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Real-Time Traffic Controlling Through Multi-Agent Technology

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Abstract: In Sri Lanka, most of the traffic controlling happens through a fixed time controlling and runs on a static environment. However, these traffic control systems are not much effective compared to human-based traffic control. This research is focused on the design and development of a multi-agent-based real-time traffic controlling system that should be capable of controlling traffic effectively. The proposed multi-agent system technology is one of the modern software techniques, capable of handling complexity in the dynamic environment. Thus, the multi-agent system has been designed with a vehicle, junction, and passengers are considered as agents. Traffic control has been arranged through communication among agents. As the initial stage of the research, traffic behaviour was simulated through the NetLogo simulation tool. The efficiency of the traffic controlling was calculated for the three different approaches including, an uncontrolled way, time-based static method, and agent-based controlling. According to the simulated results, agent-based traffic control provides remarkable efficiency than the other existing methods.

Keywords: Traffic congestion, Multi-agent Systems, Control

Introduction

Moving toward a digital world almost all the fields in a country face challenges. Road transportation is one field that develops with various challenging factors like vehicle density, climatic changes, infrastructure, etc. With these challenges, traffic congestion is a growing problem in transportation. According to the 2019 Urban mobility report (Schrank et al., 2019), most of the workers are on the road around 8.00 a.m. and 5.00 p.m. which are named rush hours. In these hours people who use both public and private transportations face delays due to traffic jams. In Sri Lanka, Colombo is the commercial capital and largest city. 7.8 million passengers' daily travel in and out to the Colombo region. Therefore, the average travel speed in Colombo drops to 10km per hour. It is expected that the passengers entering the Colombo region will increase by 4.4 million in 2035. There are 7.4 million vehicles in Sri Lanka and 70% of the roads hold traffic jams. Because of this heavy traffic congestion, Sri Lanka lost 1.5% of the GDP. Most of these traffic jams occur near junctions where traffic light systems are used to control the traffic. The main problem in this system is the way of allowing vehicles to cross junctions. This existing traffic control system in Sri Lanka and most of the countries are preprogrammed and timed based (M. Tomizuka, and P. Varaiya, n.d.). The periods are set according to two categories as peak hours and off-peak hours. Normally morning evening and night counts as peak hours and early mornings and midnight as off-peak hours. Although it is categorized as above, the system is still pre-timed and cannot be changed according to the situation. This causes serious problems especially near junctions because this system cannot change according to the actual traffic density and its roots to heavy traffic jams. When there are two consecutive junctions, a lot of time and

fuel get wasted. Sometimes along with the current traffic control system, police officers are also assigned to intersections. These traffic jams not only waste time but also give people stress, accidents, intention to break the law, etc.

There are various systems implemented for traffic controlling situations in the world. Among them (Arel et al., 2010),(Omar, 2015), and (Qingming et al., n.d.) are some of the traffic control systems proposed or developed using various technologies like reinforcement learning, fuzzy logic, IoT, distributed systems, learning classifier systems, and image processing. Commonly used technologies are fuzzy logic controllers and reinforcement learning. Almost all the systems developed as software simulations or as design models. Many systems are designed using common strategies like designed algorithms, mathematical functions, and models to cope with system complexity. Those systems address the traffic congestions in urban areas while a limited number of them address the traffic specifically in four-way junctions with the above ideas, the research has been conducted to develop an intelligent traffic control system through the multi-agent system technology.

The rest of the paper is organized as follows. The second section gives a brief review of related works including multi-agent system technology and some existing traffic control systems. The third section describes the design of the proposed system including ontology, agent model, and communication diagram. Section four demonstrates the simulation setup of the system including a detailed description of three approaches we are going to test. The last section reports the conclusion with further works of the project.

Literature Review

A. Multi-Agent System Technology

Multi-Agent System is one of the co fields that come under Artificial Intelligence. The main element in the Multi-agent System is called an “Agent-based system”. An agent has the autonomous action capability and multiple interaction ability. Simply agent is an entity that interacts with its environment. Here the environment may be a real or virtual space where the agent lives in. The use of agent concepts can be categorized into three levels as an organization, interaction, and agent level. According to main features in multi-agent systems (Graham Low and Quynh Tran Nhu, n.d.) capacity is limited in each agent, no global control, each agent has a partial point of view, decentralized data in the system and asynchronous calculations. Main Multi-Agent System applications areas include networks, distributed/concurrent systems, and human-computer interfaces. Multi-Agent technology can be used in situations where a problem cannot perfectly solve through algorithmic solutions. The problems solved through Multi-Agent Systems cannot be explained through flowcharts. Traffic congestion is also a similar problem. As in (Vlassis, 2007) some advantages of using Multi-Agent System technology in large scale software systems like traffic controlling are cost, robustness, scalability, speed, efficiency, reliability, flexibility, development and reusability. Multi-Agent software is different from conventional software. Multi-Agent software is a network of software agents, but conventional software is an application designed to perform a specific task. The differences between this two software are shown in Table I. Multi-Agent System technology can be applying to different large-scale complex systems to make the work effective. This technology gives the ability to transfer from a single intelligent model to a multi intelligent model that represents a human intelligent acting model. The next subsection briefly reports some related traffic control systems.

Table 1. Software Comparison

	Multi-Agent Software	Conventional Software
Process	Parallel	Sequential
Behaviour	Emergent	Preprogrammed
Decision	Distributed	Centralized
Approach	Knowledge-driven	Data-driven

B. Related Works

This section focused on the existing traffic control systems and their related functions. The current method used in Sri Lanka is a pre-programmed time-based controlling system (How Do Traffic Signals Work? 2006). This method did not address the problems that occur in current traffic management. It makes the situation more complex. As an example, though there is no vehicle on the road the system gives the priority to that road according to the program. (Arel et al., 2010) developed a reinforcement learning-based multiagent system for efficient traffic signal control. The system suggests a multi-agent and Reinforcement learning framework and aims to optimize queuing delays by scheduling traffic signals at junctions. An algorithm was implemented to identify heavy traffic jams or the longest queue first. (Khaled et al., n.d.) developed an intelligent decision support system to control road traffic. In this system, an intelligent agent was assigned to assist human operators in the traffic control center. The system was designed as a collection of a subnetwork that supports intercommunication. Each agent was designed to perform three functions, monitoring and detection, traffic control, and traffic device control. (Pierre-Luc Gregoire et al., 2007) developed a learning agent-based traffic control system. Here an intelligent learning agent was created to control the traffic. The agent was created to learn the control policy with the help of machine learning algorithms to adapt to the system. That was specially designed to control traffic congestions at intersections.

An intelligent traffic information system based on a combination of the Internet of Things IoT) and agent technology was developed by (Omar, 2015). It is an IoT agent-based system to collect traffic information to provide a solution to this traffic problem. The system operates with mobile agent technology. All the traffic data is collected through RFID in each vehicle and sent to the server for analysis. But using a large no of RFID is an obstacle for the improvement of security factors. Zenjiang et al. proposed an agent-based distributed and adaptive platform for the transportation system (Qingming et al., n.d.). The signal control module consists of different agents' - responses to various conditions. The module runs on the traffic controller application-specific operating system for real-time operation.

Fuzzy logic controller for a traffic junction was proposed by (C. P. Pappis ; Ebrahim H. Mamdani, n.d.). The controller was designed and compared with the actuated controller. The design model is implemented by assuming the arrival of vehicles to junctions being random. The model compiled many times for reliable results. A traffic junction controller by applying a classifier system together with fuzzy logic was designed by (Cao et al., 1999). The designed fuzzy controller connects the traffic condition and traffic lights via a classifier system. The classifier system was tested with both reinforcement and evolutionary learning that determine control rules in a dynamic environment. A real-time traffic signal control system architecture and algorithm were proposed by (Mirchandani and Head, 2001). The paper discusses mainly the system architecture, designed algorithm, and analysis. The system provides four main functions as chunking the traffic problem into subproblems, predict traffic flows, use

optimization modules to solve subproblems, and utilize approaches that give fast solutions. The street detectors monitor the traffic and use the data to predict future traffic streams. The controlling process was done through algorithms like intersection and flow control.

(Blosseville et al., 1990) designed and developed a traffic measurement system with the use of the image processing technique. An algorithm was developed with various traffic images obtained from intersections and roads. Further, the algorithm was created with the ability to recalibrate to detect lanes. The system consists of various modules as line detection, vehicle detection, vehicle tracking, and detection in saturated traffic. The system dedicated hardware is still under development to build new modeling of traffic behaviour. (Walad and Shetty, 2014) proposed a traffic light control system using image processing. The basic operation is vehicles were detected using image processing, analyze the traffic, and control the traffic lights according to traffic density. The system comprises hardware, software, and interfacing components. The edge detection was used to declare the presence of vehicles and roads with high vehicle density get the priority and along with that time is also used as a parameter in the operation process. The systems avoid the waste of time happening in the existing system with priority, but the accuracy is not a hundred percent confirmed in both systems.

(Péter, 2012) proposed a nonlinear road traffic network to control the junction traffic. A specially developed mathematical model was used and through that, it examines the non-linear equation system. The regulations and large-scale traffic system can be tested using this model. Apart from that, this model is designed to use directly for simulations and analysis. Based on real-time vehicle density, the model is designed to provide instructions for traffic canters to avoid traffic jams. (Bull et al., 2004) proposed a distributed adaptive traffic control using learning classifier systems. This approach gives the ability to develop signal control strategies according to the performance. The learning classifier system was used mainly because its rules were interpreted as action controlling, a mathematical function adopted to transform traffic measures and choices of measures of traffic conditions. (Di Febbraro et al., 2004) designed a traffic control structure using Hybrid Petri Nets (HPN). HPN model is used to supervise the controller in the system and to describe vehicle flow by discrete event models and represent traffic dynamics. The model uses traffic coordination to give priority to special vehicles like ambulances. (Maduwanthi et al., 2016) proposed a traffic management scheme for both vehicles and pedestrians. The study was done to analyze the current traffic situation in Kottawa city and store the data for predictions. It uses the data to predict traffic congestion in the year 2034. The summary of the related works is shown in Table 2.

Table 2. Review Summary

Reference	Technology	Features
(Arel et al., 2010)	Reinforcement Learning	Algorithm-Based and designed for junction
(Khaled et al., n.d.)	Multi-Agent	Monitoring and detection, and traffic device control
(Pierre-Luc Gregoire et al., 2007)	Machine Learning	Learning algorithm and designed for junction congestion
(Omar,2015)	IoT RFID	Controller-Based with designed algorithms
(Qingming et al., n.d.)	Learning Agents, Distributed system	Real-time and controller based

(C.P.Pappis ; Ebrahim H. Mamdani, n.d.) ,(Cao et al., 1999)	Fuzzy Logic, Classifier Systems	Four lanes with centre controller based.
(Mirchandani and Head, 2001)	Designed Algorithm	Chunking the traffic problem into subproblems, predict traffic flows, use optimization modules
(Blosseville et al., 1990)	Image Processing	Designed Algorithm for the intersection
(Walad and Shetty, 2014)	Image Processing	Real-time and not for the junction.
(Péter, 2012)	Mathematical Modelling	Controller base for a junction and real-time Provide advices for traffic centres
(Bull et al., 2004)	Learning classifier system	Four-way junction and real-time.
(Di Febbraro et al., 2004)	Hybrid Petri Nest	Real-Time. Give priority to special vehicles.
(Maduwanthi et al., 2016)	Analysing	Real-time system and give Predictions for both vehicles and pedestrians

The study depicts the way of increasing traffic congestion and suggests some solutions like communicating with vehicles to use other roads, efficient pedestrians, and better traffic light controlling methods.

Design of The System

Traffic controlling system has been designed with the four different types of agents namely vehicle, junction, pedestrian, and controlling agent. Figure 1 shows the agent design of the proposed system.

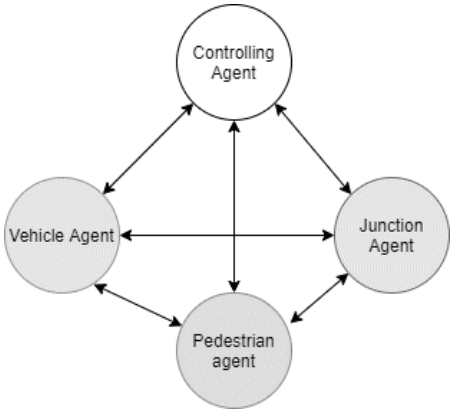

Figure 1. Experimental design for traffic control using Multi-Agent Technology

Junction Agent controls the traffic lights in each lane of the junction. The junction agent communicates with both vehicle and pedestrian agents to make the decisions. Junction Agent mainly considers the maximum waiting time of a lane in dynamic environmental situations. The vehicle agent communicates with the main agent at the intersection and it will analyze the situation.

Vehicle agents will get the priorities according to the situation. The vehicle agent also has to give a chance for the pedestrian agent. The pedestrian agent can communicate with the junction agent and may have to wait for permission to cross until other agents handle the condition efficiently. The controlling agent handles all the requirements and requests coming from the vehicle, pedestrian, and junction agent in a dynamic environment.

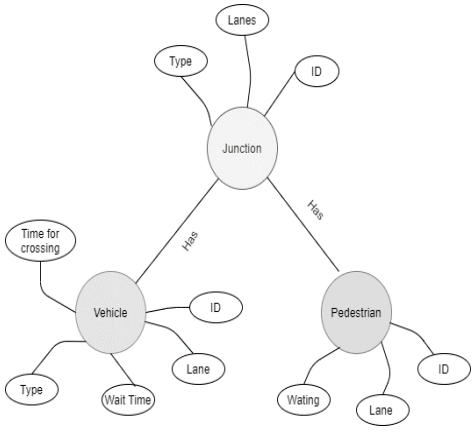

Figure 2. Ontology of the Traffic Controlling System

The ontological model of the proposed system has shown in Figure 2. In Multi-Agent technology, ontology is the main diagram that depicts detailed information of agents. It provides the metadata associated with agents and their relations.

The ontology consists of static knowledge of junction, vehicle, and pedestrian agents. This ontological data can be used to build up the knowledge base for the system. The agent communication of the proposed system has shown in Figure 3.

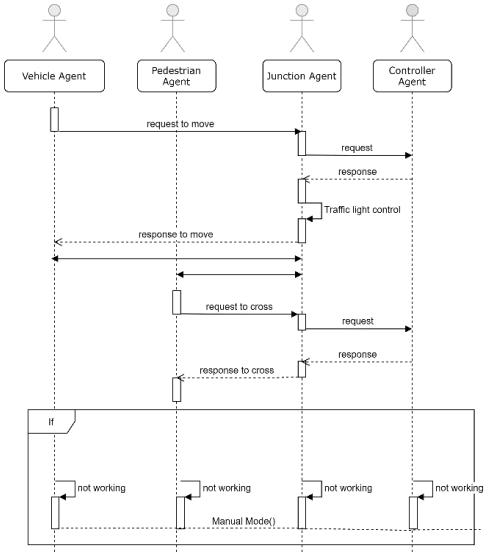

Figure 3. Communication Diagram

Agent communication in the system happens through three basic rules.

•Keep the lanes without any vehicle in disable state

•More period is allowed for lanes with more vehicle.

•Each lane comprises a maximum waiting time.

With the agent communication, controlling has been re-arranged. The vehicle agent requests the junction agent to move through the junction. The vehicle agent requests the junction agent to move through the junction. The request communicates to the controller agent and handles the scenario. The permission for moving directs to the junction agent and then to the vehicle agent. As same the pedestrian's request to cross the road go through the agent to the controller agent. The response to cross the road guides to the junction agent for traffic light controlling and to the pedestrian agent. If any error arises in one of the agents, the system automatically switches to the manual mode, which is the time-based method because the failure of one agent collapses the whole system.

Working Through A Simulation Environment

With the above, concepts, as the first stage of the research, the performance of the system has been compared with other existing methods using Net Logo simulations. Figure 4 shows the simulation environment of the proposed system. With the simulation environment, performance has been calculated by comparing other approaches.

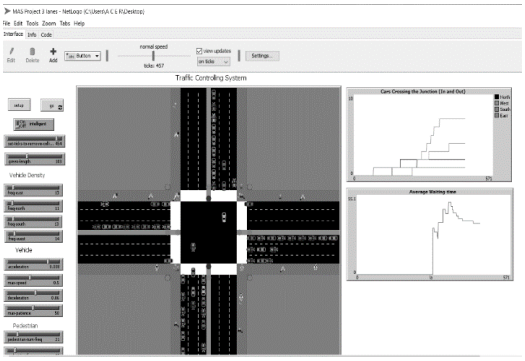

Figure 4. Netlogo Simulation Environment

In the simulation, both preprogrammed and multiagent based systems are implemented. The traffic lights in the preprogrammed system are operated into the given pattern and keep active for the given time. In Multi-agent simulation the system takes the decisions according to the previously defined rules. The lanes without any vehicles won't get active until a vehicle appears. These situations can be simulated bt changing the no of vehicles on each road. More time allocated for lanes with higher vehicle density. Some varying factors have been graphed in the simulation.

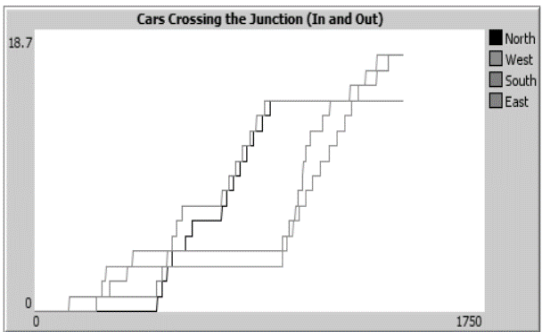

Figure 5. Graph of Vehicles crossing the junction

Figure 5 shows the density of vehicles crossing junction and goes in and out on each road. The graph values gradually increase as the vehicles come to the junction. The graphs keep in a continuous value when pedestrians crossing the roads.

Conclusion and Further Work

According to the review, most of the traffic control systems work using fuzzy logic and reinforcement learning technologies. These systems were implemented with common functions like real-time controlling, center controller-based, with specially designed algorithms, etc. However, most of the traffic control systems don't achieve dynamic control. Especially when moving from a fixed time-based system to an autonomous intelligent system, dynamic scheduling is important to control the junctional traffic jams. Apart from fuzzy logic and reinforcement learning, technologies like image processing, learning classifier systems, IoT has been used for autonomous traffic control. When it comes to the use of Multi-Agent technology, very few systems have been implemented for traffic control. However, those systems are also mostly limited to software programs, A traffic controlling system comprises agents capable of acting independently, exhibiting control over their internal state. The environment is the interaction between the outside world and agents is determined through the environment. In a traffic control system environment is dynamic where it changes while an agent is deliberating. Ontology is the collection of knowledge, rules, and actions. The ontology must be agreed and understood among the agent community to enable each agent to understand messages from other agents for traffic control.

The main difference in using Multi-Agent system technology for traffic control is that the system can fulfill the dynamic environmental requirements. Each lane in the junction can be monitored through this autonomous system and be able to change according to the situation. That fulfills the adaptability function. Through agent communication function the system environment can be from static to dynamic. Choosing the best agent methodology for creating a system can be a challenge. As per the study, using Multi-Agent system technology together with software and hardware solutions to traffic control could be more efficient and productive than the current time-based system.

In the next phase, we will test the system in a real-time environment by developing the hardware module. The system will implement on raspberry pi modules and image processing techniques will be used to track the vehicle density in each lane. The actual performance of the proposed system can be evaluated after implementing on real environment.

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