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FIS Based Speed Scheduling System of Autonomous Railway Vehicle

Aiesha Ahmad, M.Saleem Khan, Khalil Ahmed, Nida Anwar and Umer Farooq

Abstract—This paper presents the design model of speed scheduling system of autonomous railway vehicle control using fuzzy inference system (FIS). Successful development of speed scheduling and maintaining system plays crucial role to make autonomous railway vehicle control system more effective under constraint of uncertain conditions. This research work emphasis to develop the speed scheduling system with capability to adjust in uncertain conditions magnificently by improving performance, stability, controllability and safety of railway vehicles and ultimately reduce the risk to meet the needs of modern trend of autonomous control system. The proposed design model is capable to successfully cope with hard conditions; junction track information (JTI), crossing gate information (CG) and track clearance (TCL), and flexible conditions; vehicle tilting (VT), track conditions (TC) and environment monitoring (EM) using fuzzy inference system with better and quicker response with human knowledge incorporation. This system will be helpful to successfully maintain the speed of railway vehicles with environment monitoring, time scheduling and minimizes the risk of overturning.

Index Terms— Autonomous Railway Vehicle, Control System, Environment Monitoring, Fuzzy Inference System, Speed Scheduling, Time Scheduling.

1 Introduction

ADVANCEMENT in railway vehicles technology has been increased from last few years to facilitate passengers by improving performance with speed, time scheduling, traffic control and passenger management [1]. The importance of control, management and monitoring for railway vehicles progress gradually under modern solution of embedded systems, software based computer aided control systems, sensors and data communication technologies. The design and development of agent base autonomous railway vehicle control system is considered important for flexible and well established network to enable collaboration between centralized and distributed systems of railway tracks [2]. In these autonomous railway control systems, agents are defined as condition monitoring units with capability to collect information independently and control system autonomously according to their design control [3]. The monitoring and control of railway vehicles are mainly focused on speed management and scheduling, traffic control and time scheduling. Speed scheduling plays vital role for successful development of autonomous railway control system by focusing on hard conditions; Junction track information (JTI), crossing gate information (CG) and track clearance (TCL), and flexible conditions; vehicle (VT) tilting, track condition (TC) and environment monitoring (EM). To maintain information about track condition with support of acceptable ride quality and tilting of trains around curved tracks with speed adjustment have been done through some sensors, mathematical modular technique and kalman filtering for data estimation and tracking in existing systems. Mathematical modular techniques sometimes unable to meet the need of real time environment due to lack of flexibility while kalman filtering technique also can't perform well in presence of noise in initial stages with modeling of system [4]. The complexity and dynamic nature of autonomous railway control system is needed some sophisticated method with domain knowledge representation and save time with quick response to handle uncertain situations successfully during running on track. Fuzzy inference system has capability to perform uncertain reasoning under incorporation of human knowledge in real time environment with better and quicker response. The proposed design model will be capable to adjust speed under uncertain conditions with high safety, performance and time management.

The arrangement of this research paper is as follows: section 2 consists of brief overview of fuzzy logic and fuzzy inference system that helps to understand the importance of fuzzy base systems. Structure of proposed speed scheduling system is discussed in section 3. Design algorithm is presented in section 4 and results and discussion is described in section 5 on the basis of design algorithm. Section 6 presents conclusion and future work on the basis of design algorithm.

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2 Overview of Fuzzy Logic and Fuzzy Inference System

Imprecise modes of reasoning are successfully demonstrated by fuzzy logic with appropriate answer that considered fundamental aspect of human rational decision making under ambiguous and uncertain environment based on incomplete, inexact or bit reliable knowledge [5], [6], [7], [8]. Fuzzy logic simulates human reasoning through mathematical theory of fuzzy sets with power of high precision while mapping of input values to an output values is done using process of fuzzy inference which drives to the final decision. Therefore fuzzy inference system (FIS) is considered as one of main computing framework in artificial intelligent (AI) that integrate human knowledge with idea of fuzzy IF-THEN rules to determine imprecise and uncertain reasoning in real time environment. FIS provides better, quicker and more appropriate solution as compared to traditional approaches because these approaches worked with crisp set of distinct and precise boundaries while in fuzzy set transition from non-membership to membership is gradual.

3 Strucutre of Proposed Speed Scheduling System

The fuzzy inference based proposed speed scheduling system consists of preloaded information of track in form of root chart and design to cope with uncertain conditions successfully with minimum response time. Railway track system receives two main conditions (hard and flexible) from environment and uses sensors to differentiate between these conditions. In case of flexible conditions (FC): VT, EM and TC observed through sensors and given to FIS. These sensors are capable to monitor EM, TC and VT individually by subdividing into 0 to 5 volt in which 0 volt represents the absence of these flexible conditions with no need of speed adjustment while from 1-5 volt shows gradual increase in these conditions with respective decrease in speed, like 5 volt represents worst condition against one or more flexible conditions (VT, TC or EM) with slow speed. Hard conditions (HC) like JTI, TCL and CG are sensed through sensors at particular distance and ultimately stop the train whatever adjusted speed may be after existence of flexible conditions. Fig.1 is representing the basic structure of FIS based speed scheduling system in presence of both FC and HC using fuzzy logic.

The proposed system will be capable to reduce speed or stop by increasing time according to requirement in uncertain environment. Then it will compare the increase time with root chart estimated time to reach next junction and increase speed to its maximum possible limit to overcome the delay after handling uncertain situation.

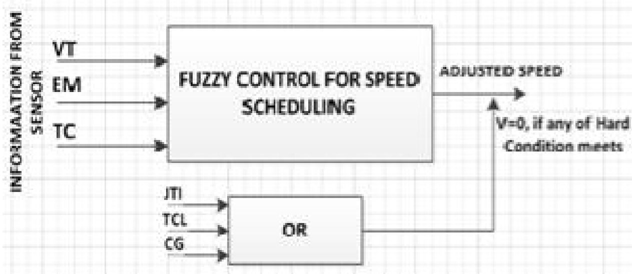

Fig.1. Block Diagram of Speed Control System using FIS.

The design procedure can be explained with the help of mathematical equations.

In the start, speed is

$$S = V * t$$

After uncertain conditions, the speed reduced as

$$S = (V + \Delta V)\, t$$

Change in velocity calculated as

$$S/t - V = \Delta V$$

Then this change in speed will compare with root chat estimated speed to overcome the delay to reach the next junction according to root chart calculated time. An overview of speed scheduling system with fuzzy control and speed adjustment is given in Fig. 2.

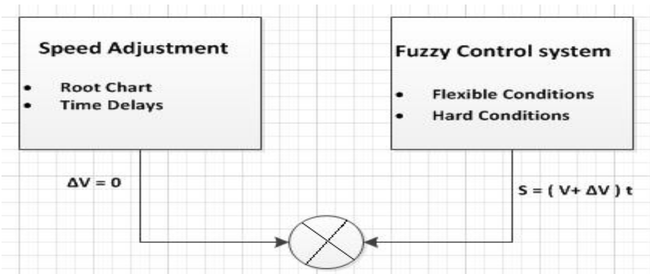

Fig.2. Block Diagram of Speed Scheduling System.

Fuzzy control system is used to adjust speed quickly and precisely in the presence of any flexible condition or delay due to any hard condition after comparing with root chart. The fuzzy control system for proposed speed scheduling system consists of fuzzifier, inference kernel with knowledge base including database, rule base and output membership functions, and defuzzifier block as shown in Fig.3. The crisp values of input variables VT, TC and EM are reached to fuzzifier after passing through sensors to identify the types of these input variables [7], [9], [10]. In fuzzifier, comparison of input crisp values up to certain levels is done by generating linguistic values (Low, Medium, Average, High and Very High) against each input variable. These linguistic values are passed to inference kernel connected with knowledge base which further categorize into database, rule base and output membership functions.

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In knowledge base, key feature of database is to manipulate fuzzy data and provide essential definitions to describe the linguistic control rules which help the rule base to define the control goals and control policy of particular system such as speed scheduling of railway vehicle in this scenario while output membership functions define the strength of output variables with formulation to adjust speed. After receiving feedback from knowledge base, the next step of inference kernel is to simulate the human decision with fuzzy logic rules to make the control decision in term of adjusted speed, the final outcome. In the next step, defuzzifier maps fuzzy output variable (Slow, Average, Fast and Very Fast) to a crisp value which finally comes to railway track system after passing through actuator.

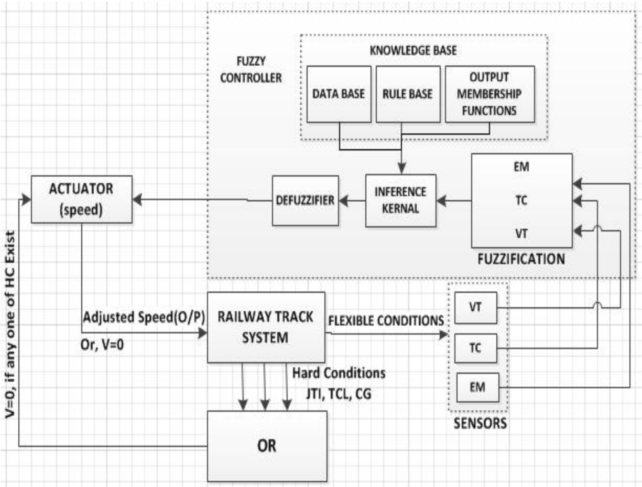

Fig.3. Design Model of FIS Based Speed Scheduling System.

4 Design Algorithm of Proposed Model

The proposed model is designed for three input variables (VT, EM and TC) which are derived from flexible conditions. The membership functions for these three input variables are shown in Table1.

TABLE 1.
INPUT MEMBERSHIP FUNCTIONS

Scale	VT. Membership Function-MF	EM. Membership Function-MF	TC. Membership Function-MF
0-30	Low	Pleasant	Good
0-60	Medium	Below Pleasant	Below Good
30-90	Above Medium	Average	Average
60-100	High	Below Storm	Bad
90-100	Very High	Strom	Worst

The five membership functions mf1 [1], mf1 [2], mf1 [3], mf1 [4] and mf1 [5] are used to represent the different ranges of input fuzzy variable "Vehicle Tilting" as shown in Fig. 4. The plot of VT consists of four regions. The other two variables, EM and TC are design on the same pattern for simplification and better understanding.

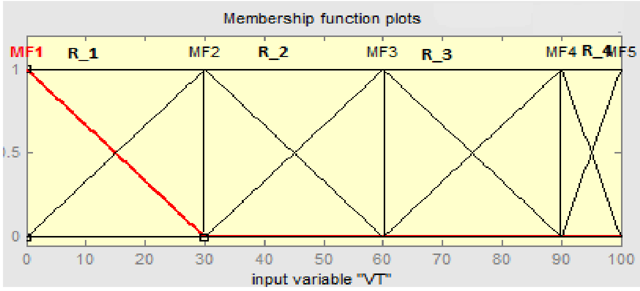

Fig. 4. Plot of Membership Functions for Input Fuzzy Variable- Vehicle Tilting.

The output variable speed consists of seven membership functions. The detail about each membership functions with scale and singleton values are shown in Table 2. The plot of seven membership functions of speed with maximum speed limit 120km/h is shown in Fig. 5.

TABLE 2
OUTPUT MEMBERSHIP FUNCTIONS

Membership Function	Range	Speed	Singleton Values
MF1	0-20	Very Slow	S1=0
MF2	0-40	Slow	S2=0.16
MF3	20-60	Average	S3=0.33
MF4	40-80	Above Average	S4=0.5
MF5	60-100	Normal	S5=0.66
MF6	80-120	Fast	S6=0.83
MF7	100-120	Very Fast	S7=1

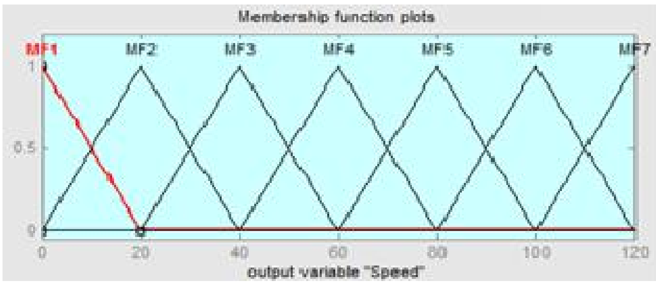

Fig. 5. Plot of Membership Function for output Fuzzy Variable- Speed.

4.1 Fuzzification

There are three fuzzy input variables in proposed design model of speed scheduling and each variable is divided into four regions while f1 and f2 are linguistic values of fuzzy variable "Vehicle Tilting", f3 and f4 for "Environment Monitoring" and f5 and f7 for "Track Condition".

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The linguistic values described as the mapping values of these three fuzzy input variables: VT, EM and TC with their membership functions categorize into four regions as shown in Table 3.

TABLE 3
LINGUISTIC VALUES OF FUZZIFIERS OUTPUTS IN ALL REGIONS

Input Variables	Linguistic Fuzzifier Outputs	R_1	R_2	R_3	R_4
VT	f1	mf1 [1]	mf1 [2]	mf1 [3]	mf1 [4]
	f2	mf1[2]	mf1 [3]	mf1 [4]	mf1 [5]
EM	f3	mf2 [1]	mf2 [2]	mf2 [3]	mf2 [4]
	f4	mf2[2]	mf2 [3]	mf2 [4]	mf2 [5]
TC	f5	mf3 [1]	mf3 [2]	mf3 [3]	mf3 [4]
	f6	mf3[2]	mf3 [3]	mf3 [4]	mf3 [5]

Input variables, VT, EM and TC are inversely proportional to speed while each variable has independent effect on speed, even with minor change in any one variable. The number of rules for complete simulation of design model is 64 and rule base will maintain the record of these rules. In this case, 8 rules are used for the values of specific region of input variables like VT=10, EM=15 and TC=25 are taken for region 1 with membership functions and corresponding mapping values mf1 [1], mf1 [2], mf2 [1], mf2 [2], mf3 [1], mf3 [2]. The Fig. 6 is representing the fuzzification process of these input variables crisp values to linguistic variables.

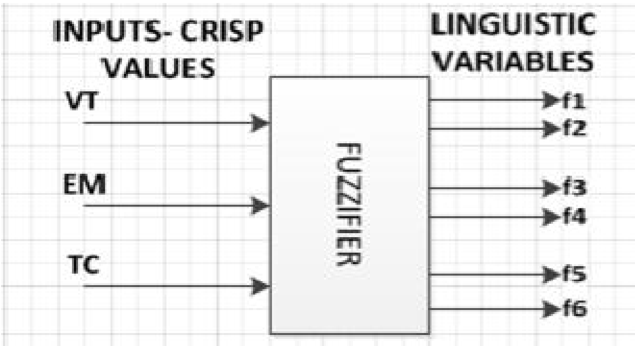

Fig. 6 Fuzzifier Representing, 3- Inputs- Crisp Values with 6- Outputs- Linguistic Variables.

4.2 Fuzzy Inference Engine

The inference engine consists of eight AND operators which select minimum value from linguistic values of three input variables. The working technique of these AND operators are different form logical ANDs. This inference engine accepts six inputs from fuzzifier and applies min-max composition to obtain the value to adjust speed. The min-AND operation is used from min-max technique to get minimum value from input variables TC, EM and TC as shown in Fig. 7 which gives the overview of fuzzy inference engine working strategy.

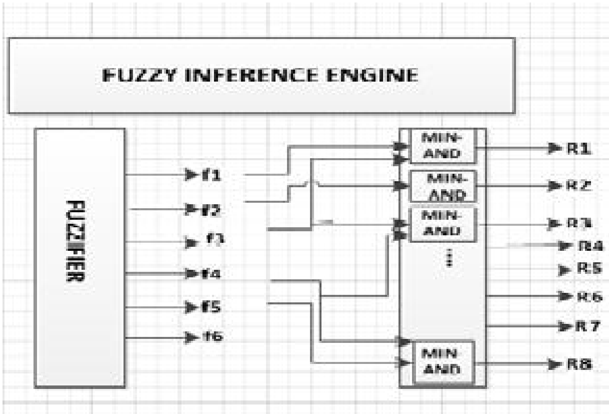

Fig. 7. Block Diagram of Fuzzy Inference Engine.

Rule1 = f1 ^ f3 ^ f5 = mf1 [1] ^ mf2 [1] ^ mf3 [1]
= 0.33 ^ 0.5 ^ 0.83 = 0.3
Rule2 = f1 ^ f4 ^ f6 = mf1 [1] ^ mf2 [2] ^ mf3 [2]
= 0.33 ^ 0.5 ^ 0.16 = 0.16
Rule3 = f1 ^ f3 ^ f6 = mf1 [1] ^ mf2 [1] ^ mf3 [2]
= 0.33 ^ 0.5 ^ 0.83 = 0.33
Rule4 = f1 ^ f4 ^ f5 = mf1 [1] ^ mf2 [2] ^ mf3 [5]
= 0.66 ^ 0.5 ^ 0.83 = 0.5
Rule5 = f2 ^ f3 ^ f5 = mf1 [2] ^ mf2 [1] ^ mf3 [1]
= 0.66 ^ 0.5 ^ 0.83 = 0.5
Rule6 = f2 ^ f4 ^ f6 = mf1 [2] ^ mf2 [2] ^ mf3 [2]
= 0.66 ^ 0.5 ^ 0.16 = 0.16
Rule7 = f2 ^ f3 ^ f6 = mf1 [2] ^ mf2 [1] ^ mf3 [2]
= 0.66 ^ o.5 ^ 0.16 = 0.16
Rule8 = f2 ^ f4 ^ f5 = mf1 [2] ^ mf2 [2] ^ mf3 [1]
= 0.66 ^ o.5 ^ 83 = 0.5

The ^ operator between membership function values is used for min-AND process to get minimum value of the function.

4.3 Rule Selector

The rule selector of proposed model receives three crisp values of VT, EM and TC, and provides singleton values of output function with specific rules of the design model requirement. In this case, 8 rules are required to find the required values S8, S9…, S15 according to division of regions for soft conditions while hard conditions are absent.

The rules are listed in Table 4 with existence of both hard and flexible conditions for quick overview of rules for speed control system.

4.3 Defuzzifier

In defuzzification process, crisp values for final estimated speed are obtained after estimating its inputs regarding

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TC, EM and VT from the rule base.

TABLE 4
ILLUSTRATION OF APPLIED RULES

INPUT						OUTPUT	Singleton Values
FLEXIBLE CONDITIONS			HARD CONDITIONS			SPEED In km/h	
VT	EM	TC	JTI	TCL	CG		
1	1	1	N	N	Y	Stop	S1
1	1	2	N	Y	N	Stop	S2
1	2	1	Y	N	N	Stop	S3
1	2	2	N	Y	Y	Stop	S4
2	1	1	Y	N	Y	Stop	S5
2	1	2	Y	Y	N	Stop	S6
2	2	2	Y	Y	Y	Stop	S7
1	1	1	N	N	N	100-120	S8
1	1	2	N	N	N	80-120	S9
1	2	1	N	N	N	80-120	S10
1	2	2	N	N	N	80-120	S11
2	1	1	N	N	N	80-120	S12
2	1	2	N	N	N	80-120	S13
2	2	1	N	N	N	80-120	S14
2	2	2	N	N	N	60-100	S15

There are 16 inputs are given to the defuzzifier, eight values from eight rules (Rule1-Rule8) and eight values from rule selector (S8-S15). The center of average method (C.O.A) is used by each defuzzifier to estimates the crisp value with mathematical expression $\sum Si * Ri \ / \ \sum Ri$, where i = 1 to 8 in the given scenario as shown in Fig. 8.

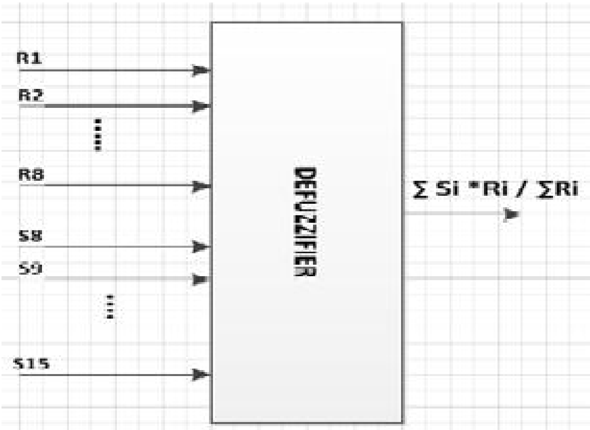

Fig. 8. Block Diagram of Defuzzifier.

The mathematical expression $\sum Si * Ri \ / \ \sum Ri$ has used for crisp values of output variables which are according to MATLAB simulation results as shown in Fig. 9.

The values of input variables, VT, TC and EM are taken as the same for MATLAB simulation as for mathematical calculation that shows correct results with quick response.

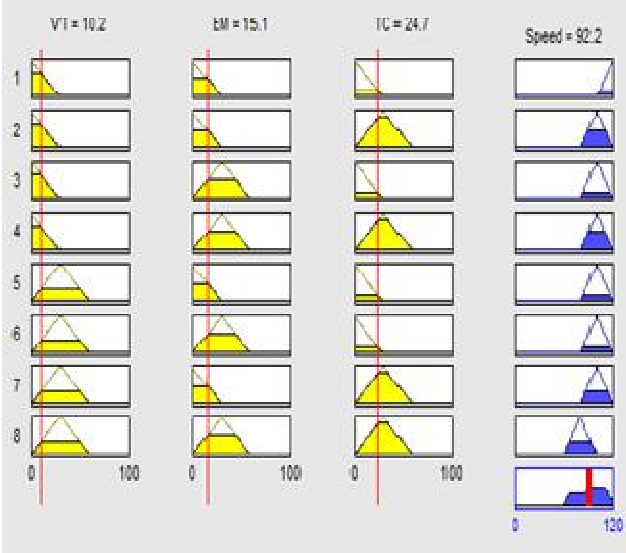

Fig.9. MATLAB- Rule Viewer and Simulation Results for Speed Scheduling System of Railway Vehicles.

5 Results and Discussion

The design model of proposed speed scheduling system of autonomous railway vehicle has shown significant improvement in performance regarding safety and time to meet uncertain conditions with minimum delay using fuzzy inference system with MATLAB simulation as compared to traditional approaches. Soft conditions like VT, EM and TC are inversely proportional with respect to speed and have shown substantial effect on it in case of any change in input variables individually and combined as well. The effect of these inputs on speed has shown in Fig.10 which is according to rule base of design algorithm.

Fig. 10 (a) has shown that at 0 of both VT and EM, the speed is fast, more than 100 km/h which gradually decrease with increase in values of EM and VT.

Fig. 10 (b) has shown the same effect with input variables VT and TC which is according to rule base by assigning specific values to input variables to specific region and prove that these three variables have same effect on speed.

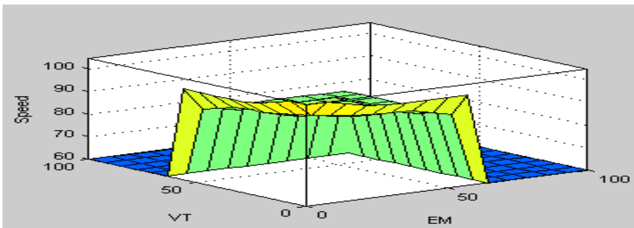

Fig. 10 (a) Plot between Environment Monitoring and Vehicle Tilting.

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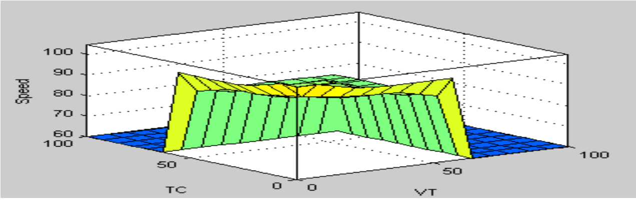

Fig. 10 (b). Plot between Vehicle Tilting and Track Condition.

6 Conclusion and Future Work

FIS based speed scheduling system of autonomous railway vehicles has shown remarkable improvement to compete the demands of new trends with safety and minimum time delay. Now day's railway control system requires some sophisticated method to handle real time problems without compromising on schedule time and security. MATLAB results have shown that proposed model of railway speed scheduling system will be capable to handle uncertain conditions successfully with better and quicker response as compared to existence methods with time management and safety by reducing risk. In future, fuzzy inference system base railway control system will be more secure with performance enhancement in real time environment. State of the art Microelectronics technology can be used to develop FPGAs based control chips for this autonomous railway control system.

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