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An approach for traffic signal control using RFID sensors

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Abstract

The Korean government is building several futuristic cities, ubiquitous City (u-City), with the latest information technology (IT) infrastructure and "ubiquitous" environment. In the "u-City", Intelligent Transportation System (ITS) will be one of the important services. This study proposed a traffic responsive urban traffic control system applicable in those u-City, using RFID (Radio Frequency Identification) technology to get traffic information. And, we proposed a predictive control model using the real time traffic information achieved from the proposed system. A simulation example is provided to demonstrate the applicability of the proposed system and model.

Key Words : RFID, traffic signal control, u-City, ITS

1. Introduction

The Korean government plans to build futuristic cities, ubiquitous City (u-City), with the latest information technology (IT) infrastructure and "ubiquitous" environment (Songdo City, 2007)[1]. This plan will be achieved by integrating IT infrastructure and ubiquitous information services into urban space. In the "u-City", Intelligent Transportation System (ITS) will be one of the important services like Hong Kong (W. LAM, 2001)[2]. ITS refers to transportation related guidance, control and information systems. These system use computer and information technology to address transportation functions at the level of individual vehicles roadways and large transportation networks.

ITS needs to get the real time traffic information. Especially the problem of how to measure traffic through urban area as a real time is one of important research topic. There is reviewed several systems that are capable of estimating traffic situation using different detectors (S. M. Turner, 1995)[3]; DMI (The integration of an electronic Distance-Measuring Instrument with the floating car technique), Cellular phone (used by motorists to report their position at designated checkpoints), AVI (Automatic vehicle identification), AVL (Automatic vehicle location), GPS (Global Positioning System)receivers.

Now days, the RFID technology gained rapidly development[4]. There could be a system using RFID tag to control traffic signal. There is a vehicle security system using RFID (e-Plate)[5]. In this case, all vehicles have an electronically tagged self-powered number plate for identifying whether stationary or on the move. In another works, it is introduced the RFID-based logistic system and information services in ITS (F. LIU, 2006)[6]. They capture and transfer logistics information on the basis of the RFID technology and the associated ITS computer network. Yang developed RF controller for ITS application (Yang G., 2007)[7]. It is not focused on traffic signal controller. The operation of a passive RFID system in fast identification application is researched and analyzed (K. Penttila, 2004)[8]. They found the achievable identification velocities of a passive RFID system. Reliable identification accuracy was achieved up to 40 km/h moving velocities.

The quality of a traffic signal control system is generally defined in terms of safety and efficiency. Many methods have been developed to solve the intersection signal control problems[9-16,25,26]. A commonly used signal timing model is provided by Webster (1958)[17], who developed a detailed procedure to calculate cycle length and green times. M. Papageorgiou reviewed most of the currently implemented traffic control systems may be into two principal classes; Fixed-time, Traffic responsive (M. Papageorgiou, 2003)[18]. Fixed-time strategies

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for a given time of day are derived off-line by use of appropriate optimization codes. Traffic-responsive strategies (TRS) make use of real-time measurements to calculate in real time the suitable signal settings. Due to dynamic nature of the technological development, traffic responsive strategies are expected to have better performance in the ubiquitous cities.

In the literature, advanced traffic-responsive programs for networks include OPAC (Garter, 1983) PRODYN (Farges et al, 1983) CRONOS (Noillot et al, 1992) and COP (SEN and Head, 1997) (M. Papageorgiou,2003)[18-20]. These strategies calculate in real time the optimal values of the next few switching times over a future time horizon H, starting from the current time and the currently applied stage. To obtain the optimal switching times, these methods solve in real time a dynamic optimization problem employing realistic dynamic traffic models with a sampling time, fed with traffic measurements. In another work, a Fuzzy traffic controller was presented with traffic responsive strategies [21,22]. It is composed a set of two inductive loops, spaced by a distance (one set per lane), to detect vehicle as well as its speed[23].

On the other hand, isolated strategies are applicable to single intersections while coordinated strategies consider an urban zone or even a whole network comprising many intersections. In the ITS, it would be considered the traffic responsive, coordinated intersection control. TRS can be considered a centered and decentralized. A combination of decentralized multi-destination dynamic routing and real-time intersection signal control for congested traffic network is proposed by Ümit Özügner (J. Lei 1999)[24]. They considered the effects of applying routing and signal controlling in a traffic network to handle saturated an under saturated traffic conditions.

In this paper, RFID based traffic data collection system is proposed in section 2. We focused on measuring traffic information in the road. In Section 3, a model predictive control system is proposed in order to minimize the number of vehicles in queue in a arterial road. We simulated the proposed model in different situations.

2. A proposed traffic control system using RFID

2.1. A proposed traffic control system configuration

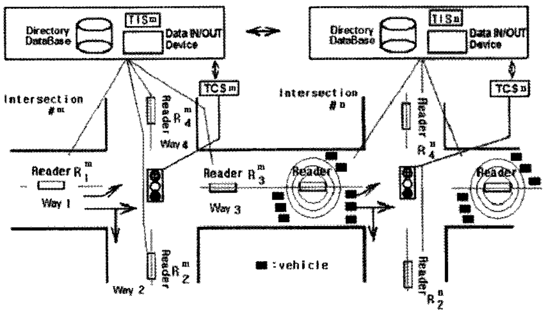

Fig. 1. The architecture traffic signal control using RFID in two intersections.

The traffic signal controller used two loop detectors on road to get traffic information. That system detects the velocity of vehicle[23]. If we get more data about traffic situation, we can control more exactly. So, we proposed a new system using RFID to get more traffic information.

We assume that every vehicle has its own RFID tag in the u-city. A unique electronic identification code is established for each vehicle tag and each unique code is linked to Traffic Information Server (TIS) and a database in the centralized vehicle-database. We proposed a traffic control system using semi-active RFID tag to get traffic information. The structure of this system in the two intersections is outlined in Fig. 1. Consider each intersection with 4 ways and the way with 3 lanes.

The proposed system consists of two parts: (1) TIS, (2) Traffic control system (TCS). Each TIS manages more than one RFID reader, which detects the presence of small RF transmitters (often called tags), and provides the traffic information to the traffic control system. The system allows controlling the omni directional range of each of the RF readers to read tags within a range of 1 to 20 meters.

The distance between RFID reader and the stop line of intersection is about 80 m meters, which is decided and could be changed by estimating the waiting queue length in the red time. One reader on the way will detect bidirectional vehicle movements. TIS #m and #n communicate each other to share their data.

TCS control traffic signal and calculate green time for each lane with traffic information; queue, incoming flow rate, outgoing flow rate, turning rate, link velocity, and delay time.

2.2. Link velocity and travel time measuring

Link velocity and travel time are important for applications ranging from congestion measurement to real-time travel information (S. M. Turner, 1995)[3]. The link velocity (m/s) can be calculated by dividing distance with travel time. In the system, the distance between two RFID readers is fixed and known on road. RFID reader detects the compatible tags within its range, then "asks" the detected tag to transmit its identity. The information received by the reader is then passed to TIS database to store arriving time. The travel time of a vehicle is the difference of arriving time between two readers. The link velocity V_{link} of one vehicle $V(i)$ between reader R_m^p and R_n^r is given by;

$$V_{link}(V(i),R_m^p,R_n^r) = D(R_m^p,R_n^r)/(T_a(V(i),R_m^p) - T_a(V(i),R_n^r)) \quad (1)$$

where Ta represents an arrival time of vehicle at the reader R_m^p, R_m^p and R_n^r represent RFID readers in the m, n way and intersection #p, # r; D(R_m^p,R_n^r) is a distance between the reader R_m^p and R_n^r.

The average of link velocity is more reasonable to inform the traffic situation. The average link velocity V_{link_aver} between the reader R_m^p and R_n^r is set;

$$V_{link\_aver}(R_m^p,R_n^r) = \sum_{i=1}^{N} V_{link}(V(i),R_m^p,R_n^r)/N \quad (2)$$

where N is the number of vehicle passed between the reader R_m^p and R_n^r during time interval.

2.3. Queue length measuring in the lane

The queue length on each way is considered for most traffic signal model. The turning movement rates is assumed known and fixed in the model (C. Diakaki, 2002)[18]. We showed the example to count the number of vehicle on each lane in the way in Fig. 2. In the case, TIS #p detects one tag at reader R_m^p and does not detect at any other points ($R_{m\neq s}^p$, s=1,2,3,4) within the intersection, the vehicle owned that tag is come from other intersection and waiting on the way m, TIS #p increases then the queue length at reader R_m^p.

The total queue length $q_m^p(k)$ and the each lane queue length of the way m, at the discrete time kT, in the intersection #p is given by:

$$q_m^p(k) = q_{m,left}^p(k) + q_{m,straight}^p(k) + q_{m,right}^p(k) \quad (3)$$

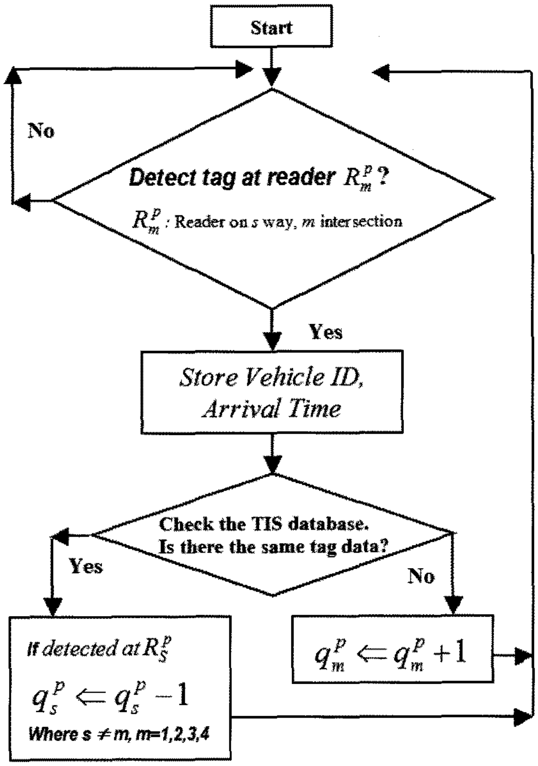

Fig. 2. An algorithm of calculating of queue length of the way m in the TIS #p.

where $q_{m,left}^p(k)$, $q_{m,right}^p(k)$ and $q_{m,straight}^p(k)$ represent the queue length of the left, right turn and straight going lane on the way m.

The traffic on each lane is expressed by numbers of vehicles conservation equation:

$$\begin{aligned} q_{m,left}^p(k+1) &= q_{m,left}^p(k) + q_m^p(k)^* T_{m,left}^p - q_{m,m\_L}^p(k) \\ q_{m,right}^p(k+1) &= q_{m,right}^p(k) + q_m^p(k)^* T_{m,right}^p - q_{m,m\_R}^p(k) \quad (4) \\ q_{m,straight}^p(k+1) &= q_{m,straight}^p(k) + q_m^p(k)^* T_{m,straight}^p - q_{m,m\_S}^p(k) \end{aligned}$$

where $q_{m,left}^p(k)$, $q_{m,right}^p(k)$ and $q_{m,straight}^p(k)$) are the queue length on the left, right turn and straight going lane of the way m in the intersection #p. The incoming queue length to each lane is given by multiplying total queue length $q_m^p(k)$ with the turning rate form m way to left ($T_{m,left}^p$), right ($T_{m,right}^p$)and straight way ($T_{m,straight}^p$); The numbers of vehicle going out from the way m to left, right, and straight are $q_{m,m\_L}^p(k)$, $q_{m,m\_R}^p(k)$ and $q_{m,m\_S}^p(k)$. We measured the queue length of each lane using the TIS #p database.

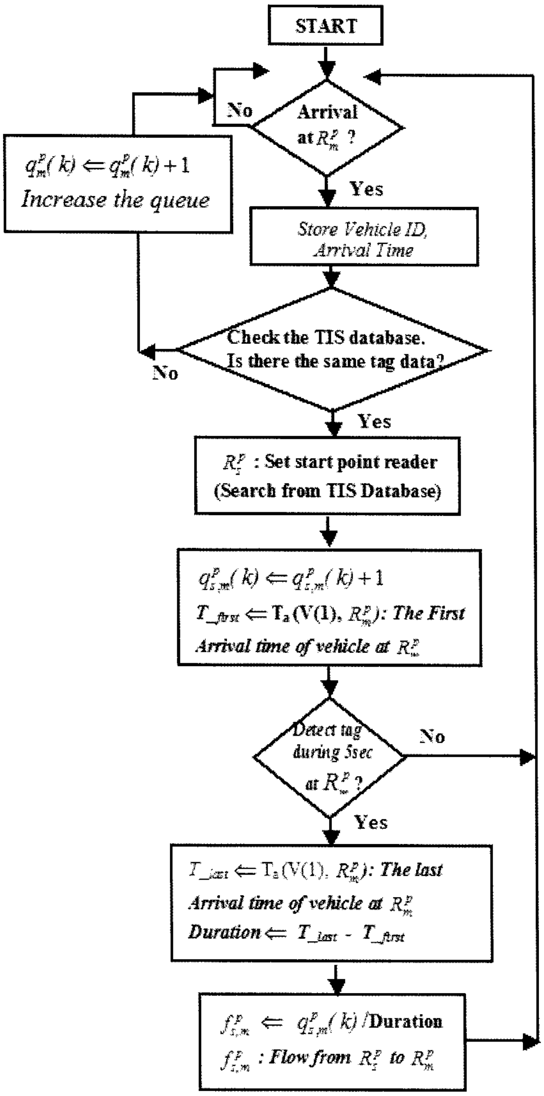

Fig. 3. The algorism calculating the out-going flow rate from the way s to m within the intersection # p.

2.4. Out-going Flow rate measuring in the lane

In section 3, we proposed a traffic model. The out going flow rate (vehicles/sec) on "each lane"is needed for that traffic model. We should know the numbers of vehicle during cycle time to calculate the flow rate within the intersection. With one reader on the way in the intersection, it cannot be known where the tag is from, before searching the TIS database about the tag. The algorism is shown in Fig 3. If the detected tag at the reader R^p_m is come from one of reader R^p_s in the same intersection #p, increase the number of vehicle $q^p_{s,m}(k)$ between reader R^p_s and R^p_m. If there is no data about the detected RFID tag in the TIS #p, increase the number of vehicle $q^p_m(k)$ of that lane like counting queue length. We set "5 sec" to decide whether there are arriving vehicles to reader R^p_m or not.

The outgoing flow rate $f^p_{s,m}$ could be calculated by dividing the queue length $q^p_{s,m}$ with the duration of passing from first starting to last end vehicle.

2.5. Incoming Flow rate in the lane

We could calculate the incoming flow rate (vehicles/sec) on "each lane" by dividing the incoming numbers of vehicle with the time duration of arriving vehicles at RFID reader like calculating "out-going flow rate". The arrival time and the incoming numbers of vehicle could be calculated by checking TIS database and TCS green time sequence.

In this section, we briefly described about one way, but it could be extended about the other way and coordinated intersection. We focused on measuring traffic information in the proposed system; the link velocity, the queue length of each lane and flow rate. In the section 3, we optimized the traffic signal control to decrease vehicle queue length and delay time on the lane, using the traffic data; vehicle number, flow rate and capacity.

3. Control of Single Intersection

In this section, we first introduce the queue model for a given single intersection which considers the red-green switching times explicitly. We consider this model use the data for the proposed system in section . Subsequently, the model predictive control model to calculate the green signal times for N step horizon is developed. After analysis of the results in the single intersection, it will be generalized to the multi intersection case.

3.1. Single intersection queue model

Consider a four way intersection with lanes L_j where j=1, 2, ..., 8 (Fig. 4). When green signal is ON at each lane, vehicles on odd indexed lanes should turn left and vehicles on even indexed lanes should go directly or turn right. No car is allowed to turn right without a green signal at any given direction.

The green signal times t_i, $i=1, 2, 3, 4$ with corre-

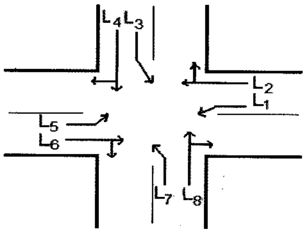

Fig. 4. Single intersection with 4 incoming lanes.

Table 1. Green Signal Times for the Lanes

Signal times	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8
t_1	ON	-	-	-	ON	-	-	-
t_2	-	ON	-	-	-	ON	-	-
t_3	-	-	ON	-	-	-	ON	-
t_4	-	-	-	ON	-	-	-	ON

sponding directions are given in Table 1. The summation of these green signal times is equal to the cycle time C which may vary between a lower and upper bound depending on the traffic density. A single intersection can be modeled by discrete time system in which the state variables $q_j(k)$ with $j=1, 2, ..., 8$ represent queue length at the beginning of the kth cycle (C). Individual queue lengths are mainly determined by incoming flows (f_j, $j=1, 2, ..., 8$), outgoing flows (c_j, $j=1, 2, ..., 8$) or lane capacities, and duration of the green signal time at each lane for that cycle.

Assuming the average flow f_{av}^{td} to be known during any time interval (td), a generic queue model for the jth lane can be written as

$$q_j(k+1)=\max[q_j(k)+t_{bg}f_j^{bg}+t_g f_j^g-t_j c_j,0]+t_{ag}f_j^{ag}$$

where t_{bg}, t_g, t_{ag} denotes before green time duration, green time duration and after green time duration in a cycle respectively.

The max term guarantees non-negative queue length in this model.

For an intersection in Fig. 4, the queue on each lane can be written as

$$q_1(k+1)=\max[q_1(k)+t_1f_1^1-t_1c_1,0]+t_2f_1^2+t_3f_1^3+t_4f_1^4$$

$$q_2(k+1)=\max[q_2(k)+t_1f_2^1+t_2f_2^2-t_2c_2,0]+t_3f_2^3+t_4f_2^4$$

$$q_3(k+1)=\max[q_3(k)+t_1f_3^1+t_2f_3^2+t_3f_3^3-t_3c_3,0]+t_4f_3^4$$

$$q_4(k+1)=\max[q_4(k)+t_1f_4^1+t_2f_4^2+t_3f_4^3+t_4f_4^4-t_4c_4,0]$$

$$q_5(k+1)=\max[q_5(k)+t_1f_5^1-t_1c_5,0]+t_2f_5^2+t_3f_5^3+t_4f_5^4$$

$$q_6(k+1)=\max[q_6(k)+t_1f_6^1+t_2f_6^2-t_2c_6,0]+t_3f_6^3+t_4f_6^4$$

$$q_7(k+1)=\max[q_7(k)+t_1f_7^1+t_2f_7^2+t_3f_7^3-t_3c_7,0]+t_4f_7^4$$

$$q_8(k+1)=\max[q_8(k)+t_1f_8^1+t_2f_8^2+t_3f_8^3+t_4f_8^4-t_4c_8,0]$$

Although this queue model is designed to find queue lengths over the period $[kC, (k+1)C]$ it has inherently two sub-states. One is from the start of the kth cycle to the end of the green time in which non-negative queue lengths are guarantied by the max terms. The other sub-state is between the end of the green time and the end of the kth cycle. Additionally, this model not only considers the queue lengths but also the incoming flow rates that are helpful for unsaturated traffic conditions.

An intersection simulator is developed in MATLAB environment. This simulator uses queue lengths, green times, incoming flow values, and lane capacities of each lane to simulate the intersection.

3.2. Model Predictive control for determining signal times

Assuming average flow during one cycle of store and forward model provide using well known controller design tools in control theory (Diakaki C, 2002)[18]. In this case, the resulting controller can do better for saturated traffic conditions. But if the network includes some unsaturated intersections, the designed controller may not behave well. Because the red-green signal passes are not considered for average flow assumption during one cycle. If the red-green signal passes are taken into consideration, then it will be almost impossible to represent the system for applying standard control theory tools with a sample time value of one cycle. On the other hand, some constraints related to traffic control system needed to be handled separately. Model predictive control presents the capability of handling the nonlinear model as well as some constraints of the system. It is an increasingly popular control approach because of its use of a possibly nonlinear control models and its ability to handle constraints on inputs, states and outputs (Rawlings, 2000).

In the following, the queue model and some constraints related to the traffic signal control problem are combined together in the model predictive control formulation.

$$\min_{\substack{t_i(k,N)\\ i=1,2,3,4}} \sum_{k=1}^{N}\sum_{j=1}^{8} w_j q_j(k) \qquad (5)$$

s.t.

$$q_1(k+1)=\max[q_1(k)+t_1(k)f_1^{1-k}-t_1(k)c_1,0]$$
$$+t_2(k)f_1^{2-k}+t_3(k)f_1^{3-k}+t_4(k)f_1^{4-k}$$
$$q_2(k+1)=\max[q_2(k)+t_1(k)f_2^{1-k}+t_2(k)f_2^{2-k}-t_2(k)c_2,0]$$
$$+t_3(k)f_2^{3-k}+t_4(k)f_2^{4-k}$$
$$q_3(k+1)=\max[q_3(k)+t_1(k)f_3^{1-k}+t_2(k)f_3^{2-k}+t_3(k)f_3^{3-k}$$
$$-t_3(k)c_3,0]+t_4(k)f_3^{4-k}$$
$$q_4(k+1)=\max[q_4(k)+t_1(k)f_4^{1-k}+t_2(k)f_4^{2-k}+t_3(k)f_4^{3-k}$$
$$+t_4(k)f_4^{4-k}-t_4(k)c_4,0]$$
$$q_5(k+1)=\max[q_5(k)+t_1(k)f_5^{1-k}-t_1(k)c_5,0]$$
$$+t_2(k)f_5^{2-k}+t_3(k)f_5^{3-k}+t_4(k)f_5^{4-k}$$
$$q_6(k+1)=\max[q_6(k)+t_1(k)f_6^{1-k}+t_2(k)f_6^{2-k}-t_2(k)c_6,0]$$
$$+t_3(k)f_6^{3-k}+t_4(k)f_6^{4-k}$$
$$q_7(k+1)=\max[q_7(k)+t_1(k)f_7^{1-k}+t_2(k)f_7^{2-k}+t_3(k)f_7^{3-k}$$
$$-t_3(k)c_7,0]+t_4(k)f_7^{4-k}$$
$$q_8(k+1)=\max[q_8(k)+t_1(k)f_8^{1-k}+t_2(k)f_8^{2-k}+t_3(k)f_8^{3-k}$$
$$+t_4(k)f_8^{4-k}-t_4(k)c_8,0]$$

$$\sum_{i=1}^{4} t_i(k)=C,\ k=0,\ 1,\ \ldots,\ N\text{-}1$$

$$T_{\min}\le C\le T_{\max}.$$
$$t_{i\_\min}\le t_i(k,N)\le t_{i\_\max},\ i=1,\ 2,\ 3,\ 4$$
$$q_j(k)\le \alpha_j,\ i=1,\ 2,\ 3,\ 4,\ k=1,\ 2,\ \ldots,\ N$$

where C , T_{min} and T_{max} represent cycle time, lower and upper bound for the cycle time respectively. The term $t_i(k,N)$ stands for the green signal time variable of each lane over N-step horizon. It can be written as

$$t_i(k,N) := [t_i(k)\ \ t_i(k+1)\ \ \ldots\ \ t_i(k+N)]^T,\ i=1,2,3,4.$$

For each step the horizon, summation of green times is equal to cycle time which may vary between a lower and upper value. Each green time values also has minimum ($t_{i\_\min}$) and maximum value ($t_{i\_\max}$) which is fixed over the horizon. The summation of the minimum green time values assumed to be equal or less than $T_{\max}$, also summation of the maximum green time values assumed to be equal or greater than $T_{\min}$ for feasibility concerns. The queue lengths are constrained by α_j $i=1, 2, 3, 4$ for each lane in the current intersection (spillback constraint for multi-intersection case).

The objective function includes weighting parameters w_j which assigned to the each lane. For each lane it has a default value of $w_j=1$ for which the objective becomes minimizing the total queue length. The weighting parameter w_j may be set regarding different criteria's; maximum or average delay, priority of one lane, emergency vehicle passing etc., then the optimization objective also change depend on assigned weighting parameter values.

The resulting nonlinear programming problem described above is solved using the sequential quadratic programming algorithm, implemented by the MATLAB function *fmincon.*

3.3. Simulations for one intersection

In this sub section, we apply the above control method to control single intersection. The initial queue lengths and incoming flows between 100-200 seconds are given as for each lane.

$q_1(0)=5$, $q_2(0)=65$, $q_3(0)=34$, $q_4(0)=80$, $q_5(0)=5$, $q_6(0)=20$, $q_7(0)=6$, $q_8(0)=12$,

$f_j=0.1$ veh/sec for $j=1, 3, 5, 7$

$f_j=0.2$ veh/sec for $j=2, 4, 6, 8$

The capacity of lanes are assumed to be fixed and given

$c_1=0.25$ veh/sec, $c_2=0.5$ veh/sec, $c_3=0.25$ veh/sec, $c_4=0.5$ veh/sec, $c_5=0.25$ veh/sec, $c_6=0.5$ veh/sec, $c_7=$

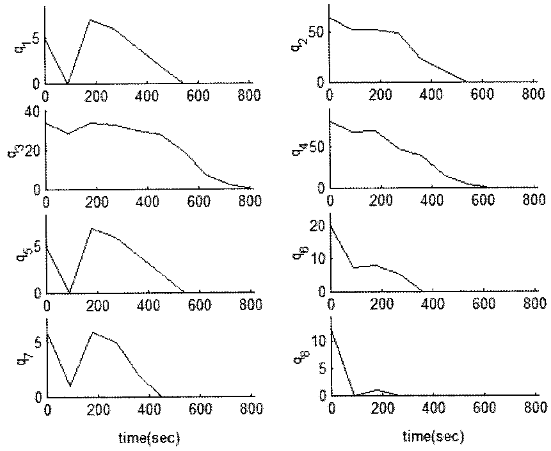

Fig. 5a. Queue lengths versus time at each lane.

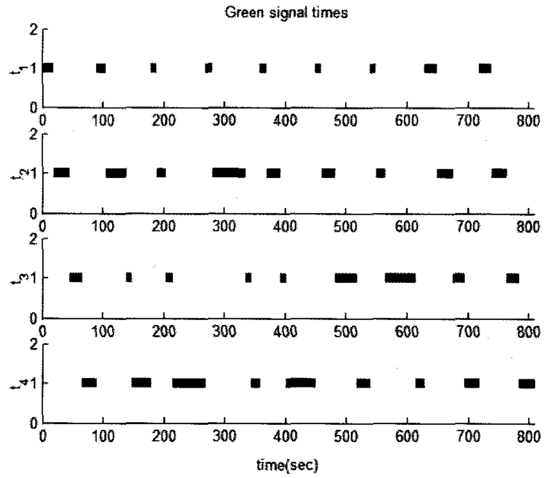

Fig. 5b. The Green signal times.

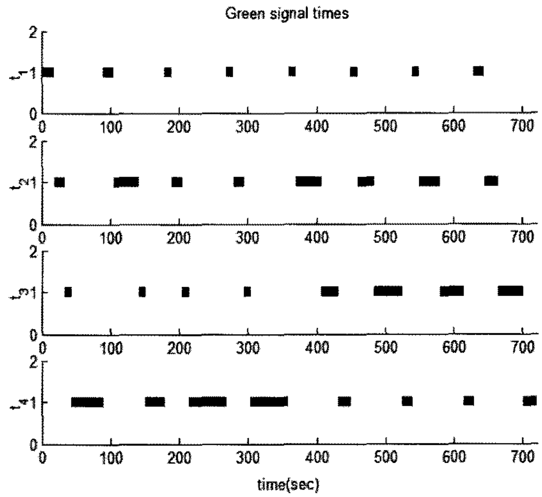

Fig. 6b. Green signal times.

0.25 veh/sec, c_8=0.5 veh/sec,

The lower and upper bound for the cycle time is selected 90 secs (C fixed) and minimum green times are follows: $t_{i\_min}=10$ sec i=1,3., $t_{i\_min}=15$ sec i=2,4, maximum queue lengths $\alpha_j=100$, and predicting the future step is selected as N=3.

The simulation results are given in Fig. 5.a-b. The queue lengths versus time results are shown in Fig. 5.a, and the duration of the green signal times at each cycle versus time are shown in Fig. 5.b.

In the second simulation, an emergency vehicle is assumed to pass from lane 4 for the same conditions in Fig. 5. So we increased only weighting factor of this lane to the $w_4=20$. Fig. 6.a-b shows the queue lengths

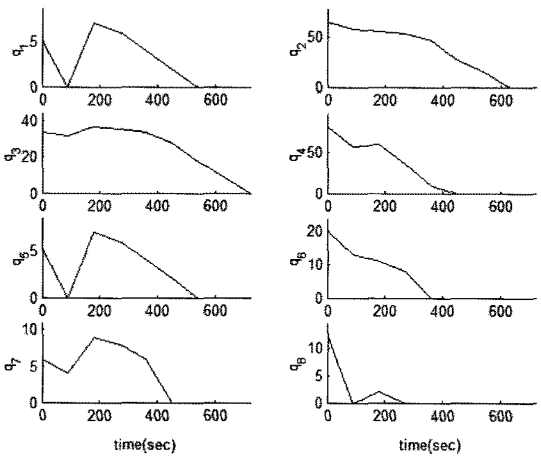

Fig. 6a. Queue lengths versus time at each lane.

and the green signal times respectively. Notice that the queue length in lane 4 gets zero in less time (compare Fig. 5.a and Fig 6.a) and more green time is assigned to that lane in the starting cycles (compare fourth column of Fig. 5.b and Fig. 6.b).

4. Conclusion

We proposed a system using RFID for traffic data acquisition and suggested a decentralized traffic control for multi intersection case. The proposed signal controller considers not only the saturated traffic conditions but also the unsaturated traffic conditions by assuming nonfixed average incoming flow during a cycle. In the future work, it is necessary more research for getting traffic actual data using RFID and storing the traffic data and searching the database.

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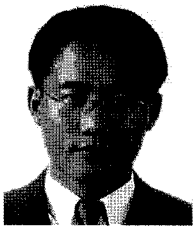

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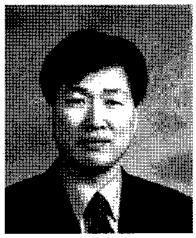

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