Embedded ICT For Railway Safety

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***Abstract* - Railway safety is important task and start with steam locomotive development beginning. Today EU-Artemis Joint Undertaking has placed several activities to achieve improvements in this field. Main goal is to improve safety via embedded ICT. Some problems or difficulties are caused by fact that today one of the oldest mechanical transport industries still are one of the most conservative industries. This article takes a look how to improve railway safety under current ICT technologies offer. Massive safety improvements can take place only in case if solutions will acquire low level investments.**

***Keywords* - railroad, safety, ICT**

I. Introduction

R. Stephenson "Rocket" [2] (build 1829) set the standard for more than hundred years of steam locomotive power. The first railway accident took place on the 15th of September, 1830, during Manchester - Liverpool Railway opening where "Rocket" was presented. Later diesel engine and electric (both - end of 19th century) locomotives just follow the overall design and the main difference was power unit or engine. The same story is about railroad and railroad accessories. Regardless of later technical discoveries and new technologies, railway moving wagons, locomotives and even stations still looks "old fashion" in most of the cases compared to automotive, aircraft, ship or automotive industries products. Side by side also railway safety systems are developed and in a lot of cases also is "old fashion". Energy inefficiency (here is calculated as transportation mean weight against passenger count or cargo weight) is not acceptable today and revision all around the world must be made. Lightweight automotive car represent efficiency approx. 0,2 tons/seat against Acela electric train-sets[3] introduced by Amtrak[4] in the early 21st century representing 2,1 tons/seat. Doubtful are comparisons provided to represent Acela efficiency – Btu [5] per passenger-mile [6]. In-spite of lightweight and lifted train designs and implementations of DMU (Diesel Multiple Unit) loco-hauled designs still are on the way representing energy waste and non-economy [7]. It is no reasonable answer on the question today - why so heavy? It is found that work to carry net weight against work to carry tare weight of the wagon is approx. 1:2[8]. Can this be the reason why airfreight or automotive transportation become more profitable compared to railway [9] and as paradox - railway profit grow via auto vehicle shipments [10]? Today's wagon and locomotive large scale weight, size and proved conservative design don't allow install up-to-date ICT technologies in easy way. Existing billion scale investments cannot accept rapid changes so railroad safety improvements must be based existing stuff in-spite of written above.

II. Safety

Safety cannot be achieved via one piece or via one process. Several types of equipment and several processes must work in parallel to be sure that safety system will work as planned when needed. Safety tasks can be achieved in case if safety system is based on several "field tested" reliable software and hardware for parallel working systems. If one fail, next will alarm. Of course, overall installation and maintenance costs grow up.

Safety systems are actuate very rare or no at all (the best case) during many years of work. System reliability and work tests are provided once a year or less according to the state or international standards. Between defined tests system self-test must be provided by default. For example, on every locomotive "Power ON" or on every wagon count or wagon or locomotive position in to the line is changed. Partial self-test must take place during travel before known complicated or dangerous route points. All actions must be registered in to database.

Today safety systems are based on the ICT elements or systems and electromechanical or pneumatic actuators. The first thing - applied ICT and actuators must be reliable. And only the next are safety warning design and safety system action design.

It is known that computer viruses can destroy all ICT based security system. Protection against viruses is very important.

Part of the safety system can act in connection with planned time-bill: if possible dangerous occurs speed is slowing down and breaking system is pre-activated. Speed is increase follow to fall back on to schedule if it is clear that there are no more danger is of the path.

III. ICT Today

Today is possible to recognise several ICT application groups. Mainly ICT is divided in to consumer ICT (PC's, cell phones, home electronics etc.), industrial ICT (PCL's, automatisation electronics, embedded microprocessors etc.), networking and networking equipment (wired or wireless), global positioning and navigation systems and satellite communications. In many cases there are practically the same equipment for consumer and industrial applications. As known, ICT consist from hardware and software. For the same hardware are possible several different software operating systems. And the came operating system can run on different hardware (not so many practical examples and mainly achieved via virtual PC machines). For the same task and the same operating system is possible to find several application programs.

Production and manufacturing authorities (including railway authorities) and other involved specialists mainly share the point of view that only proprietary software applications developed by big brand names must be used in serious applications. This not clearly true because we can count that open source or freeware software designed by individual or groups of programmers dominate against brand name developed proprietary software.

Big and expensive examples of proprietary software are Microsoft products [11]. Examples of popular open source products include[12] UNIX OS, Linux OS, FreeBSD OS, OpenBSD OS, Android OS, Emacs, GNU toolset, Apache, HTML, PHP programming languages and others. The development of Perl is an example of the open source process. Open source project SourceForge: "*2.7 million developers create powerful software in over 260,000 projects. Our popular directory connects more than 46 million consumers with these open source projects and serves more than 2,000,000 downloads a day*"[13]. Apple OS X and iOS4 partially are open source and partially proprietary. Based on UNIX, Cocoa and Ruby on Rails OS X include developed by Apple Inc. software groups (for example - drivers) and applications still are low cost proprietary software. "*Mac OS X is far from perfect. But Windows is far from adequate. Mac OS X remains the single safest GUI operating system on the planet. Only OpenBSD and FreeBSD have better security reputations. Sorry Linux*."[14] Authors 20-years long ICT experience proves that too. OS X is UNIX certified computer operating system [15].

Regardless of software proprietary, practical "field test" (millions of users every minute, hour and day) and "test" results are one of the main points (or general point) to determine possibility to implement software in safety applications. Are consumer targeted iOS4 based applications are enough reliable for safety applications? Yes. iOS4 equipped consumer equipment sales are rising every month and now (iPhone and iPad sales, first quarter 2011) they count 7,78 million per month [16] and show product reliability. Mission-critical applications use OS X and Apple hardware platform - US Army has video surveillance based on the Mac OS X platform [17] as well as more than 1500 OS X Servers installed from 2004. Latest OS X 10.7 "Lion" is the same for desktop and server applications. Such possibility significantly decrease overall system servicing downtime, increase service stuff availability as well as make easy to keep spare computers it to the stock. OS X "sister" iOS4 are specially adopted OS X for iPhone, iPod Touch and iPad mobile devices. These devices have installed GPS receiver, accelerometer, magnetic compass, WiFi data exchange and Safari internet browser as well as more 200 000 applications are available to install, including several navigation or position on the map applications. Or it is possible to design special application via iOS4 SDK (Software Development Kit).

Written above cannot be taken as advertisement - we are talking about safety and are interested to choose the best solution available - equipment and software.

It isn't necessary to develop "the wheel" - for railway safety applications widely used everyday products are applicable. As example, Indian Railways is launching its version of the three-phase electric locomotive (WAG-7 and -9 series), fitted with commercial software-controlled diagnostic tools [18] using CPU board using Intel 80486 and GSM/GPS board (both commercial products).

IV. ICT Communication Method

ICT systems for safety can be divided in several groups by communication between train (or node) and central point (or host) (Table I):

- node,
- host (central point) controlled,
- host telemetry,
- host local area.
- node local area.

TABLE I.

ICT Communication Method.

Type	Node	Host
node	detect emergency and set adequate reaction	do nothing
host controlled	detect emergency	set node adequate reaction store data
host telemetry	detect emergency, set adequate reaction	receive information from node, store data
host local area	detect emergency, set adequate reaction, a) receive information from host b) receive control from host	detect emergency, a) inform node, b) set node reaction, store data
node local area	communicate with other nodes and host, detect **possible emergency,** inform other nodes and host, set adequate reaction, store data	detect emergency, a) inform node, b) set node reaction, store data

Communication in railway field can by provided by:

- means of satellite data exchange,
- directly via radio frequency link,
- directly via ICT radio-link,
- cell phone network - SMS communication.

Communication distance between two points is in range from several hundred meters up to ten's of kilometres. Large distance variations are one of the main problems for today's railway safety systems.

V. Global Positioning System

GPS and GNSS (Global Navigation Satellite System) implementation are based on radio transmission travel time from outer space satellites to land or air based receiver. At least 4 satellites must be visible to perform positioning. Today 4 systems are in use: GPS (USA), GLONASS (Russia), Galileo (EU) and Compass (China). There are different GPS precisions: military and lower civil. Precision can be up to several centimetres for expensive systems and <3...10 m for common systems. 3...10 m precision is enough good for railway safety tasks so here we can recognise a wide choice of available equipment. GPS is one of the main safety system parts - connected with well developed computer maps and mapping software GPS allow detect objects and place them on the map.

VI. Crossing Points, Switches and Junction With Land-Roads

Railway points, switches and junctions with land-roads are most important places on the roadmap. Typically light signs inform train machinist and automotive driver about possibility to cross junction or not. Adequate reaction to the signs allows exclude accidents. Automate these processes to exclude human mistakes is the main task. Signalisation equipment and equipment installed on these places over network must be low-cost due to large number of these dangerous places.

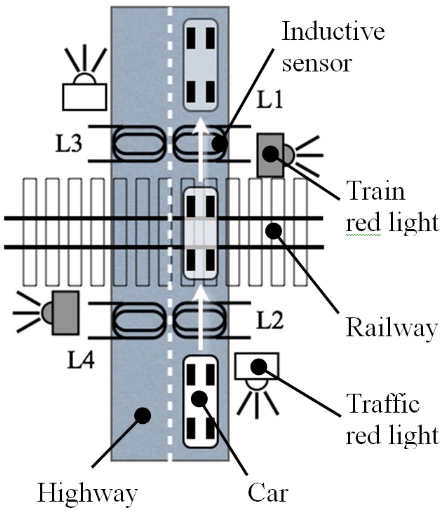

Fig.1. L-sensors equipped junction

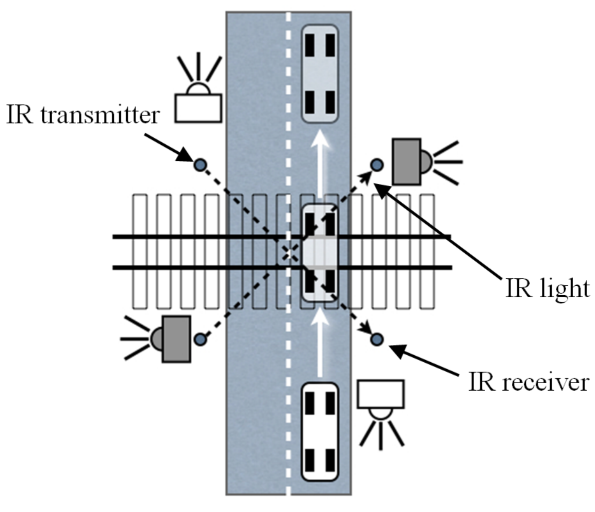

Fig.2. IR-sensors equipped junction

Every point, switch and junction must be equipped with signal lights and sensors. For example, junction can be equipped with inductivity L-sensors (similar like highway traffic count sensors) Fig.1. Inductive coils L1, L2, L3, L4 detect if automotive vehicle is over the coil or not. Vehicle must pass both coils L1-L2 or L3-L4. Emergency occurs in case if inductance L2 is passed but L1 isn't during determined time.

Traffic and train red light must be flashing LED light instead of continuous ON. Flashing red light can be recognised more easily by train machinist or vehicle driver. Besides, additional safety loop can be organised if locomotive safety system is equipped with light sensor to detect flashing STOP light.

Another option is IR-sensor application Fig.2. Here emergency signal occurs if IR light transmission between transmitter and receiver is interrupted by obstacle for determined time. IR transmitter and receiver must be vandal resistant. Both options can be used to increase control reliability. Energy consumption is different for both methods and L-sensor method is more effective. In the same time this method is more expensive from installation point of view.

Due to possible long distances between junction and other safety system elements problem occurs looking forward to sensor communication type with other system elements. It is possibly relay on third party service providers like cell phone operators or wireless internet service providers in urban area but such decision is doubtful from safety point of view. Mentioned determine that only "node local area" ICT communication method are enough reliable safety system.

VII. Control Algorithms and Methods

Objects (trains) are characterised by: size, weight, speed, braking time, breaking travel, predefined movement (travel) path (Fig.3).

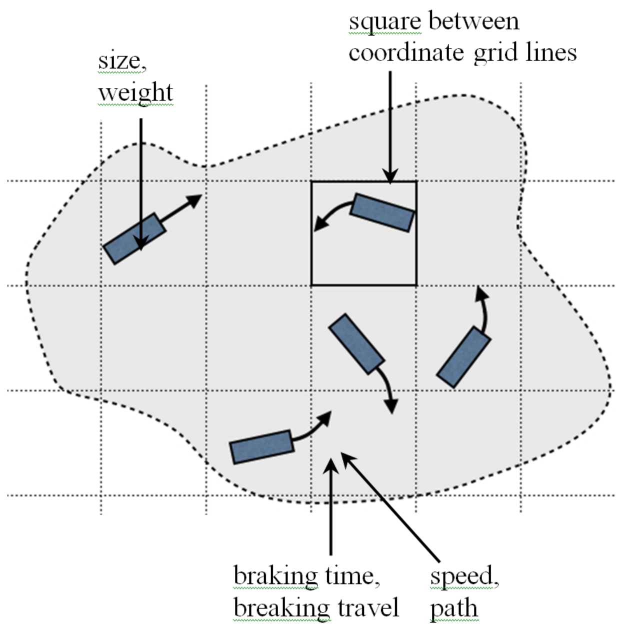

Fig.3. Train position and characteristics

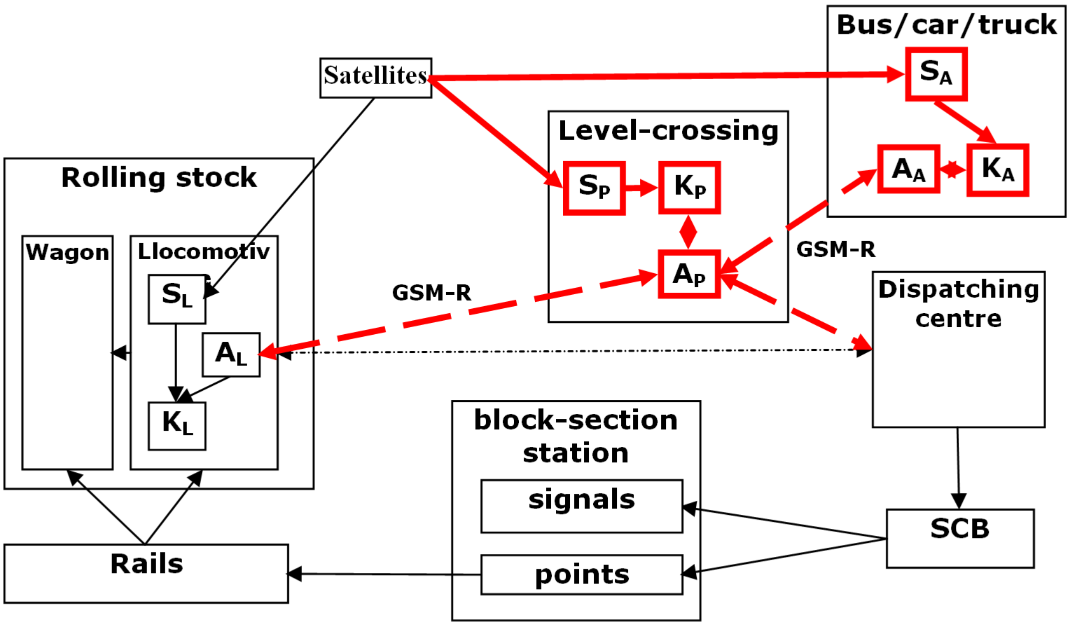

Fig. 3. Structure of proposed embedded ICT for railway level-crossing safety

Braking time and travel are important characters due to changing large weight and practical absence of antilock breaking system (ABS). Under different environment conditions (rain, snow, ice etc.) braking time and travel can have significantly different values on the same long route.

Many algorithms are used for path planning: such as depth first search, iterative deepening, breadth first search, Dijkstra's algorithm, best first search, A* algorithm and iterative deepening A*[19]. Well known different types of genetic algorithms are applied too. Algorithms must be fast and cannot acquire big computing power and this is one of the important points. For chosen algorithm and ICT communication method practically are just several optimal system ICT hardware configurations.

Promising are 3D algorithms and possible applications for railway safety systems must be researched. On current stage square-time 3D algorithm are under development. Algorithm is based on suggestion that two trains cannot be in the same coordinate grid square in the same time and today's database organisation scheme. Current application algorithm is described below.

VIII. Structure of Proposed System

In additional to existing railway safety system the proposed system consists of

K_L – controller of the locomotive;
S_L – satellite (GPS) receiver of the locomotive;
A_L – GSM-R transmitter of the locomotive;
K_p – controller of the level-crossing;
S_p – satellite (GPS) receiver of the level-crossing;
A_p - GSM-R transmitter of the level-crossing;
K_A – controller of the auto-transport unit;
S_A – satellite (GPS) receiver of the auto-transport unit;
A_A – GSM-R transmitter of the auto-transport unit.

IX. Mathematical Model for Algorithm

Following objects are given:

$ST = \{ST_1, ST_2, \dots ST_k\}$ - set of stations

$LC = \{LC_1, LC_2, \dots, LC_m\}$ - set of level crossings, where each level crossing is between two stations STi, STj.

$RS = \{RS_1, RS_2, \dots, RS_n\}$ - set of rolling stocks

$V = \{V_1, V_2, \dots, V_s\}$ - set of auto transport vehicles

Infrastructure constants:

$S_{STi,STj}$ - distance between stations ST_i, ST_j, [m];

$S_{ST,\,LC}$ - distance from station ST to level-crossing LC, [m];

t^{calc}_{clos} minimal time to close the level-crossing, [s];

d - directions;

$R^d = \{R1, R2\}$ - set of routes in each direction d;

Sc^d_R - distance from level-crossing to closure control point for each route R in each direction d, [m];

tc^d_R - time delay between crossing the closure control point and level-crossing closure for each route in each direction, [s].

Rolling stock RS constants:

id^{RS} - id number;

t^{RS} - type;

d^{RS} - direction;

R^{RS} - route;

Lw^{RS} - length of wagon, [m];

Nw^{RS} - number of wagons;

L^{RS} - length of train, [m];

V^{RS} - initial speed, [m/s];

$Vmax^{RS}$ - max speed, [m/s];

Td^{RS} - scheduled departure time, [min];

Ta^{RS} scheduled arrival time, [min];

a^{RS} - acceleration, [m/s^2];

b^{RS} - deceleration, [m/s^2].

Equations for each rolling stock RS:

$t_a = (V_{\max} - V)/a$ - acceleration time to maximal speed, [s];

$S_a = (V_{\max} - V) \times t_a / 2$ - acceleration distance to maximal speed, [m];

$S_{const} = |(S_{ST,LC} - Sc_R^d)| - S_a$ - distance of movement with constant speed to the closure control, [m];

$t_{const} = S_{const} / V_{\max}$ - time of movement with constant speed to the closure control, [s];

$t_{total} = t_a + t_{const}$ - total time from starting movement to the closure control, [s];

$$\left.\begin{array}{l} IF\ S_{ST,LC} >= Sc_R^d\ THEN \\ \quad t_{clos} = 60Td + t_{total} + tc_R^d \\ ELSE \\ \quad t_{clos} = 60Td - t_{total} + tc_R^d \end{array}\right\}$$ - level-crossing closing time, [s];

$S_{clos} = S_a + S_{const} + tc_R^d \times V_{\max}$ - distance from movement starting to closing point, [m];

$S_{clos,LC} = S_{ST,LC} - S_{clos}$ - distance from closing point to level-crossing, [m];

$t_{clos,LC} = S_{clos,LC} / V_{\max}$ - time of movement from closing point to level-crossing, [s];

Specific deceleration force

$$b_\Sigma = b_T + \omega_{OZ} + \omega_d , \quad (1)$$

where:

b_T - specific braking force;

ω_{OZ} - specific basic movement resistance;

ω_d - specific additional movement resistance.

Braking force of rolling stock is defined taking in account pressing force of braking stocks

$$b_T = 1000 \cdot \varphi_{OZ} \cdot \vartheta_P , \quad (2)$$

where:

φ_{OZ} - friction coefficient of braking stocks;

ϑ_P - calculated braking coefficient.

Braking way consists of preparation way and real braking way

$$S_T = S_P + S_D . \quad (3)$$

In (3) the preparation braking way is found as

$$S_P = 0.278 \cdot v_0 \cdot t_p , \quad (4)$$

but real braking way as

$$S_D = \sum \frac{500 \cdot (v_N^2 - v_K^2)}{\zeta(1000 \cdot \varphi_{kp} \cdot \vartheta_P + \omega_{Ox} \pm i_C)} , \quad (5)$$

where:

v_0 - initial speed of rolling stock;

v_N - speed at beginning of braking stage;

v_K - speed at the end of braking stage;

φ_{kp} - calculated friction coefficient;

ω_{Ox} - specific resistance in open-circuit mode;

i_C - slope of the way (can be positive or negative);

t_p - braking system preparation time.

If rolling stock is located in various stages of the railway profile, then movement equation is

$$\frac{dv}{dt} = \zeta \left[\begin{array}{l} \dfrac{B(t,v) + W(v)}{G} + \dfrac{l}{l_v} \cdot s_0 \cdot i_1 + \\ + \dfrac{l}{l_v} \sum_{j=2}^{m-1} s_j \cdot i_j + \dfrac{l}{l_v} \left(l_v - s_0 - \sum_{j=2}^{m-1} s_j \right) i_m \end{array} \right] , \quad (6)$$

where:

$B(t,v)$ - braking force;

W - basic movement resistance force;

l_v - length of rolling stock;

G - weight of rolling stock;

s_0 - distance between first and second element of the railway profile to the beginning of the rolling stock;

i_j - slope of j-th element of profile;

s_j - length of j-th element of profile.

In case if any auto transport vehicle is standing on level-crossing and distance to level-crossing is equal to braking distance it is necessary to start emergency braking of rolling stock immediately.

X. Conclusions

Today's ICT mobile computing devices allow build up-to-date inexpensive or medium-expensive railway safety systems. ICT consumer targeted equipment show good reliability from safety point of view. Safety system ICT communication method is determined in general. Future research must be pointed to communication methods between safety system elements as well as square-time 3D positioning or position determination algorithm must go through practical tests.

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