A RAILWAY COLLISION AVOIDANCE SYSTEM EXPLOITING AD-HOC INTER-VEHICLE COMMUNICATIONS AND GALILEO

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ABSTRACT

The introduction of the European global navigation satellite system GALILEO allows also for a modernization of automatic train control technology. This is advisable because of the still enormous amount of collisions between trains or other kinds of obstacles (construction vehicles, construction workers, pedestrians), even if comprehensive and complex technology is extensively deployed in the infrastructure which should help to avoid such collisions. Experiences from the aeronautical *Traffic Alert and Collision Avoidance System (TCAS)* as well as the maritime *Automatic Identification System (AIS)* have shown that the probability of collisions can be significantly reduced with collision avoidance support systems, which do hardly require infrastructure components. In this article, we introduce our "RCAS" approach consisting only of mobile ad-hoc components, i.e. without the necessity of extensions of the railway infrastructure. Each train determines its position, direction and speed using GALILEO and broadcasts this information, complemented with other important information such as dangerous goods classifications in the region of its current location. This information can be received and evaluated by other trains, which may – if a potential collision is detected – lead to traffic alerts and resolution advisories up to direct interventions (usually applying the brakes).

STATE OF THE ART IN TRAIN CONTROL

Today the safety of railway operation is mainly ensured by the interlocking which sets and locks the train route. All track elements are set and locked in the correct position, before signals are set to green. The trains are equipped with the onboard part of the train control system which triggers automatically a braking if the train passes a signal at danger. The safety of railway operation depends on the correct operation of the interlocking and the train control system. Human errors [2] lead to most of the accidents [6]. Nevertheless the safety technology has some important drawbacks:

- Trains which are not equipped with onboard train control systems may pass signals without problems. Typical trains of this kind are construction trains, foreign trains or groups of wagons.
- A malfunction in the railway control centre or in the onboard safety system can prevent monitoring entirely.

- Major parts of the European railway network are not equipped with railway control and signalling technology due to the low traffic density in these areas. Trains which never leave these areas or most often neither equipped with train control systems.
- Deployment of signalling infrastructure is expensive and inflexible. The position of the signals, together with the train safety components which initiate the brakes in case of a signal passed at danger is fixed. Temporal deployment of signalling infrastructure is rarely done because of the efforts.

Due to this reasons rail vehicles collide with each other (Trains, work trains, road rail vehicles, etc.). Another typical type of accident is collisions with road vehicles or persons on level crossings. The reason is either a malfunction of the control system or misbehaviour of the person or driver, e.g. a driver of a car drives around closed half barriers.

STATE OF THE RESEARCH IN TRAIN CONTROL AND RAILWAY SATELLITE POSITIONING

A remarkable number of research projects have been performed in the field of satellite positioning used for train control [4][10][13] which can be used as input for RCAS. In the project RUNE (Rail User Navigation Equipment) funded by the European Space Agency (ESA) has a suitable set of equipment been developed. It has been demonstrated that a satellite based system can be used to localise a train.

The project LOCOPROL (Low Cost satellite based train location system for signalling and train protection for low density lines – see http://www.locoprol.org) has been funded by the European Commission. This project used US GPS (Global Positioning System) and its Russian pendant GLONASS as well as EGNOS (European GNSS Overlay System) to reach a safe positioning of trains. LOCOPROL and RUNE like some others base on the idea to capture a position on the train and to transmit it to a trackside system. RCAS uses the basic proof-of-technology which has been given in the mentioned projects, but integrates it in a different application. The communication concept does not use the path via the infrastructure. The trains are informing each other directly about their position and other parameters as will be described in the following sections.

The GALILEO programme is Europe’s initiative to develop a civil global navigation satellite system that provides highly accurate and reliable positioning, navigation and timing services. GALILEO will provide instantaneous positioning services at the metre level as a result of improved orbits, better clocks, dual frequency and enhanced navigation algorithms as well as integrity information. For safety of life applications, local elements can be integrated to provide more accurate positioning, communication and/or information services. For example, GALILEO Local Elements will be developed and adapted to meet specific requirements in rail transportation.

APPROACH

The basic idea of the Railway Collision Avoidance System (RCAS) is – similar to the airborne TCAS/ADS-B [1] and the maritime AIS [8,12] – to broadcast information about position, movement vector and others form the moving units as well as from specific infrastructure elements. Basically the trains and rail vehicles determine their position and movement vector and broadcast this information to all other trains in the area which is only limited by the range of the RCAS-sender. Each moving unit on the rails like regular trains, work trains, road rail vehicles, etc. can be equipped with RCAS. The RCAS-units receive all broadcasted information and compare position and movement vector with the own one to detect possible collisions. Fig. 1 shows the basic interaction of the RCAS components.

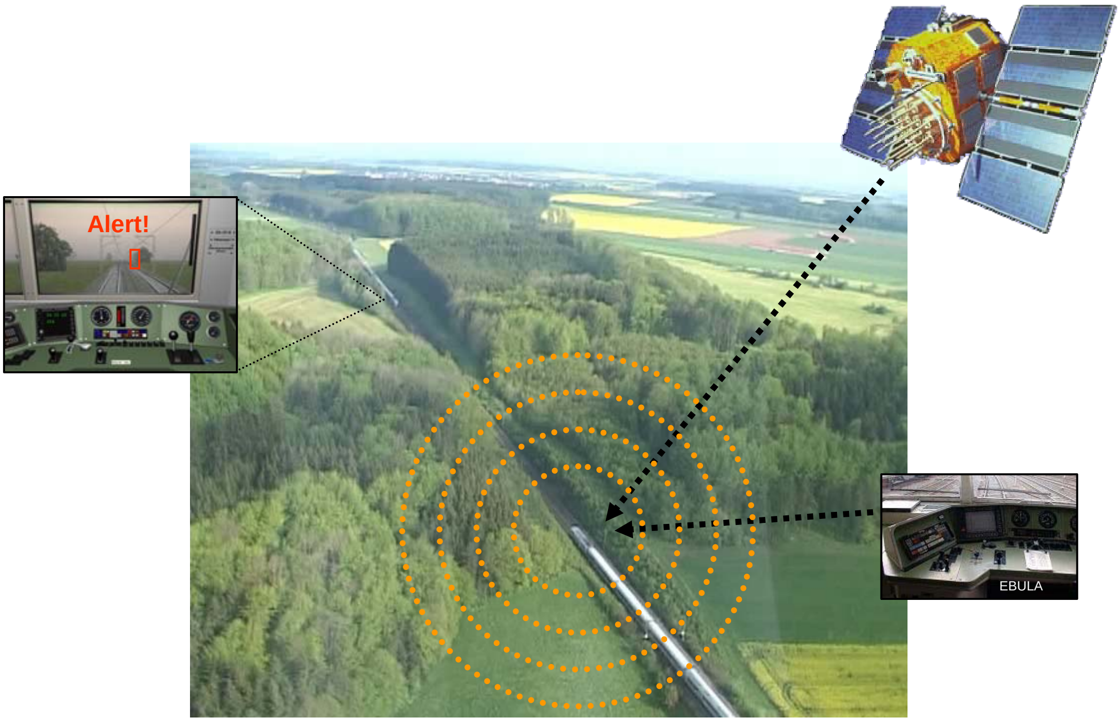

Fig. 1: Interaction of the components of RCAS

Two major aspects are different form TCAS/ADS-B and the maritime AIS: the mechanical guidance by the rails reduces the options for possible reactions of the driver: The driver can brake the train in one dimension[1]. The set and lock of train route is done by the signaller and so he has to get the information about possible collisions, too.

Another differing aspect is that movement vectors of rail vehicles may pass extremely close or even point to each other e. g. two trainsets performing a joining procedure or banking are two kinds of “allowed collisions”. Overhauling while in motion and passing of trains is allowed as well as two high speed trains passing each other with a relative speed difference of 600 km/h at 4 m lateral distance. Because of the extremely deterministic movement behaviour of rail vehicles are all these situations can be identified and classified, so that RCAS can send a warning to the driver or the signaller. If a collision cannot be avoided any more the driver can start braking end – at least – reduce the consequences of the collision. Other resolution possibilities can be chosen by the signaller in the interlocking, which will be discussed later in section 0.

The position can be determined in particular using the global satellite navigation system GALILEO [7], which can be extended by local elements to ensure coverage in areas without direct satellite visibility (e.g. in tunnels). The accuracy can be further improved by using a differential overlay-system (typically down to cm). A precision on the cm level is for instance required for a reliable track determination. While passing trackside installed Balises[2], another source of data for the identification of the current track is available which can be used to increase the safety level.

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[1] This dimension follows the track and is so no Cartesian co-ordinate.

[2] A *Balise* is a passive transponder which is activated during the passing of the train and sends a telegram to the receiver on board of the train [9]. Two types are in use: *Fix data Balises*, which transmits one predefined telegram and *transparent* or *switchable Balises*, which can be connected to a signal source and transmit different telegrams according to the incoming signal. Balises are used to transmit topological location references.

The main challenge of RCAS is the evaluation of the trajectories of the vehicles. It is quite normal that the movement vectors of trains are direct in opposite (e.g. coupling) respectively almost in opposite (e.g. passing trains on parallel tracks). This is a distinctive factor compared to TCAS/ADS-B, where the air traffic control has the responsibility to separate aircrafts in three dimensions.

Track identification of the traffic in the vicinity of a train is done within the RCAS receiver by matching the precise positioning information transmitted by the RCAS senders on a track map. Some topological information like a list of expected Balises are available on trains which are equipped with ETCS[3]. The correctness of the matched tracks can be verified by further evaluating the track IDs as long as these are contained in the messages of the RCAS senders (cf. Figure 5).

Beside information about the current position and the speed of a train, an RCAS sender also transmits information about the track in front of the train (topological route). If the train is equipped with an *electronic timetable* (e.g. the German *Ebula*) it knows the entire route in non-safe information. The safe route for the next 5 to 50 km is known at the interlocking and can be sent to the train. If the RCAS receiver of another train has access to the topological vector of the train, it can determine the probability of a conflict by vector superpositioning. If the safe route and the position determined by map matching are not identical, this is already a first indication for a potential conflict and can cause an alert to be transmitted via RCAS to the trains in the vicinity.

RCAS works also without digital trackmaps. In this case the determination of conflicts becomes less reliable with the distance and the relative speed between two trains. This can partially compensated with further sensors. For instance, an inertial platform (gyroscope) integrated into RCAS can be used to determine the cross acceleration which than can be used to estimate curves in the track. Obviously this may help on tracks with lots of curves (e.g. in an alpine region) but does not allow for improved estimates on straight tracks. Digital maps allow for a track-lane selective, i.e. left-right distinguished estimate and thus a much more precise detection of potential collisions, respectively out-of-gauge load conflicts.

APPLICATION AND IMPLEMENTATION EXAMPLES AND CONCEPTS

In this section are some examples of implementations discussed with some details. The basic system is invariant, the different application variants.

COLLISION AND FLANK PROTECTION

The basic concept is the collision detection of two trains: both trains determine their position and movement vector using GNSS. This information is transmitted together with some other information like type of mission and train number by mobile radio to the trains in the area around.

[3] The new European Train Control System (ETCS) in the European Rail Transport Management System (ERTMS) is the basis for the technical interoperability in Europe.

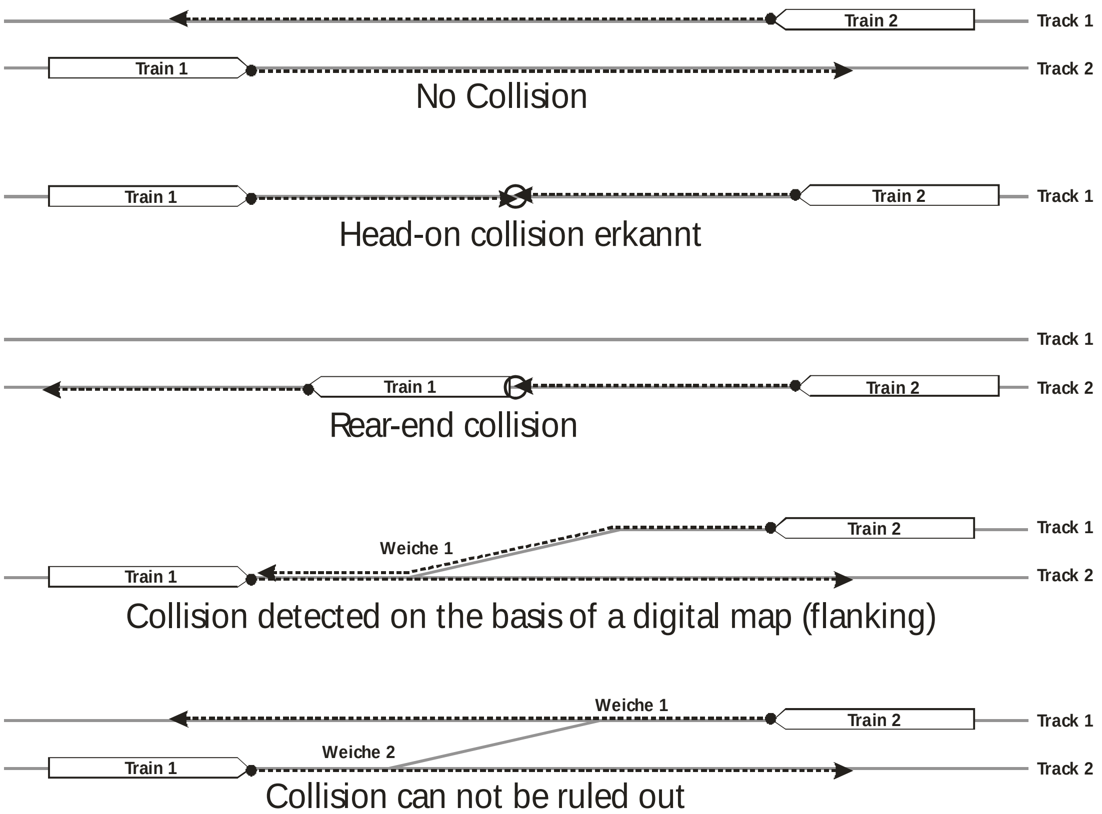

Fig. 2: Collision detection with RCAS

Each receiver compares his own position and vector with all received vectors. As soon as a collision in the four-dimensional space (time and three space dimensions) has been identified a specific reaction is triggered. Depending of the parameters like remaining distance, time to collision and the speed the reaction is selected beginning from different types of warning up to an automatic braking.

TRACK WORK PROTECTION

Track work protection can be performed in several aspects by RCAS: the construction track itself can be transmitted as blocked track and – using the same telegram – the neighbouring track can be transmitted as area with reduced allowed speed. In the opposite direction the working gang can be warned against an approaching train.

LEVEL CROSSINGS (LX)

A significant number of collisions are happening with road vehicles on level crossings with half-barriers. One application of RCAS is the supervision of the danger zone of the level crossing with magnetic detection, RADAR, Video or similar technologies. Instead of the movement vector is he occupation status of the danger zone the criterion which is transmitted.

- LX secured and danger zone free => proceed
- LX secured and danger zone occupied by moving object => Warning
- LX secured and standing object in the danger zone => Danger
- LX not correctly secured

The application of RCAS for level crossings uses the detected status of the road vehicle passing the rails and informs the driver of the train. The detected and transmitted obstacle information triggers a warning or removers the warning if the road vehicle leaves the danger zone.

TRANSPORT WITH OUT-OF-GAUGE LOAD

Another application of RCAS is the warning of advancing trains against trains with out-of-gauge load. Four classes of out-of-gauge load can be defined in difference to normal clearance gauge trains:

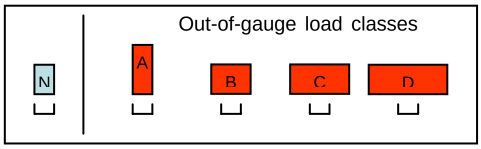

Fig. 3: Out-of-gauge classes

N: Normal clearance gauge

A: out-of-gauge load without influence to neighbour tracks, out-of-gauge vertically.

B: out-of-gauge load which can pass normal clearance gauge trains and out-of-gauge class A or B. Cannot pass train with class C or D.

C: out-of-gauge load which can pass normal clearance gauge trains (N). Cannot pass trains with out-of-gauge load.

D: Cannot pass other trains. Interlocking of neighbouring tracks required.

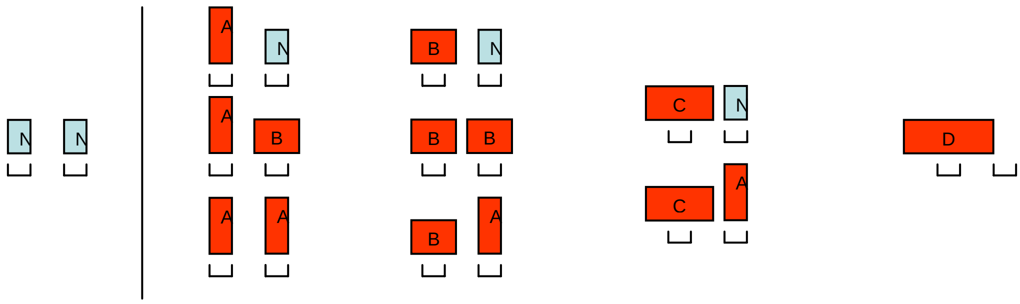

Fig. 4: Compatibility table

A train with a RCAS-sender can transmit in the broadcasted telegram an out-of-gauge warning and the related class. Normally no reaction should be needed, because the out-of-gauge trains require a specific time table and route preparation. RCAS can be used to increase the safety of out-of-gauge transports.

FREIGHT SUPERVISION

Different types of dangerous goods are transported by the railways, e.g. chemicals, explosives, radioactive material, carburant. Some of these goods together can intensify the danger in case of an accident, e.g. by reaction. In [11] is a system discussed which identifies these situations by the use of Shortrange-RF-Controllers and knowledge based rulebase. RCAS goes a step further and transmits the dangerous goods identifier. Trains with another “incompatible” freight can be warned early.

PERMISSIVE OBSTACLES

RCAS can transmit warnings against “hard” obstacles like advancing trains as well as “permissive” obstacles like small flooding or avalanches. In this case the reaction of the trains must not be an emergency stop; the train has to reduce the speed and continues. The detection of these “permissive” obstacles can be done be automatically by a sensing system or manually by drivers of previous trains. Areas which are known for their risk of floodings or avalanches can be equipped with a number of RCAS devices.

TRAFFIC MANAGEMENT

The integration of the RCAS communication network in the railway control center some more options are possible to resolve detected collisions. Train paths can be modified or signals set to stop by the train dispatcher [3]. These reactions at the infrastructure side increase the number of possible reactions.

REALISATION APPROACH

LOCALISATION TECHNOLOGY

The basic localisation technology is a global navigation satellite system (GNSS) like the European GALILEO or the US GPS (Global Positioning System). This system delivers in fixed time steps with 1 Hz or 10 Hz or even more information about the current geographical position. Using a digital map this geographical position is transformed into a topological position. By using two or more topological positions the speed and movement vector of the train can be calculated. Along-track Balises are queried where available to further identify discrete positions along the track. Any other available positioning technology may be integrated.

TRANSMISSION TECHNOLOGIES

RCAS requires a robust and fast, ad-hoc inter-vehicle communication procedure. In principle, any type of wireless communication procedure with supports concurrent access to the shared resource “frequency” can be adopted, including TDMA, CDMA, OFDM or MC-CDMA [5]. Optional, synchronisation on the medium access layer can be done using GALILEO, e.g. by calculating TDMA timeslots from the current geographic position of an RCAS sender. Alternatively the slots can be calculated from the train ID or the RCAS-ID using a hash function.

Because of the geographic disjunction eventually the frequencies allocated for the maritime AIS can be reused for RCAS. Another option is to share the frequency band with other vehicle-to-vehicle communication systems, such as the one developed in the Car2Car Communications Consortium[4].

RCAS senders periodically transmit telegrams describing the status of vehicles (e.g. train) or obstacles (e.g. construction team on track) coupled to them.

[4] http://www.car-2-car.org

Parameter	Meaning	Possible values
RCAS-ID	Unique identification of the RCAS unit	
Time stamp	Absolute time e.g. UTC	
Type of object	Classification of the RCAS Unit	Train mission Shunting Out-of-gauge transport LX construction site permanent obstacle (e.g. missing track) permissive obstacle
Position in train	Position of the RCAS unit in the train	Head Tail
Out-of-gauge class	Class of out-of-gauge load transport	None, A, B, C, D
LX status	Result of danger zone supervision	Secured, cleared Secured, temporarily occupied Secured, static occupied Unsecured unknown
Train length	Total length of train	in m
Topol. position	Track element ID	
Track vector	List of next track elements	
Geogr. position	WGS84 Position information	Lat, Lon, Alt
Speed	Absolute speed of train	in km/h
Dangerous goods classifier	Classifier of dangerous goods according to the European standards	

Fig. 5: Sample structure of a RCAS telegram

CONCLUSION AND PERSPECTIVE

This contribution discusses an approach for a trainborne system to avoid collisions called railway Collision Avoidance System (RCAS). This system is located completely on board of the rail vehicles and uses basically the information about position, speed and direction determined by a global navigation satellite system (GNSS) and a regional broadcast of this and further information with mobile radio.

The implementation of this idea just started. A working consisting of DLR and external partners is on the way to define the details of a future implementation. The next step will be the realisation of a prototype to show the feasibility if the approach.

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