the TRV, in relation to key features of the S&C, the toe or nose. This will reveal the accurate position of the faulty S&C in the output maintenance report of the TRV. Thus, improvement in the track geometry defect reporting will help to direct the maintenance staff to the exact location on S&C that requires maintenance. Ultimately this ought to reduce disruption on the rail network due to S&C failure.

To date, the positioning system requirement and specifications have been captured and identified. The modelling work has been developed and presented in this paper. The lab demonstrator of the proposed system is currently being developed and the intention is to test it on a full-scale railway. Two types of RFID technologies, passive and semi-passive RFID, are to be tested and compared for further evaluation in terms of system performance and repeatability. Also, the work will further develop the best approach that would deliver a comprehensive Digital Twin representation of the deployed assets. It is expected to integrate the current TRV GPS positioning system with this proposed new positioning system based on RFID technology. The expected high accurate location system is under development to improve the reliability of the overall railway inspection/maintenance system and in turn, reduce the delay on the rail network due to inaccurate positioning of the defect on the rail section.

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