Research Article
Turkish Journal of Maritime and Marine Sciences Volume: 2 Issue: 1 (2016) 37-48

Comparing Collision Avoidance Systems of Different Type of Transportation Mode

Farklı Taşıma Modlarının Çatışmadan Kaçınma Sistemlerinin Karşılaştırılması

Türk Denizcilik ve Deniz Bilimleri Dergisi Cilt: 2 Sayı: 1 (2016) 37-48

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ABSTRACT

Different modes of transportation are often used in our daily lives. Therefore, how safe these modes are commonly researched by researchers. Many models and methods are developed to avoid collision with the development of technology. This development is aimed to improving the safety of life and property. The technological developments also aim to reduce the minimum level of the human error. Technological devices developed to prevent collision are applied in systematic way according to type of transportation mode. When comparatively examined, it is similar to each other technology used in different modes. In this respect, proposed model and methods are similar in general. These approaches are generally based on position of vehicles relative to each other and also rules have been developed taking into consideration the possibilities that may occur. Real-time sensors used to avoid collision in vehicles reduce risk of collision and provide significant achievements on behalf of avoiding collision. Besides this, it has been considered important a communication network between vehicles. As a result, the importance of the technological devices developed to ensure collision avoidance is increasing in our life. Thus, the study aims to explain and compare the methods, models and techniques used in the different transportation modes so as to avoid collision.

Keywords: Collision avoidance, Transportation mode, Autonomous systems, Artificial intelligence

Article Info
Received: 12 September 2016
Revised: 25 October 2016
Accepted: 15 November 2016

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ÖZET

Günlük hayatımızda farklı ulaşım modları sıklıkla kullanılmaktadır. Bu sebeple bu modların ne kadar güvenli olduğu sıklıkla araştırılmaktadır. Teknolojinin gelişmesi ile birlikte çatışmadan kaçınma amacıyla birçok model ve metot geliştirilmektedir. Bu gelişmeler can ve mal güvenliği arttırmayı amaçlamaktadır. Teknolojik uygulamaların amacı insan hatasını en az seviyeye indirmektir. Çatışmayı önlemek için geliştirilen teknolojik donanımlar önem sırasına göre farklı ulaşım yollarında sistematik bir şekilde uygulanmaktadır. Karşılaştırmalı olarak incelendiğinde ise farklı ulaşım modlarında kullanılan teknolojiler birbirlerine benzemektedir. Bu bakımdan, önerilen model ve metotlar birbirine benzer niteliktedir. Genel olarak bu hesaplamalarda ulaşım araçlarının birbirlerine göre konumları baz alınmış, oluşabilecek ihtimaller göz önüne alınarak kurallar geliştirilmiştir. Ulaşım araçlarında çatışmayı önlemek için kullanılan gerçek zamanlı sensörler riski azaltarak, çatışmadan kaçınma adına önemli ölçüde başarılar sağlamaktadır. Bunun yanında araçlar arası bir iletişim ağı ile doğrudan haberleşmeye de önem verilmiştir. Sonuç olarak çatışmadan kaçınmayı sağlamak için geliştirilen teknolojik donanımların hayatımızdaki önemi gün geçtikçe artmaktadır. Buradan hareketle, bu araştırmada günümüz teknolojileri ile farklı ulaşım modlarındaki çatışmadan kaçınma amacıyla kullanılan metotlar, teknikler ve yöntemlerin açıklanması ve karşılaştırılması hedeflenmektedir.

Anahtar sözcükler: Çatışmadan kaçınma, Ulaşım modları, Otonom sistemler, Yapay zeka

1. INTRODUCTION

Collision avoidance systems are believed to reduce the risk of accidents, improve safety, increase capacity, enhance overall comfort and performance for drivers or navigator. There has been enough reason to assume that more automated vehicles relieve the driver from many undesirable routines of driving or navigation task. It has also been known that many of the vehicles accidents are due to human errors. Therefore, the conclusion has been that with robust automated systems, artificial intelligent systems and real time systems the chance of vehicle accidents can be reduced. Future system devices aim to provide decision-making, instead of the decision of the people (Vahidi and Eskandarian, 2003).

Collision avoidance is a crucial issue in most transportation systems as well as many other applications. The task of any collision avoidance system is ultimately to avoid two or more objects from colliding. In today's world, in addition to meeting high standards of safety, environmental conservation and performance, transportation industry has to meet the demands of enhanced safety. Collision avoidance systems are being used in a wide range of different areas and under very different circumstances (Jansson et al., 2002; Tamura et al., 2001 as cited in Jannson and Gustafsson, 2008). The collision avoidance systems show a very rapid development in recent years. Detecting and avoiding a possible collision have been studied for several different fields of application such as maritime collision avoidance, aviation collision avoidance, road collision avoidance, railway collision avoidance (Jansson, 2005).

2. MARITIME COLLISION AVOIDANCE SYSTEMS

Nowadays, maritime collision avoidance and its optimization have been researched frequently. The topic become a hot topic within the researchers. The reason substantially is accidents such as meteorological conditions, collisions or groundings, traffic density, navigator experience/skill and condition of ship. This can substantially threaten crew safety and impact the marine environment. Statistical analysis indicates that accidents of ship collisions at sea are 80% because of human factors (Li et al., 2006 as cited in Tsou and Hsueh, 2010). This refers inaccuracy of navigator assessments in respect to collision avoidance timing, ship movement, favorable avoidance strategies and collision risk prediction.

Nowadays, because of technological development and the new maritime regulations, novel types of navigational equipment are being developed. This may cause navigational information data overload, that may affect a navigator or operator with inadequate knowledge and experience when make a decision. For this reason, by making the ship more intelligent via technology in order to decrease manual operations and subjective decision, ship collision avoidance becomes more intelligent and a navigator's burden is reduced. This can be solution for human-based problems (Tsou and Hsueh, 2010). For this reason, many methods were researched for solving the human-related problems.

There have been many methods, techniques and models proposed for solving maritime collision avoidance. These approaches can be divided into three main categories as deterministic approaches (Szłapczyński, 2007; Perera and Soares, 2015; Chang and Jan, 2003; Zhang et al., 2015; Itoh et al., 2003), artificial intelligent approaches (Tsou and Hsueh, 2010; Lazarowska, 2012; Zhu et al., 2001; Zeng, 2003; Smierzchalski and Michalewicz, 1998; Hwang, 2002) and hybrid systems (Harris et al., 1999; Chohra et al., 1997; Borenstein and Koren, 1989; Lee at al., 2015).

Deterministic approaches refer to the certain mathematical definition of navigation environment. This type of approaches utilizes a precise description for solving collision avoidance problem. These algorithms are important in terms of providing exact solutions compared to heuristic algorithms, but the solution time may take a long time.

Artificial intelligent approaches comprise primarily of fuzzy logic (Zadeh, 1965) heuristic approaches, neural networks and etc. These type of algorithms can make easier complicated problem by means of its high computational competence and learning capacities.

Hybrid systems propose a combination of all mentioned above.

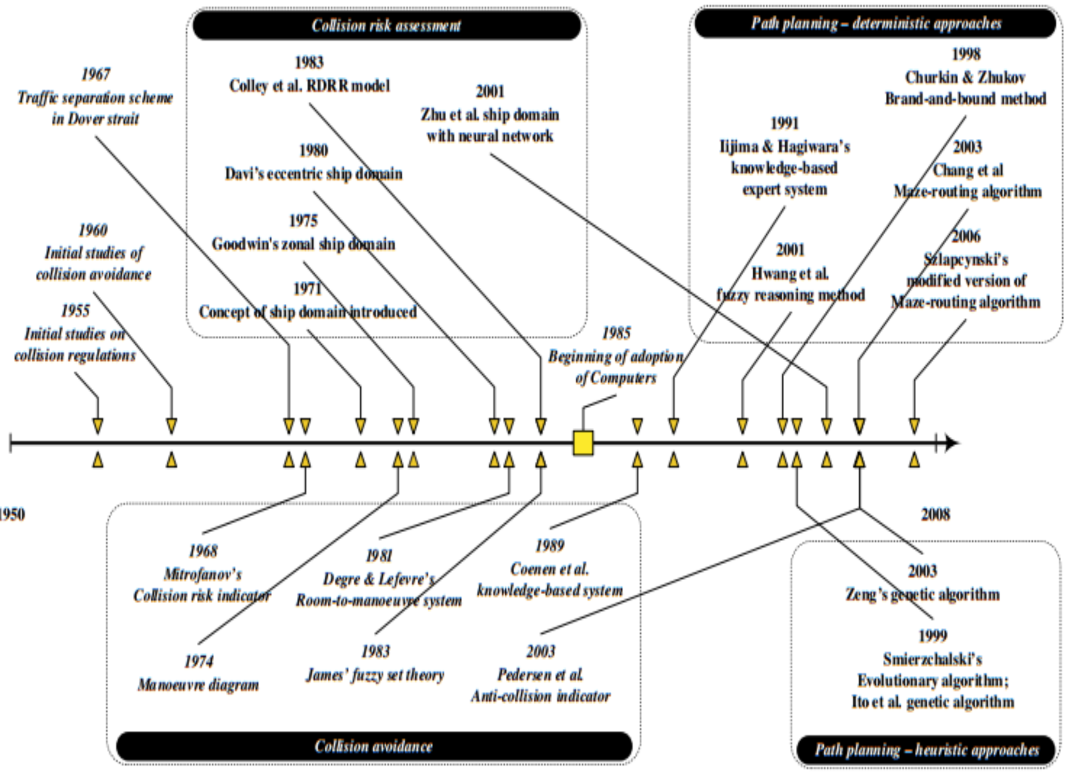

Figure 1. Timeline development of maritime collision avoidance models (Tam et al., 2009).

3. AVIATION COLLISION AVOIDANCE SYSTEMS

A collision between aircraft is one of the most catastrophic transportation accidents (Kuchar and Drumm, 2007). In spite of the aviation travel is incredibly safe, plane failure or mistake are not possible to repair in the air and terrifying prospect of a mid-air collision. This collision causing the death of human life. So collision avoidance system for aviation are developed continuously. The most important collision avoidance system is TCAS (Traffic Alert and Collision Avoidance System). TCAS is the aviation community to develop a viable collision avoidance system to complement the Federal Aviation Administration's (FAA) ground-based air traffic control (ATC) system (Williamson and Spencer, 1989). TCAS is an airborne system used for detecting and tracking aircraft near your own aircraft. The Traffic Alert and Collision Avoidance System has been shown to significantly reduce the risk of mid-air collision and is currently mandated worldwide on all large transport aircraft (Kochenderfer et al., 2011). Even though there are different theories for collision avoidance for aviation, most of theories based on Traffic Alert and Collision Avoidance System.

TCAS was defined by Kuchar and Ann Drumm (2007). It is a kind of a multi-layered avoidance system for mid-air collisions. Aircraft are generally engaged 1000 ft vertically and three to five miles laterally so as to ensure satisfactory margin of safety. In some cases, if there is a traffic procedure fall down, the guidance from TCAS system helps pilots for possible dangers. An air collision occurred between two U.S. air carrier aircraft over the Grand Canyon is the beginning historical development of aviation collision avoidance (1950s). After for a while, several approaches and models proposed for collision avoidance. The Federal Aviation Administration (FAA) focused its attention to the Beacon Collision Avoidance System (BCAS) a transponder-based airborne collision avoidance system until 1974. Another air collision happened near San Diego between air carrier and aircraft in 1978. The incident lead to development of BCAS. The developed version of it was named as Traffic Alert and Collision Avoidance System (TCAS) in 1981.The other mid-air collision in 1986 near Cerritos, California, prompted Congress in 1987 to pass legislation requiring the FAA to conduct an aircraft collision avoidance system by the end of 1992. The force performed to all large turbine powered aircraft in the US. An ensuing law expanded the original deadline by one year to the end of 1993. The first merchant TCAS systems commenced flying in 1990. After, TCAS has become changes, referred to as Version 7, or the Airborne Collision Avoidance System (ACAS). ACAS was forced by The International Civil Aviation Organization for all turbine powered aircraft capacity of more than 19 or maximum take-off weight above 5,700 kg in January 2015. TCAS is commonly being used approximately 25,000 aircraft over the world, today.

TCAS includes different elements. The first one is that surveillance sensors collect state information as to the intruder aircraft and second set of threat-resolution algorithms designates a favorable response. The response is coordinated via a data link to provide that each aircraft maneuvers in a compatible direction. TCAS gives advisories to flight crews about threats. TCAS methods are surveillance, threat detection, and threat resolution. Observation of the air traffic is corresponded to air-to-air inquiries broadcast once per second from antenna on the TCAS aircraft using the same frequency and waveform as ground-based air traffic control sensors (Park and Tomlin, 2012). TCAS has menace fixing algorithms commenced by classifying intruders into one of four divide levels. The algorithm manages various key metrics to confirm whether an intruder is a threat, involving the estimation vertical and slant-range separations between aircraft. TCAS's threat-resolution algorithms confirm that maneuver is appropriate to avoid collision. First, the algorithm decides the vertical sense of the maneuver such as climb or descend. Second, the plane needs to modify its altitude.

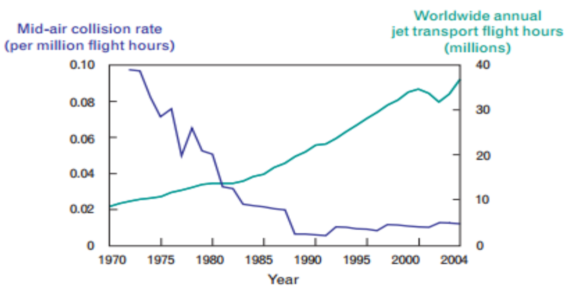

Figure 2. Worldwide annual flight hours and mid-air collision (Kuchar and Ann Drumm, 2007).

Figure 3 shows that TCAS relies on a combination of surveillance sensors to gather dataset on the state of intruder aircraft and a set of algorithms that confirm the best maneuver that the pilot ought to conduct to avoid a mid-air collision (Kuchar and Ann Drumm, 2007).

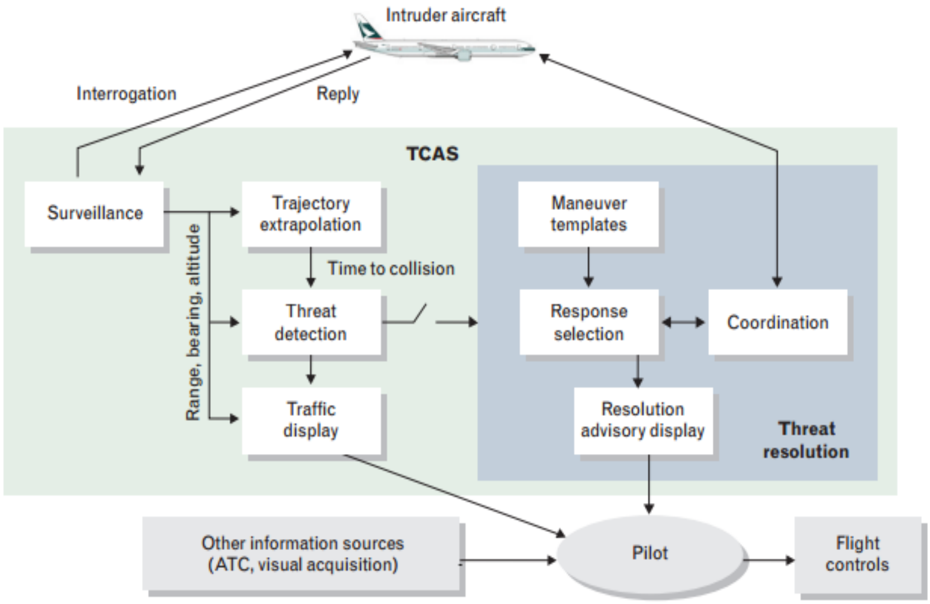

Figure 3. TCAS relies on a combination of surveillance sensors (Kuchar and Ann Drumm, 2007).

4. ROAD COLLISION AVOIDANCE SYSTEMS

Traffic accidents are the major reason for fatal accident nowadays. Automotive producers have begun to establish much more driver support systems to prevent accidents. Passenger car safety is a matter that has received enhancing attention over the last few decades. Over the last decades, automobile crashworthiness has developed severely. The rate of fatal accident in a car has diminished by 90% compared to an early car (Jansson, 2005). The automobile industry made an effort to develop anti-collision systems. In 1959, the first three-point seat belt was developed by Volvo. The first driver assist system was also developed in the 1980s. Following anti-blockier system (ABS) brake system was introduced. In the 1990s more driver support systems became common, such main systems are yaw control systems, traction control systems, roll stability systems, ABS brake systems. The first adaptive cruise control (ACC) system was developed in 1999 by Mercedes. Nissan developed the first lane-keeping assist system. It is also the first a collision mitigation by braking (CMbB) system, in 2002. Another primary trend through the last twenty years is the using of airbag systems. The system is the major reason for enhancing crashworthiness of contemporary cars (Jansson, 2005).

Automatic Pre-Crash Collision Avoidance Strategy: Ferrara and Paderno (2006) presented general automatic pre–crash collision avoidance strategy. There are two type systems for collision avoidance and mitigation of injury: a driver assistance system for cars manage to conducting a decision between an emergency braking and a collision avoidance maneuver. If the collision risk occurs, driver assistance system will be suitable for automatic action, in a time shorter than a favorable lower bound of the human reaction time. If velocity had controlled in real sense, accidents and injuries would have reduced.

Wireless Sensor Networks and Laser Sensors: Ramesh et al. (2012) presented the vehicle collision avoidance system using wireless sensor networks. In this study, main idea is using wireless sensor networks, and these sensors contain Laser sensor. Car anti collision system could be defined by using Laser rays with the laser transmitter and laser receiver. Laser transmitter is fastened to the laser sensor. CAN controller is connected to the all sides of the nodes and send the data via Zigbee (kind of wi-fi) and transmit the message to the LCD output on the driver side. Laser receiver is connected to the CAN controller. Controller area network (CAN or CAN-bus) is designed to let microcontrollers and tools to communicate with each other. CAN is a message based protocol, designed particularly for automotive implementations. Lasers using in variety areas such many academic, military, medical and merchant laser applications. A laser is a tool that emits electromagnetic radiation via a progress of optical elevation based on the emission of photons. Stands for laser is Light Amplification by Stimulated Emission of Radiation. A liquid crystal display (LCD) is used for monitoring of message. A wireless sensor network (WSN) comprises of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as sound, pressure, temperature etc. and to cooperatively pass their data via the network to a main place. Sensor network node has some parts: an electronic circuit for interfacing with the sensors, a microcontroller, a radio transceiver with an internal antenna or connection to an external antenna, and an energy source, usually a battery or an embedded form of energy harvesting.

Automotive Collision Warning/Avoidance System (ACWAS): Mahmud and Shanker (2003) presented the applicability of using Bluetooth or wireless devices along with GPS receivers to develop an Automotive Collision Warning/Avoidance System (ACWAS). A vehicle gathers information from the GPS receiver, accelerometer, electronic compass, speed sensor, etc., and then exchanges that set of data with other neighboring vehicles so as to alarm drivers about possible collisions. This operation of a Collision Warning / Avoidance system will depend upon how rigorously the distance between vehicles can be measured and how fast the set of data can be exchanged among the vehicles. If Bluetooth technology is used for the inter-vehicle wireless links, then each vehicle could hold track of another seven vehicles in real-time. The bandwidth serviceable from Bluetooth devices is adequate to exchange all vehicle definite information in real-time. If the subject vehicle and all object vehicles around it use the same set of satellites, then distance between the vehicles can be determined with a greater accuracy.

5. RAILWAY COLLISION AVOIDANCE SYSTEMS

Railway is an economic mode of transport in cities of the world. Train is widely used and comfortable nodes of transportation system. The railway is considered to be the safest and easiest network. Approximately 10 billion people and 1050 million freight are transported by train annually. Railway transport is necessary in modern day life, both for occupation and private users. Todays, railways in worldwide are getting busier with trains travelling at higher speeds and carrying more passengers and heavier axle loads than ever before. The integration of the factors has put significant pressure on the existing substructure, leading to increased demands in supervision and overhaul of rail assets (Saijyothsna and Umamaheswari, 2014).

Strang et al. (2011) introduced three main systems for collision avoidance of trains. The model consists of three basic technologies: a direct train-to-train communication system, a certain localization system and a cooperative situation analysis and decision support system. This system has been also applied with real trains and it is rather well for saving lives and avoiding collision. The trains could attain their topological and geographical position, speed and the planned route using direct train-to-train communication as soon as they are within radio range of one another. The system alarms train operator and guides them with a pre-assessment of the present condition. The first base constituent of RCAS is a short range communication system for being used in a railway environment with its spesific characteristics. It is used on favorable frequency band and proper signal propagation channel modeling. The second significant constituent of RCAS is its localization system. The system provide position of each train on the track network is an important data for the situation analysis. For supporting the system, using a set of functional complemental position sensors such as RADAR, cameras, GPS, odometer, eddy current sensors. The data from all the sensors are assessed for consideration of anti-collision. The third significant constituent of the RCAS is its internal situation prediction and analysis algorithm. A probabilistic situation prediction algorithm has been used, considering all data as to the trains in a zone of at least 10 km in diameter, and their movements across the track topology in the next minutes. The algorithm increases an alarm level depending on the probability of a collision and the remaining time to this event.

Saijyothsna and Umamaheswari (2014) proposed a model for railway collision avoidance by creating mutual communication using Zigbee. In the system insure communication between trains to prevent in same track, every train send its track id to other trains, if the one train goes in a first track, the signal is applied to the another train, if any other train get in same track and it also send out first track to other, then two trains gets same track id then alert two train operators and stop train at a distance to avoid collisions, which can urgently stop the train. The proposed system uses with buzzers, microcontroller, switches, LCD, Bomb detectors, MAX-232 Serial communication, DC Motor, Temperature Sensor, Zigbee transmitter, Motor drive and receiver. Zigbee is an IEEE 802.15 - based specification for a suite of high-level communication protocols used to generate personal area networks with small, low-power digital radios. Zigbee tools could convey information over long distances by passing information via a network of intermediate tools to get more distant ones. Zigbee is ordinally used in low data ratio applications that require long battery life and secure networking. ZigBee has an identified ratio of 250 kbit/s, best suited for intermittent data transmissions from a sensor or input tool. Characteristics of the system are well sensitivity, perfect determination, well localized ability, loudspeaker output, ordinary construction and set up, tuning lets for ground and low cost.

6. COMPARISON OF COLLISION AVOIDANCE SYSTEMS

Collision avoidance systems are simulated in various type of situations and these situations ordinarily are encounter situations and obstacle avoidance situations. In recent years, it is observed that advances in technological studies has been came into use. Also, collision situations play a significant role in the development of the systems. As seen in all means of transportation, after major accidents and loss of life or property create rules, regulations and collision avoidance systems.

In marine implementations, radar systems with ARPA are widely used to specify other vessels or objects. Radar provides significant guide for encounter situations. But in the near future, artificial intelligent systems and collision avoidance of autonomous ships will join in the maritime industry. In aviation applications, Radar-based air traffic control (ATC) systems have been being used for last decades. Traffic alarm and collision avoidance system (TCAS) has been being used on aircraft since 1990s. The systems generally aim at guiding pilots and traffic controllers in keeping a regulated minimum separation between any two aircraft. Nowadays, researches are developed base on TCAS. In road applications, long range radar or optical sensors, a lane detection system, lidar, ABS brake systems, yaw control systems, traction control systems, roll stability systems and adaptive cruise control commonly used. Also the proposed system vehicle to vehicle communication is important for road collision avoidance system. Driver can learn the other driver's intention with this system and we can avoid instability (Jansson, 2005). In rail applications, most of the current work in collision warning systems are GPS based Cab Signaling, Block Signaling, Automatic Train Control, Railway Collision Avoidance System (RCAS) Train Collision Avoidance System (TCAS). Today railway industry focuses on communication between trains with zigbee protocol and their devices. (Saijyothsna and Umamaheswari, 2014).

This study shows that the majority of researches is observed that a human error. Therefore, the majority of researches are intended to eliminate the human error factor. Authorities has concentrated on the research of unman vehicles with collision avoidance systems. There are plenty of applications with unmanned autonomous vehicles. It tries to reach the goal in an effective manner and at the same time avoid collisions with any obstacle.

Most of the work was accomplished, but there are a real-time systems problem due to complicated algorithmic calculations and long duration of calculation. Some proposed systems have been applied for collision avoidance system in heavy traffic area. These systems will have a wide field when finding a solution for the real-time problems.

Table 1. Comparison of Collision Avoidance Systems

Maritime Collision Avoidance Systems	• Path planning with ant colony, Genetic algorithm for safe path • Determination of safe optimal trajectory of ship with COLREG • Safety domain model, EP/N (evolutionary planner / navigation) • H_∞ - autopilot on ships, Collision avoidance of autonomous ships • Visualization-based collision avoidance support system • A multi-ship anti-collision decision support formulation • Optimal routes with collision avoidance on raster charts • Collision risk detection and quantification in ship navigation with integrated bridge systems • Real-time ship obstacle avoidance and clearance
Aviation Collision Avoidance Systems	• Three dimensional audio display system • Traffic alert and collision avoidance system (TCAS I, TCAS II and TCAS III) • The traffic alert and collision avoidance system • Autonomous flight systems • Pseudo code and evaluating the system in encounter models • Variable autonomy ground collision avoidance system • Autonomous formation control for unmanned aerial vehicles • Probabilistic Collision Avoidance in Air Traffic Control
Road Collision Avoidance Systems	• Application to automotive collision mitigation • Automotive collision avoidance system (ACAS) • Strategies and coordinated control of passenger vehicles • Application of switching control for automatic pre-crash • Integrated collision avoidance systems • Wireless vehicular networks
Railway Collision Avoidance Systems	• Train collision avoidance system using vibration sensors • Zigbee technology and Microcontroller based model • Rail scout • Mutual communication using embedded system • Railway collision avoidance system (RCAS)

7. CONCLUSIONS

In this study, collision avoidance system was studied on different transportation modes. There are similarities and differences of collision avoidance systems. All systems' aim is to prevent the collision, moral and material losses, also collision warning. All transportation modes generally attach importance to communication, detection systems, real-time systems and artificial intelligent systems. In the future, these systems will be integrating and they are intended to be used more effectively.

Artificial intelligence studies are carried out intensively in the maritime sector. Intensive data transfer of the current systems is forcing people in decision-making. Computers with artificial intelligent systems facilitate the decision-making as optimal and safe path planning, collision avoidance and collision warning systems in aviation, road and rail transportation modes. So, collision avoidance system which takes control of the vehicle when drivers give no response to warnings given by warning system and applies emergency maneuver to avoid possible collision risk were designed, during complex traffic environments. In particular, road and rail systems focused on communication and real-time obstacle avoidance. There is TCAS for aviation and most of the work is being developed through this system. In recent years, especially in highways intensive research is carried out on collision avoidance systems due to the increase in the human population and traffic.

Aviation collision avoidance systems firstly began to be researched after that respectively marine, rail and road collision avoidance systems were researched. But in the 20th century, it is observed that all collision avoidance system in different transportation modes developed as parallel. It is observed that the transportation systems more similarities than differences. These systems are used extensively such as RADAR, laser, obstacle detection systems, communication systems, network systems, path planning systems, optimal and safe tracking sensor. It is certain that this future technology will greatly influence Collision Avoidance System which is dependent to artificial intelligent systems and hybrid systems.

8. ACKNOWLEDGEMENTS

This article was prepared from the Final Project titled “Comparing Collision Avoidance System of Different Types of Transportation Mode”, Dokuz Eylül University, Maritime Faculty, Department of Marine Transportation Engineering, İzmir, 2016.

9. REFERENCES

Vahidi, A., Eskandarian, A., (2003). Research advances in intelligent collision avoidance and adaptive cruise control. *IEEE Transactions on Intelligent Transportation Systems* 4(3): 143-153.

Jansson, J., Ekmark, J., Gustafsson, F., 2002. Decision making for collision avoidance systems. In: SAE technical paper 2002-01-0403, Society of Automotive Engineers 2002 World Congress, Vol. SP-1662, Detroit, MI, USA.

Tamura, M., Inoue, H., Watanabe, T., Maruko, N., 2001. Research on a brake assist system with a preview function. In: SAE technical paper 2001-01-0357, Society of Automotive Engineers 2001 World Congress, Detroit, MI, USA.

Jansson, J., Gustafsson, F., (2008). A Framework and automotive applications of collision avoidance decision making, *Automatica* 44(9): 2347-2351.

Jansson, J., (2005). Collision avoidance theory with application to automotive collision mitigation, Department of Electrical Engineering, Linköping University, Linköping, Sweden.

Li, L. N., Yang, S. H., Cao, B. G., Li, Z. F., (2006). A summary of studies on the automation of ship collision avoidance intelligence, *Journal of Jimei University* 11(2): 188-192.

Tsou, M. C., Hsueh, C. K., (2010). The study of ship collision avoidance route planning by ant colony algorithm, *Journal of Marine Science and Technology* 18(5): 746-756.

Szłapczyński, R., (2007). Determining the optimal course alteration manoeuvre in a multi-target encounter situation for a given ship domain model, *Annual of Navigation* 12: 75-85.

Perera, L. P., Soares, C. G., (2015). Collision risk detection and quantification in ship navigation with integrated bridge systems, *Ocean Engineering* 109: 344-354.

Chang, K. Y., Jan, G., (2003). A method for searching optimal routes with collision avoidance on raster charts, *The Journal of Navigation* 56: 371-384.

Zhang, J., Zhang, D., Yan, X., Haugen, S., Soares, C. G., (2015). A distributed anti-collision decision support formulation in multi-ship encounter situations under COLREGs, *Ocean Engineering* 105: 336-348.

Itoh, H., Numano, M., Pedersen, E., (2003). Modelling and simulation of sea traffic and a visualization-based collision avoidance support system. *Papers of National Maritime Research Institute* 3(5).

Lazarowska, A., (2012). Decision support system for collision avoidance at sea, *Polish Maritime Research* 19(74): 19-24.

Zhu, X., Xu, H., Lin, J., (2001). Domain and its model based on neural networks, *Journal of Navigation* 54(1): 97-103.

Zeng, X., (2003). Evolution of the safe path for ship navigation, *Applied Artificial Intelligence* 17(2): 87-104.

Smierzchalski, R., Michalewicz, Z., (1998). Modeling of ship trajectory in collision situations by an evolutionary algorithm, *IEEE Transactions on Evolutionary Computation* 20:1-18.

Hwang, C. N., (2002). The integrated design of fuzzy collision-avoidance and autopilots on ships, *The Journal of Navigation* 55: 117-136.

Harris, C. J., Hong, X., Wilson, P. A., (1999). An intelligent guidance and control system for ship obstacle avoidance, *Proceedings of the Institution of Mechanical Engineers, Part 1: Journal of Systems and Control Engineering* 213: 311-320.

Chohra, A., Farah, A., Belloucif, M., (1997). Neuro-fuzzy expert system E_S_CO_V for the obstacle avoidance behavior of intelligent autonomous vehicles, *Advanced Robotics* 12(6): 629-649.

Borenstein, J., Koren, Y., (1989). Real-time obstacle avoidance for fast mobile robots, *IEEE Transactions on Systems, Man, and Cybernetics* 19(5): 1179-1187.

Lee, Y. I., Kim, S. G., Kim, Y. G., (2015). Fuzzy relational product for collision avoidance of autonomous ships, *Intelligent Automation and Soft Computing* 21(1): 21-38.

Zadeh, L. A., (1965). Fuzzy Sets. *Information and Control* 8: 338–353.

Tam, C. K., Bucknall, R., Greig, A., (2009). Review of collision avoidance and path planning methods for ships in close range encounters, *The Journal of Navigation* 62: 455-476.

Kuchar, J. K., Drumm, A. C., (2007). The traffic alert and collision avoidance system, *Lincoln Laboratory Journal* 16(2): 277-296.

Williamson, T., Spencer, N. A., (1989). Development and operation of the traffic alert and collision avoidance system (TCAS). *Proceedings of the IEEE*, 77(11): 1735-1744.

Kochenderfer, M. J., Chryssanthacopoulos, J. P., Weibel, R. E., 2011. A new approach for designing safer collision avoidance systems, Ninth USA / Europe Air Traffic Management Research and Development Seminar, Massachusetts Institute of Technology Lexington, Massachusetts, USA.

Park, P., Tomlin, C., 2012. Investigating communication infrastructure of next generation air traffic management, IEEE/ACM Third International Conference on Cyber-Physical Systems, 35-44.

Ferrara, A., Paderno, J., (2006). Application of switching control for automatic pre-crash collision avoidance in cars, *Nonlinear Dyn.* 46: 307-321.

Ramesh, S., Ranjan, R., Mukherjee, R., Chaudhuri, S., (2012). Vehicle collision avoidance system using wireless sensor networks, *International Journal of Soft Computing and Engineering* 2(5): 300-303.

Mahmud, S. M., Shanker, S., (2003). An architecture for intelligent automotive collision avoidance systems. *Ionosphere* 5: 183-188.

Saijyothsna, T., Umamaheswari, P., (2014). Collision avoidance of trains by creating mutual communication using embedded system, *International Journal of Innovative Research in Computer and Communication Engineering* 2(7): 5203-5208.

Strang, T., Lehner, A., Rico Garcia, C., Heirich, O., Grosch, A., 2011. Cooperative situation awareness for a railway collision avoidance system (RCAS). In Adjunct Proceedings.