Design Model of Multi-Agents Based Autonomous Railway Vehicles Control System

M.Saleem Khan, Khaled Benkrid

Abstract—**This paper presents a complete design model of advanced autonomous train control system. This research work proposes a novel approach of multi-agents based control system to enhance the efficiency of the vehicles under the constraint of various conditions and contributes in stability and controllability issues by considering relevant safety and operational requirements with command control communication and various sensors to avoid accidents. This modular design approach gives the train management with speed scheduling and control, communication of information, traction, breaking control under certain conditions, record history of all the events as a black box and capability to fulfill the dire needs of modern trend to enhance the vehicles control systems in automation.**

***Index Terms*— Multi-agents, railway vehicle control system, autonomous design, train management, speed scheduling and control.**

I. Introduction

Over the last three decades railways vehicle technology has been going improving and in some countries autonomous systems are partially implemented. The modern technology reviewed the subject of Mechatronics and Electronics. Software based computer aided control systems, embedded systems, sensors and data communication technologies have become the essential part for the railway vehicles control and management systems. The general features and benefits of control and monitoring for the railway and transportation vehicles are well understood. The agents based technology is needed in Mechatronics to achieve flexible, network enabled collaboration between centralized and distributed system for high level autonomous vehicle control [1].

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The advanced concepts for monitoring and control of railway vehicles dynamics can provide better performance to facilitate higher speed, traffic control, time scheduling, environment monitoring and passengers management. The increasing amount of Electronic control reinforces the trend from passive to active systems. The proposed autonomous system gives the solution of track condition with the acceptable ride quality over lower quality tracks, tilting of trains around curved tracks with speed adjustment. The record of history for poor tracks and tilting of trains through curved track to maintain speed according to the requirements needs to be maintained in the existing systems to avoid the risk of overturning and passengers un- comfort [9].

The mobile data link field trials initiated to evaluate the feasibility of digital communication for Advanced Train Control System-ATCS found the best results and suggested the forward error correcting code for the data communications radio link for ATCS [3],[8].

GPRS/GSM based wireless communication strategies between vehicles to vehicles, crossing gates to vehicle, distance mileage allocation to vehicle and vehicle to the main control play a significant role in this system. This communication also helps to monitor the position, distance, speed, acceleration and errors detection.

In this paper, time measurement, station location, passengers information, root chart and utilities provision are proposed to be checked at the starting point. A system for calculation and determination of position, distance travelled/remained, speed, acceleration/deceleration is suggested.

The observations regarding the condition of crossing gates Open/Close, junction track changes, track clearance, tracks condition, vehicle tilting, request acknowledgement from stop/non-stop stations, utilities monitoring, mileage record, environmental monitoring, GPRS/GSM based links and Kalman Filtering technique for tracking and data estimation are proposed [5],[7].The operational view points are: the speed control and adjustments, breaking control, stop/move, utility request to station, communication between vehicle to control room, and vehicle to vehicle.

II. Advanced Train Control Systems Evolution

The development to enhance the capabilities of the train control systems is under progress at various platforms.

The evolution of train control methods, key functional requirements including location determination, detection, monitoring, autonomous control, data communication systems, Global Positioning System (GPS) and information processing are the main issues to review the existing train control system technology. In order to enhance safety of train operations new autonomous technology is needed to replace the existing systems [11]. Various architectures and methodologies for executing a train control in safe manner are being tested for implementation [12]

The open system interconnection-OSI model for radio data link communication to vehicle tracking and operational requirements has been suggested [13], [14]. A strategy for designing a network management system is required. Applications of modern command control and communication technology are required for Advanced Train Control System-ATCS [15],[16]. The existing systems need the unified operations in central traffic control with multi sensors conditions monitoring systems, position information systems including transponders and satellite for a two way digital communications network covering rail road, way side switch, detector interfaces and powerful central computer systems [17].The study of railway system with the problem of evaluating the benefits of safety enhancement to avoid rare but catastrophic accidents revealed that advanced train protection systems should have been installed [18].

The integrated control features of automatic train technology being in process, are the continuous communications-signaling system to update the driver's limit of authority, train location and route data transmitted to train from track transponders, automatic train protection for full speed, limit of authority supervision and computer based train control systems with real time train scheduling capability [19].

III. The Requirements of the Proposed System and the Initial Adjustments

In this section, the overall structural requirements of the system are discussed. The proposed system is based on: the starting adjustments; initial time, starting station, information about passengers, complete root chart loading, and with all the utilities, observations; junction track change information, crossing gate information, track clearance, track condition, environment monitoring, request from non-stop stations, vehicle to vehicle, and vehicle to control room communication facilities. autonomous decisions and operations; time, distance, and speed measurements, speed scheduling , management and control

A. *Internet Access and Communication System*

A railway Internet communication system can combine a bidirectional satellite link with a distributed system (wireless LAN and optical fibre) on the train. The train running up to 350 km/h needs at least 4 M bits/s in downlink and 2M bits/s in uplink data rates with a GEO stationary satellite.

The system is composed of a communication subsystem, a pointing subsystem and a distribution subsystem. The communication subsystem possesses the Antenna, Transmitter, Modem, and router IP connectivity.

The pointing subsystem performs the satellite acquisition and tracking. In order to maximize the received or transmitted signal, several elements like IMU-Inertial measurement unit, AGC (automatic gain control) and control unit are required. The distribution subsystem possesses the optical fibre connection between the central server and each train car for signal distribution to the passengers [5].

B. *Internet Utilities to Passengers*

Via the internet the passengers with prepaid cards can be provided a username and password to log on to the system to get web access, voice over IP connectivity and email services. Via railway operator's Internet they can avail of on line games, trip maps and facts, ticket reservations and sales, video streaming and electronic newspapers.

C. *Close Circuit Television (CCTV)*

IP-based video surveillance system can record picture on the train to be monitored by staff in centralised control room to counteract anti-social activities.

D. *Railway Measurement System*

This system implements real time telemetry services for the railway system using the information of equipments for rail wheels, acceleration on train axles, vibrations, monitoring the signals of junction track information JTI, crossing gates CG, track condition TC, track clearance TCL, Request from non-stop stations, mileage record MR, environment monitoring EM, vehicle tilting VT, on track vehicle to vehicle and between vehicle and main control information exchange. This information is help full for vehicle speed control and scheduling [7].The loaded information of the root chart in the system is according to the prerequisite conditions for a particular track. This information is used in speed control and scheduling. At the starting point, pre-loaded information about vehicle root is selected or other information is allowed to be loaded into the system memory by the control room. The manual entry is also allowed with the authentication of the operator identification. This initial information includes the start time, speed schedule, position of stopping stations, locations of junction track change and crossing gates and track condition

IV. Over all Structure of the Proposed Railway Vehicle Control System- RVCS

The proposed system is able to receive the information regarding the request to/from non-stop stations, position, velocity and actual distance covered from mileage record. The position, velocity and mileage records help for error correction in speed adjustment. The speed scheduling and management arrangement is shown in Fig. 1. The overall speed control and adjustment are shown in Fig. 2.

The block scheme of the whole system is shown in Figure 3.

In this block, links of internal sub- blocks are shown.
The proposed design model is shown in the form of various blocks with interlinks in Fig. 8 (a) and 8(b).The main part of this design strategy is the speed scheduling, management and control system. This whole system is completely autonomous and based on multi-agents.
Sensors based monitoring system and data communication system play vital role. Data code correcting techniques and Kalman filters can contribute in the stability and controllability of the overall system. RAM and ROM based storing units can be used for root chart information storage and incoming and outgoing information records. This arrangement is shown in block format in the design.

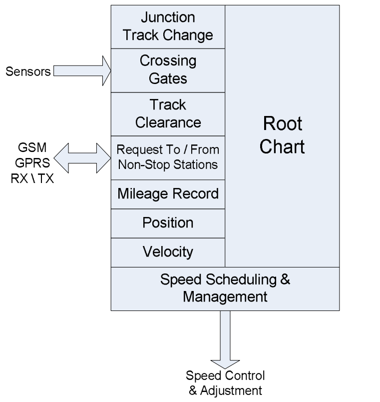

Figure. 2(a) Block Arrangement of Speed Scheduling & Adjustment

Fig. 1 Arrangement of speed scheduling & management

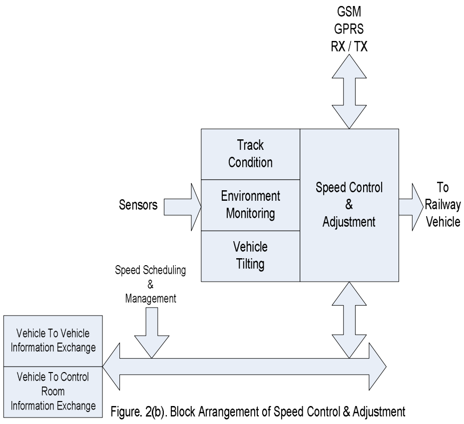

Figure. 2(b). Block Arrangement of Speed Control & Adjustment

Fig. 2 Block arrangement of speed control and adjustment system

V. Multi-Agents, Conditions Monitoring, Adaptive Kalman Filtering and Traffic Control

Multi-agents based autonomous system can play a vital role in the vehicle speed management and traffic control. An adaptive Kalman filter is suggested to estimate precise data for railway vehicle control system.

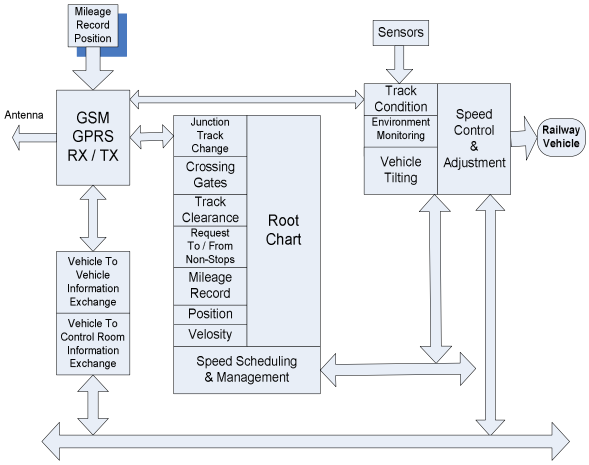

Figure. 3. Scheme of Speed Scheduling & Management and Speed Control & Adjustment Systems

Fig. 3 Scheme of speed scheduling & management – speed control & adjustment system

A. *Multi-Agents*

Fig. 7 shows the complete arrangement of multi-agents based railway vehicle control system-RVCS. The various conditions monitoring units are called multi-agents because these units get the information from their own resources and overall control the system autonomously according to their control designs. These agents also transmit their information to some parts of the communication system. Therefore, the railway vehicle system is controlled and managed through their participation.
The intelligent railway control system can use the structures and cooperative relations of the main agents by using train G-Net operation model [2].

B. *Conditions monitoring*

Hard conditions: junction track information JTI, crossing gate information CG, and track clearance TCL, need to stop the vehicle in the presence of any one condition as shown in fig. 4

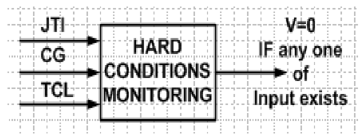

Fig.4 Hard conditions monitoring

Flexible conditions: vehicle tilting, track condition, and environment monitoring need to reduce the vehicle speed according to their design entries in the look up tables. In case of the existence of more than one conditions least value of speed demand is considered for safety as shown in fig. 5

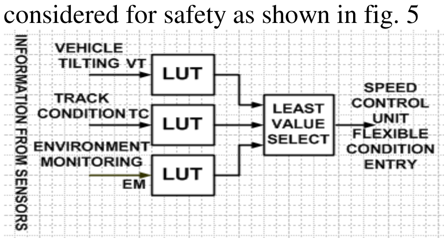

Fig. 5 Flexible conditions monitoring

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C. *Adaptive Kalman Filtering*

This whole proposed system of railway vehicle is based on the communicated information. The delivery of precise data is highly recommended for the stability and controllability of the system. The vehicle to vehicle and between vehicle and control room, information management units are used to control the speed of railway vehicle. In this arrangement track condition, environment monitoring and vehicle tilting monitoring systems are designed to control the system. In order to avoid data losses and noise, Kalman filters are the best option to be used at the receiving end of the system [6].

D. *Traffic Control*

For the vehicular traffic control on a track or on adjacent tracks joining at junction, conditions for normal traffic or rear-end collision must be examined.

A mathematical modular approach is proposed for the safe vehicle speed adjustment to reduce any time delay due to any reason i.e. JTC, TC, CG etc in the journey.

The characteristics of mathematical formulation for normal vehicle traffic encountered in practice are proposed for the proper speed control and adjustment. The characteristic behavior for normal traffic is adapted in the final speed calculations on the basis of vehicle to vehicle and vehicle to control room communication in distributed environment.

If vehicles A, B and C are in first, second and third order, their speeds arrangement for normal traffic system should be maintain as $V_C \leq V_B \leq V_A$.

The vehicle in front can start and move with the maximum speed on empty track but the following trains behind the first one will adjust their speed within certain limit to recover their time delay [4].The possible ways to increase the speed and improve the synchronisation of trains are required to be adopted for the stability of railway networks [10].

This model has the capacity through its speed scheduling unit to include the consideration about random delays of trains and the propagation of delay across the network. This discussion shows that the final speed adjustment in these types of special cases requires the information exchange between vehicles in automation, and another option proposed to be used is to mount high quality SONOR sensors at the front and rear ends of the vehicle to collect the information for the speed estimation. The speed control unit block is shown in fig.6.

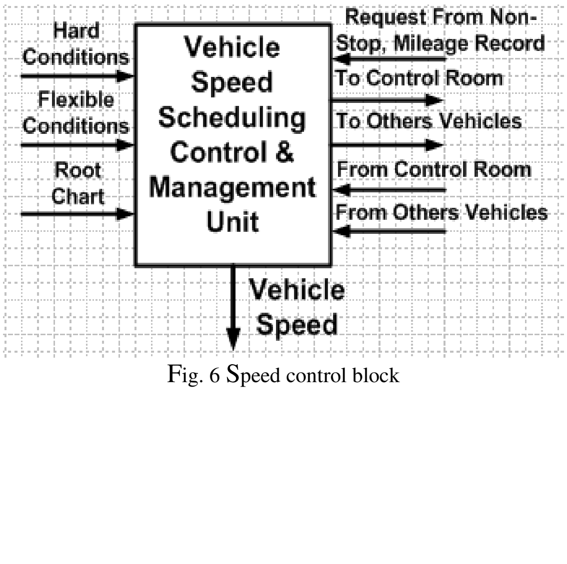

Fig. 6 Speed control block

For this part of the circuit, Kalman filters play the vital roles in data estimation for proper speed adjustments. This information should be accurate and without any noise or delay. The mechatronics uses the electronics components and tools together with the mechanical systems. High-tech electronics is increasingly being used to develop such systems in automation but the low cost solutions for the specific tasks need to be developed [2]. In this regard, FPGAs are playing a significant role to develop high performance circuits with the added re-programmable feature [20]

VI. Design Model Blocks- Description

This proposed design of multi-agents based RVCS has the complete autonomy to handle the issues related with the desired root chart travel, various conditions monitoring and speed adjustment, vehicle speed scheduling, management and control, maintain to store the record history of all the information during travel as a black box, vehicle motor power control and motor drive and the provision of communication between main control room and others vehicles on track. It is also capable to receive the information regarding junction track change, crossing gates status, travelled distance mileage, global positioning, speed and request from non-stop stations. In this design the whole system is spread in 16 blocks.

BLOCK-1 consists of two RAMs to store the 2 tracks root chart information loaded at the starting station. One of the information is regarding the current root, while another entry is about the root which may be adapted in transit or after the first root as a provision. The entry may be through communication or by manual means. RAM-1 or RAM-2 can be enabled by the data entry selection from block 2. Memory address bus is common for blocks 1 & 3 and provided by memory address counter-1 from block 2.

BLOCK-2 gives the provision of memory selection for a particular track and data entry. Its root selection unit enables the ROMs in Block 3 and provides the address for memories used.

BLOCK-3 uses 4- ROMs to have the pre-loaded 4 tracks root chart information. Any one of these 4 roots can be selected through Block 2. The common address is provided by Block 2.The data output lines are common and connected with common root chart memory information bus.

BLOCK-4 is for hard conditions monitoring and decision about halt. It receives the three information: junction track-JTI, crossing gates-CG and track clearance-TCL. JTI and CG may be received through communication system and TCL through SONOR sensors mounted at the front and rear ends of the train. These signals are conditioned and processed for the decision of halt through hard condition decision logic unit. The output of this unit is fed to Block5 for record and Block8 for speed scheduling, management and control.

BLOCK-5 is for hard condition record. It uses RAM-7 and address counter with clock enable when new entry comes. The output of RAM-7 is connected with Block13 for black box entry.

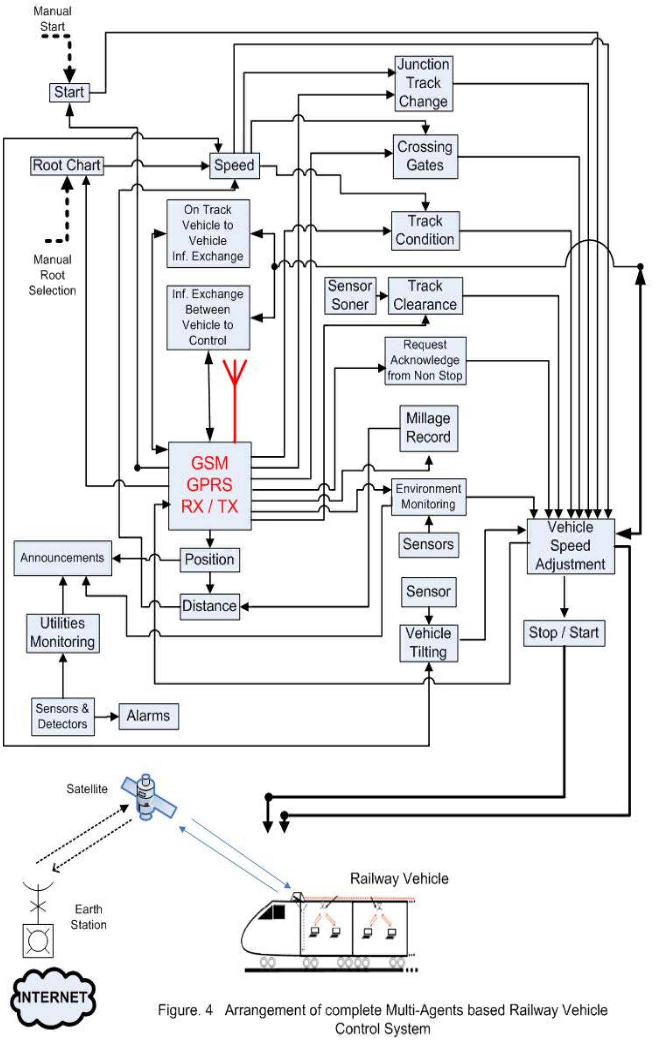

Fig. 7 Links of multi-agents in vehicle control system

BLOCK-6 is for flexible conditions monitoring and speed adjustment. It is called flexible because speed may be changed but not for the system to be halted suddenly. It monitors three conditions: track condition-TC, environment-EM and vehicle tilting-VT through the information received from various sensors used for this purpose. These signals are processed and lowest speed priority adjustment is implemented. Output of this unit is fed to block7 for record entry and Block 8 for speed scheduling, management and control.

BLOCK-7 is used for the record entry for flexible conditions. It consists of a RAM-8 and address counter with clock enable. Output of this unit is connected with Block 13 for black box entry.

BLOCK-8 is the main unit of the system. It is used for the speed scheduling, management and control. The arrangement for calculation and determination of position, distance travelled/remained, speed, acceleration/deceleration is suggested.

This block has 6 inputs: root chart memory information, hard conditions, flexible conditions, communicated information from main control, vehicle on track and same bandwidth information about junction track change, crossing gates status, distance mileage and non-stop station request on its single input.

This block has 3 outputs: one is fed to Block 10 for vehicle power drive for specific speed, second is connected to Block 16 to transmit the information for main control and to Block 9 to store this information and the third output is used for the transmission to the other vehicles on track. This information is also being stored in Block 9.

BLOCK-9 consists of two RAMs and two separate address counters. RAM-5 is used for storing the information being sent to main control and RAM-6 is used to record the information sent to the other vehicles on track. The common output of these RAMs is fed to Block13 for black box entry.

BLOCK-10 is used for vehicle power drive. This unit consists of digital to analogue converter-DAC. The input of this unit in digital form is provided by the Block 8, firstly it is converted into analogue form then it is fed to the power control and vehicle motor drive unit to maintain the required speed of the vehicle.

BLOCK-11 is proposed for storing the received information from main control and on track vehicles. This block consists of two RAMs. RAM-3 is used for storing the main control information and RAM-4 is used to record the information sent by on track vehicles. These two RAMs are provided the separate address from two clock enable counters. The common output is fed to Block13 for black box entry.

BLOCK-12 is a communication receiver unit, consisting of four different channels having different bandwidth. Each channel consists of a band pass filter-BPF, demodulator, decoder and Kalman filter. Channel-1 is used for receiving the signal from main control. Channel-2 is for receiving the information from on track vehicles.Channel-3 is set to pass through the information of root chart entry and channel-4 is used to receive the same band width information of JTI, CG, distance mileage data entry, and request from non-stop stations. This block gets the common input entry from a duplexer in Block14.

BLOCK-13 is the black box of the records of the system. It maintains the record history of all received information to/from control and on track vehicles, hard conditions and flexible conditions faced by the system during travel.

BLOCK-14 is for duplex antenna. It provides the received signals to Block12 and receives the signal for transmission from Block16.

BLOCK-15 provides the all the utilities arrangements. In case of any shortage, it sends the information to the near stations or the main control. This unit provides the internet facility to the passengers.

BLOCK-16 is for communication transmitting arrangements. It consists of a multiplexer, coder modulator and a power amplifier for the signal to be transmitted through antenna in Block14. The information to main control, on track vehicles and utilities provision are multiplexed and processed through this block.

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VII. Conclusion and Future Work

This work provides the vision of highly accurate system for the autonomous control of railway vehicles. This design model can easily be changed for memory expansion and can be implemented using high state of the art microelectronic technology with accuracy and stability as forefront goals. As the system is based on heavy information communication, therefore proper coding and filtering techniques need to be exercised.

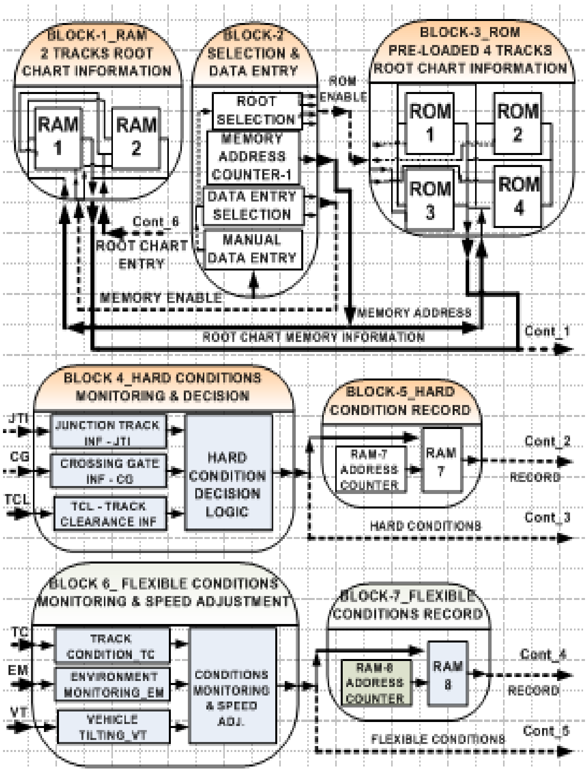

Fig. 8(a) Design blocks of the proposed railway vehicle control system-RVCS

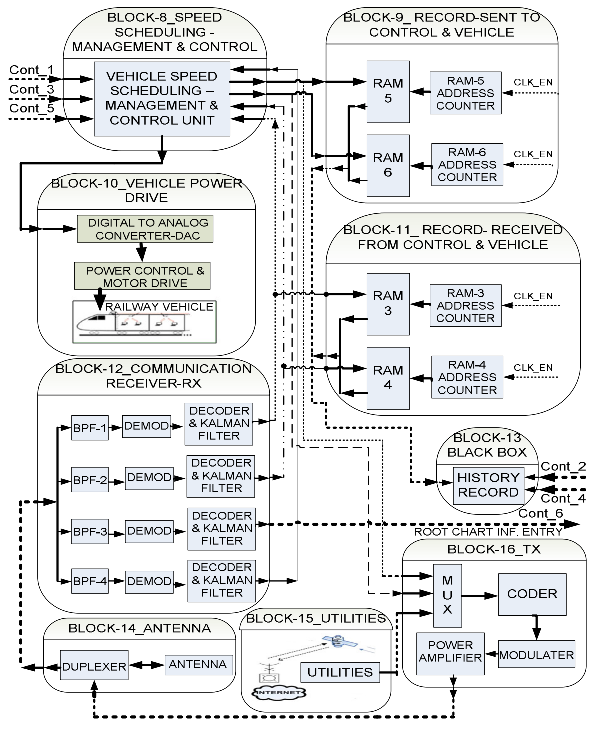

Fig.8 (b) Extension of fig.8(a)

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