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Hardware-in-the-Loop Simulation Development for Real Time Adjustment of Traffic Control System

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Abstract: Traffic control system has been developed for last 20 years. In the 1st generation, traffic controller aimed to control traffic light only, it worked based on fixed timing plan for the whole day. The problem occurred when traffic demand was changed significantly. At that situation, the traffic controller would not able to control traffic flow well. The second generation traffic controller came to address problem of previous traffic controller. The new traffic controller worked based on predetermined time interval. Time in a day was divided into several time interval and every time interval has different timing plan. Further developments of traffic controller resulted the third and fourth generation traffic controller that worked based on real time traffic demand that detected by traffic sensors. However, in order to back up the traffic controller system when there are some problems with the traffic sensors, the second generation of the traffic controller is still installed together with the third or fourth generation of traffic control. Hence, the second generation of traffic controller until now is still relevant with development of traffic control system. This study presents a method to develop second generation of traffic control system based on a micro traffic simulation system. Determination of the timing plan for every time interval is carried out using a hardware in the loop simulation system. The simulation system is not only able to visualise performance of the tested traffic control system but also able to revise the timing plan based on the simulated traffic demand. Several laboratory based testing shows that the proposed hardware in the loop simulation system is very beneficial in evaluating a traffic control system.

Key words: Control system, traffic controller, hardware in the loop simulation, traffic system, generation

INTRODUCTION

Traffic signal control or traffic control system is one of the important discussion in the field of traffic engineering (McShane *et al*., 1998). In term of traffic flow management, traffic control system would be the main thing to do that. In line with the increase of vehicle number, traffic control system has also been developed for last 20 years. Inthe first generation, traffic control system aimed to control the traffic light only and disregards the real traffic demand. The problem occurred when the traffic demand is changed significantly and not relevant anymore with the timing plan that has been determined in the traffic control system. It resulted long vehicle queue and waiting time.

The 2nd generation of traffic control system came to address the problem of the previous traffic control system. The new traffic controller worked based on predetermined time interval. Time in a day was divided into several time interval and every time interval has different timing plan. The time interval and timing plan is determined based on statistical study on traffic demand. The second generation traffic control system worked better compared to the previous traffic control system. However, evaluation on the time interval and its timing plan is still required especially when the traffic demand was changed significantly.

Further developments of traffic controller resulted the 3rd and 4th generation traffic controller that worked based on real time traffic demand. The traffic demand is detected using traffic sensors. In the third traffic control system, green time for every phase was determined based on actual vehicle present. Such strategy is called as vehicle actuated green time. Traffic sensor that usually used in the third generation traffic control system is induction loop that installed under stop line of every intersection approach. The 4th generation traffic control system works similar with the third generation traffic control system. The differences are the fourth generation traffic control system works with vision system as the traffic sensor and the traffic control systemis able to optimise traffic flow for multi intersection continuously.

However, it is realised that both third or fourth generation traffic control system has some disadvantages, especially when the traffic sensors have problem. At that situation, the traffic control system would not be able to work well and a backup system is required. The second generation traffic control usually would be installed as the backup system and until now it still relevant with the development of traffic control system.

In the early development, the 2nd generation traffic control system is developed using statistical approach. Traffic surveyors would come to a junction to observe traffic volume at every approach. Data about the traffic volume would be used to determine the timing plan for every time interval. Adjustment of timing plan would be carried out manually based on subjective opinion of traffic engineer. Such activities would be time and cost consuming. In further development, several researchers have used a traffic simulation system for traffic control evaluation. Development of simulation technology enables simulation system to simulate a real system using computer by considering complicated factors (Singh, 2009).

The traffic simulation system would be updated by latest traffic data stored in a database in order to get current traffic behaviour. Evaluation of traffic control system using a simulation system would be more effective and safe compared to directfield observation.

This study presents the development of a Hardware-In-the-Loop (HIL) simulation to evaluate a second generation traffic control system. A HIL system enables the a control system interacts with a simulation system that represents the controlled system in real time (Petersheim and Brennam, 2009). Traffic simulation in the HIL system is developed based on micro traffic simulation concept while communication with the traffic control system is developed based on standard serial communication. The HIL is not only able to visualise traffic condition when being controlled by the traffic control system, but also able to revise the timing plan based on traffic queue resulted by the traffic control system.

Literature review: Several previous studies about traffic control system could be divided into two groups. The first group discusses about traffic control system for isolated junction while the second group discusses about traffic control system for urban network intersection. Both group show that traffic control system is one of importance factor to be discussed in traffic engineering study field. Especially in urban transport system, traffic control system is one of importance challenges that need practically effective and efficient solution.

A researcher has studied about the use of Neurofuzzy system to develop a traffic control system for an isolated intersection (Bingham, 2001). Sometime, traffic flow in an urban intersection is very complicated and it is better to model it using linguistic model based on expert opinion. A Fuzzy Logic (FL) has been used for that objective. However, several parameters in the FL system is still need to be adjusted in order to response the changes of traffic flow. A Neural Network system has been applied for that and the study showed that the proposed Neurofuzzy system enables the traffic control system become adaptive. Other studies that used FL system to control an isolated traffic intersection have been investigated by several previous researchers (Trabia *et al*., 1999; Niittymaki and Pursula, 2000; Yin *et al*., 2002; Teodorovic *et al*., 2006; Chao *et al*., 2008; Nagare and Bhatia, 2012).

The use of optimisation methods to determine optimum timing plan for a traffic control system have also been investigated by previous researchers. A researcher has investigated the use of Evolutionary Algorithm (EA) to minimise number of vehicle stopped and waiting time for all of the vehicles (Taale, 2000). Traffic volume in every approach has been weighted and the solution which is timing plan, was found from some time intervals that represent minimum and maximum green time. The study showed that the use of proposed EA is not effective for traffic timing plan optimisation. Computation time of the proposed EA is the main obstacle in order to have a traffic control system that work real time. Another study that showed the ineffectiveness of EA in optimising timing plan of a traffic control system is carried out by previous researcher (Oda *et al*., 2003). Both studies above showed timing plan adjustment using direct observation is ineffective and cost consuming.

In control system engineering field, the use of HIL system to evaluate a control system is widely investigated by researchers. A previous researcher have investigated the use of HIL system to evaluate performance of speed controller for motor bike (Lin *et al*., 2006). The HIL system is used to simulate engine, transmission system and rear tyre. The study showed that the use of HIL system is more effective and efficient compared to the direct evaluation.

A researcher have carried out study about the use HIL system to design and validate an information system for car driver (Gietelink *et al*., 2009). Such information system is a complicated information system included re-routing path, turning driving wheel automatically when in a dangerous situation and keeping the lane for safety driving systems. Based on experiments, it showed that the use of HIL system is more cost effective, safe and easier to manage in order to evaluate the car driver information system.

In architecture field, a HIL system has also been used to evaluate performance of heater system for water installation network (Rhee *et al*., 2011). Performance of the evaluated heater system is very affected by pressure lost and water volume. Interaction of both variables is very complicated to be modelled using a mathematical model and HIL system is proposed for that purpose. The HIL system is used to simulate physical building and connected to the evaluated heater system. The study showed that the proposed HIL system could work effectively in evaluating the heater system.

The use a HIL system to evaluate a control system of a drone has been carried out by previous researcher (Hasnan *et al*., 2012). Objective of such study is to get parameters that affect the drone by using proposed HIL system. The study showed that the parameters could be collected successfully by the proposed HIL system.

Medical field has used HIL system as well to evaluate performance of a control system based on Type-2 Fuzzy Logic (T2FL). A previous study has implemented a T2FL based control system for controlling anaesthesia and surgery activities (El-Nagar and El-Bardin, 2014). Objective of the control system is to minimise the side effects and risks of anaesthesia and surgery activities. The control system has been trained using back-propagation algorithm with the data provided by a HIL system. The study proved that the proposed HIL system could provide accurate data so that the training process could achieve the objective. Other studies that propose the use of HIL system for evaluating a control system have been carried out by several previous researchers (Wozniak, 2011; Chu *et al*., 2012; Hooshyar *et al*., 2015; Pugi *et al*., 2015; Witt and Klimant, 2015; Mancisidor *et al*., 2015; Jung *et al*., 2015).

This study is similar with previous study (Vilarinho and Tavares, 2014) that have used a simulation system to determine timing plan for a traffic controller. The significant different between this study and the previous study is the HIL system part. The previous study just used a micro traffic simulation system to determine timing plan. Result of the timing plan is not downloaded to the traffic control system directly and the performance of the traffic control system is not evaluated by the simulation system directly. Therefore, the use of HIL system to evaluate a traffic control system in real time that proposed in this study could be claimed as a new approach in traffic engineering field. Besides, result of this study would also been used as training unit for Industrial Automation subject in institution of the researcher.

MATERIALS AND METHODS

Hil system development

System architecture: The concept of the proposed HIL system is a micro traffic simulation executes the traffic light in the simulation based on timing plan data sent by

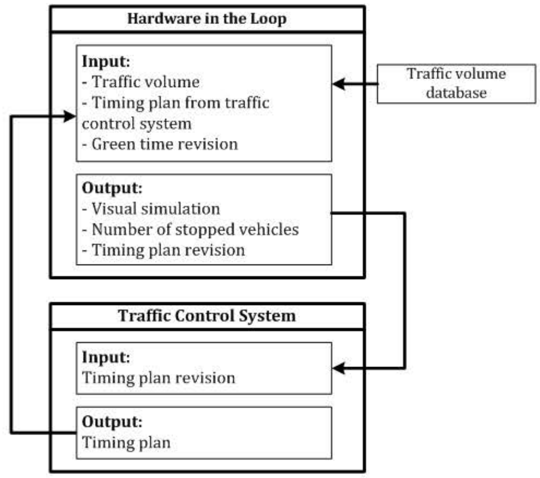

Fig. 1: Architecture of the proposed HIL system

the traffic control system. The HIL system would send feedback to the traffic control system data about timing plan revision based on number of vehicle stopped as the result of the timing plan. If green time prolonging is required and maximum green time is still not reached then the related green time would be prolonged. On the other hand, if the green time is too long to release all of the stopped vehicles, then green time cutting would be conducted. System architecture of the proposed HIL system is depicted by Fig. 1.

Data communication: The traffic signal control developed in this study is based on an industrial standard microcontroller produced by Atmel corporation. Communication between HIL system and the traffic control system is carried out through asynchronous serial communication. Therefore, the data type for the communication is string. At the beginning of every cycle, the traffic control system would send green time split data for time interval. The data format is "GS###;###;###;...". Character "GS" is a sign that such data is about green time split data. Character "###" is 3 digits of green time for every phase in second. For example, if there are four phases and green time split for phase 1-4 is 30, 40, 45 and 25 sec, respectively then, the data would be "GS030;040;045;025". By parsing the data, then the HIL system could set the green time split for that time interval.

In order to communicate real time with the HIL system, then the traffic control system would send countdown data to the HIL system. Format of the countdown data is "A ###". Character "A" represents the first phase, hence, for 2nd-4th phase and so on, the character would be "B", "C", "D" and so on, respectively. Character "###" is countdown of green time in 3 digits format. For instance if currently, the phase number is 3 and remaining green time is 10 sec, then the data would be "C009" (from 9-0, it would be 10 sec). When a phase is finished, then the control system is waiting reply from the HIL system. If there is no reply from the HIL system, it means that the traffic control system is disconnected from HIL system and it doesn't need to send countdown data to the HIL system. Waiting for the reply from HIL system before sending countdown data is very critical because if the serial data has not been read by the HIL system it could cause buffer over flow and could make the traffic control system become stag.

After a cycle is finished, then the HIL system would make a note about green time revision of every phase. The revision value could be positive or negative. Positive revision value would be noted if the current green time is still need to be prolonged as long as maximum green time is still not reached. Negative revision value would be noted if the current green time is too long and there are a lot of green time lost. Positive green time revision value (or additional green time value) for the current green time is determined based on Eq. 1:

$$AG = \{MaxGt - ((sv \times Rt) + at)\}, \quad \text{if } Gt \leq MaxGt \; 0, \text{othetwise} \tag{1}$$

Where:

AG = Additional green time
MaxGt = Maximum green time
Sv = Number of stopped vehicle
Rt = Release time
At = Reaction time
GT = Green time

Equation 1 could be explained using Fig. 2 Required time to release the first car is time for the car to reach the release point. When the first car is moving to the release point, the next car would be moving as well and when the first car reached the release point, the next car would be around the first car point. Another time for the next car reaches the release point is required. Therefore the required time is equal to Sv×Rt. Reaction time is the time differences between starting time of the green light and the starting time of the driver to start moving the car. Based on field observation, reaction time is around 3 sec.

Maximum green time is also another factor to be considered in determining the additional green time value. The maximum green time for every phase is required to avoid very long car queuing at other phases. Revision green time would be determined by the HIL system after

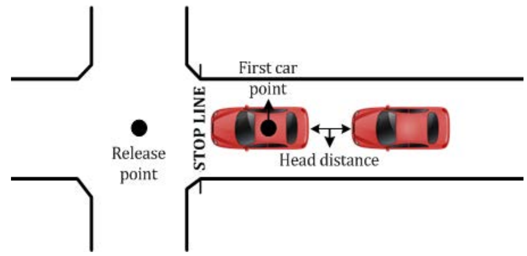

Fig. 2: Condition of stopped cars when waiting for next green time

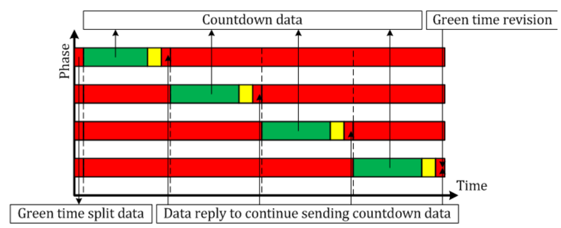

Fig. 3: Data communication in a time line from the traffic controller side

the simulation for that time interval is finished. Final green time revision value is the average value of green time revision value that collected during simulation. After the green time revision could be determined then it would be sent by the HIL system to the traffic control system with the data format is "A###;B###;...;*##". Character "A" and "B" represents phase number. When there are 4 phases then the character would be "A###;B###;C###;D###;*##". The "###" character represents 3 digits of green time revision value. The "*" character represents the closing character and the "##" character represents 2 digits number of time interval to be revised. When the traffic controller received such data, then the processor would parse the data and revise the related timing plan. Data communication in a time line from the traffic control system side is depicted in Fig. 3.

HIL system testing: There are two parameters to test the proposed HIL system. The first parameter is data communication and the second parameter is ability of the HIL system to revise timing plan to reduce number of stopped vehicle. Both parameter is observed based on visual observation. Referring to Fig. 3, the first data sent from the traffic control system is green time split. Testing to detect that the data is successfully sent to the HIL system is carried out by setting the existing green time split data in the HIL system with a set of value that different from green time split data sent by the traffic control system. From visual simulation observation, if the

Fig. 4: Screen shoot of the HIL system with traffic light simulation and countdown

traffic lights are working with the new green time split data, then it could be said the first data communication process is successful.

The 2nd data communication process is countdown data sending. Such data could be detected by visualising it in the simulation. There is visual simulation of traffic light equipped with countdown data in the proposed HILS system as depicted by Fig. 4. Based on several experiments, the traffic light simulation is able to work simultaneously with the real traffic light controlled by the traffic control system. Hence, it could be said that the second communication data process is successful.

The 3rd process in data communication is reply from HIL system to the traffic control system as a sign that the traffic control system is still connected to the HIL system. Testing for such process was carried out by disconnecting the traffic control system from HIL system and monitoring of data sending process was carried out from hyper terminal in Microsoft Windows Operating System. Several experiments were also conducted and found that the traffic control system would stop sending data to the HIL system when disconnected.

The last testing is timing plan revision process. Such process could be observed visually from the HIL system. If there is revision, then in the next cycle, the traffic lights would work with new green time split. Besides, revision of timing plan also could be observed based on number of stopped vehicle and green lost. Based on visual observations, it is found that green time in the next cycle is relatively relevant with number of queuing vehicle. Therefore, it is proven that the HIL system could be used to adjust timing plan of the traffic control system.

RESULTS AND DISCUSSION

In term of traffic control development, the proposed HIL system could be used successfully to evaluate a traffic control system for an isolated

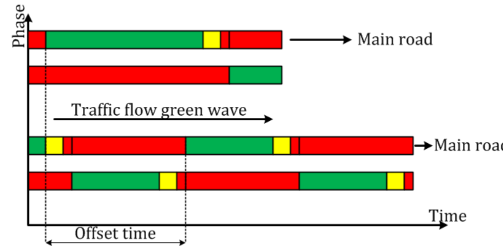

Fig. 5: Offset time illustration

intersection. However, due to the increase of vehicle significantly, traffic volume database in the HIL system is required to be updated. For further development, it is proposed to develop online updating system for the traffic volume database of the HIL system. The online system requires internet network installation in every intersection. The internet connection could be utilised not only to update the traffic volume data of the HIL system but also could be used to synchronise nearby traffic control systems. The synchronisation aims to give a green wave to the traffic flow in the main road inorder to reduce total number of vehicle stopped in an urban traffic intersections. Technically, green wave would occurred when two nearby traffic control systems could optimise offset time of the intersections. Figure 5 depicts the offset time of two nearby intersections. The proposed formula to determine the offset time is shown in following Eq. 2:

$$Ot = \frac{d - (Sv \times vl)}{b} \quad (2)$$

Where:

Ot = Offset time
d = Distance between two nearby intersections
vl = Average vehicle length+average head distance
v = Average vehicle speed in two nearby intersection

The proposed HIL system is also proposed to be developed in the future. The HIL system must be able to be used to evaluate third and fourth generation traffic control as well. Required infrastructures to support multi intersections simulation are computer with high memory graphic card and a module to handle simultaneously several serial communications from traffic control systems. However, it would be major contribution for traffic engineering field especially traffic control development if the proposed HIL system could be developed as planned.

CONCLUSION

Real time adjustment of a traffic control system is relatively a new technique in the traffic control system development. Even though the use of micro traffic simulation in evaluating traffic condition has been carried out by several researchers however, the evaluation is still separated from the traffic control system. This study proposes the development of a HIL system for real time adjustment of a traffic control system. The proposed HIL system is proven work well as intended and become novelty in the traffic control system development field.

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REFERENCES

Bingham, E., 2001. Reinforcement learning in neurofuzzy traffic signal control. Eur. J. Operat. Res., 131: 232-241.

Chao, K.H., R.H. Lee and M.H. Wang, 2008. An Intelligent Traffic Light Control Based on Extension Neural Network. In: Knowledge-based Intelligent Information and Engineering Systems, Lovrek, I., R.J. Howlett and L.C. Jain (Eds.). Springer, Berlin, Germany, ISBN: 978-3-540-85562-0, pp: 17-24.

Chu, L., L.B. Chao, Y. Ou and W.B. Lu, 2012. Hardware-in-the-loop simulation of traction control algorithm based on fuzzy PID. Energy Procedia, 16: 1685-1692.

El-Nagar, A.M. and M. El-Bardini, 2014. Interval type-2 fuzzy neural network controller for a multivariable anesthesia system based on a hardware-in-the-loop simulation. Artif. Intell. Med., 61: 1-10.

Gietelink, O.J., J. Ploeg, B. de Schutter and M. Verhaegen, 2009. Development of a driver information and warning system with vehicle hardware-in-the-loop simulations. Mechatronics, 19: 1091-1104.

Hasnan, K.B., L.B. Saesar and T. Herawan, 2012. A hardware-in-the-loop simulation and test for unmanned ground vehicle on indoor environment. Procedia Eng., 29: 3904-3908.

Hooshyar, H., F. Mahmood, L. Vanfretti and M. Baudette, 2015. Specification, implementation and hardware-in-the-loop real-time simulation of an active distribution grid. Sustain. Energy Grids Networks, 3: 36-51.

Jung, J.H., 2015. Power Hardware-in-the-Loop Simulation (PHILS) of photovoltaic power generation using real-time simulation techniques and power interfaces. J. Power Sources, 285: 137-145.

Lin, C.F., C.Y. Tseng and T.W. Tseng, 2006. A hardware-in-the-loop dynamics simulator for motorcycle rapid controller prototyping. Control Eng. Pract., 14: 1467-1476.

Mancisidor, I., X. Beudaert, A. Etxebarria, R. Barcena, J. Munoa and J. Jugo, 2015. Hardware-in-the-loop simulator for stability study in orthogonal cutting. Control Eng. Pract., 44: 31-44.

McShane, W.R., R.P. Roess and E.S. Prassas, 1998. Traffic Engineering. Prentice Hall Inc., New Jersey, USA.

Nagare, A. and S. Bhatia, 2012. Traffic flow control using neural network. Int. J. Applied Inform. Syst., 1: 50-52.

Niittymaki, J. and M. Pursula, 2000. Signal control using fuzzy logic. Fuzzy Sets Syst., 116: 11-22.

Oda, T., T. Otokita, K. Iwaoka and K. Kurata, 2003. Meta-heuristic optimization of signal control and sub-area decomposition in traffic control systems. Proceedings of the 10th World Congress and Exhibition on Intelligent Transport Systems and Services, November 16-20, 2003, Madrid, Spain.

Petersheim, M.D. and S.N. Brennan, 2009. Scaling of hybrid-electric vehicle powertrain components for hardware-in-the-loop simulation. Mechatronics, 19: 1078-1090.

Pugi, L., E. Galardi, C. Carcasci, A. Rindi and N. Lucchesi, 2015. Preliminary design and validation of a Real Time model for hardware in the loop testing of bypass valve actuation system. Energy Convers. Manage., 92: 366-384.

Rhee, K.N., M.S. Yeo and K.W. Kim, 2011. Evaluation of the control performance of hydronic radiant heating systems based on the emulation using hardware-in-the-loop simulation. Build. Environ., 46: 2012-2022.

Singh, V.P., 2009. System Modeling and Simulation. New Age International, New Delhi, India, ISBN-13: 9788122423860, Pages: 260.

Taale, H., 2000. Optimising traffic signal control with evolutionary algorithms. Proceedings of the 7th World Congress on Intelligent Transport Systems, November 6-9, 2000, Turin, Italy, pp: 1-7.

Teodorovic, D., V. Varadarajan, J. Popovic, M.R. Chinnaswamy and S. Ramaraj, 2006. Dynamic programming-neural network real-time traffic adaptive signal control algorithm. Ann. Operat. Res., 143: 123-131.

Trabia, M.B., M.S. Kaseko and M. Ande, 1999. A two-stage fuzzy logic controller for traffic signals. Transp. Res. Part C: Emerg. Technol., 7: 353-367.

Vilarinho, C. and J.P. Tavares, 2014. Real-time traffic signal settings at an isolated signal control intersection. Transp. Res. Procedia, 3: 1021-1030.

Witt, M. and P. Klimant, 2015. Hardware-in-the-loop machine simulation for modular machine tools. Procedia CIRP, 31: 76-81.

Wozniak, P., 2011. Preferences in multi-objective evolutionary optimisation of electric motor speed control with hardware in the loop. Applied Soft Comput., 11: 49-55.

Yin, H., S. Wong, J. Xu and C. Wong, 2002. Urban traffic flow prediction using a fuzzy-neural approach. Transport. Res. Part C: Emerg. Technologies, 10: 85-98.