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Microcontroller based traffic light control system

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Abstract

Largest cities in Turkey as well as largest cities in world have the problem with traffic congestion. Traffic congestion in tightly populated urban areas negatively impacts the living standard of population. A long-time delays and emergency cases at traffic light intersection are one of basics reasons of traffic congestion. The control system based on PIC 16F877A is designed to provide either normal or emergency mode cases for vehicles and reduce of traffic congestion at intersection road. The proposed control system of six ways and four junction's intersection traffic light is developed for normal and emergency mode cases. The simulation of traffic light control system is accomplished by Proteus Design Suite 8 software and developed the prototype of this system.

Key words: Traffic light, traffic congestion, PIC 16F877A microcontroller, traffic flow

1. Introduction

In recent days, moving by vehicles has expanded around the world, and many nations are confronting various issues at traffic light connection, which have brought a number of accidents between the vehicles to the emergency. The fast increasing number of passenger vehicles in urban cities and other urbanization activities have created huge problems on Turkish metropolitan transportation systems. Largest cities in Turkey as well as largest cities in the world have the problem with traffic congestion. Istanbul, Ankara and Izmir are one of the most densely populated cities in Turkey, faces increasing constraints on their resources and traffic congestions. Traffic congestion in tightly populated urban areas negatively impacts our living standard. A long-time delays and emergency cases at traffic light intersection are one of basics reasons of traffic congestion [1–4].

Traffic congestion occurs while many vehicles creates the greater space than the street space volume. The scientists state that there are several problems due to traffic congestion, such as wasting time of vehicles that reduces regional economic health; increasing air pollution and carbon dioxide emissions by waste fuel; delays; emergency cases; stress of drivers, which is a reason of increasing roads accidents; wear and tear on vehicles and so on.

So, it is important to develop reliable and easiest traffic control system to solve congestion problem at intersection road. One of the solutions to decrease traffic congestion is to build a new infrastructure of roads that should accommodate the increased number of vehicles. Another way is to improve the usage of existing roads by efficiently controlling of traffic light timings.

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2. Modeling of traffic network

The modeling of the traffic flow includes the following steps:
1. Gathering real data from.
2. Simulate traffic flow model should process and select significant traffic data.
3. Build the model of the physical road network in computer.
4. Build a mathematical model of the traffic flow.
5. Identification of the traffic flow model.
6. Corroborating of the traffic flow model.

The reading of various research papers show that there are two commonplace tactics for modeling traffic community:

1. Macroscopic model.
2. Microscopic model.

According to [5-7] macroscopic traffic model is based on kinetic model. This model uses the equations related to relationship of traffic density to velocity. Macroscopic model oriented to simulate certain behaviors of the object and cannot provide flexible way of object modeling and optimizing [7].

Microscopic models can provide simulation of object behaviors and flexible way of object modeling and optimizing. An infrastructure of microscopic model has a several cars. Each car is represented as agent. Agents interacts with its environment according to their settled rules. There are different kinds of behavior appear during cars interaction. One of these ways is *cellular automata (CA)* which designed and simulated to set a rule on an infrastructure. Nagel and Schreckenberg in [8] describe a CA model for traffic network simulation. According to this description this model explores partially connected road-cells. The system dynamic characteristics determined by local transition rules and have chaotic view. At each time interval cars rise their speed until they reach their maximum velocity. Once cars move slowly the speed decreases. This model has more adapted behavior on a single road.

Another way of microscopic model is cognitive multi-agent system (CMAS). CMAS contains cognitive agents which can interact and communicate with each other. There are several definitions of agent for multi-agent system. The “agent” definition is described by M. Wooldridge says that an agent is a system (software or hardware) that can take an autonomous decision on behalf of its user or owner [9].

Cognitive Multi-Agent System approach is the advanced approach to traffic simulation and optimization. A cognitive agent is an object that autonomously tries to reach some aim state the use of minimal attempt. The information from sensors of environment transfers to cognitive agent, and agent according to these statistics to pick an action. Each agent considers as a single entity in multi-agent system. Therefore, a cognitive agent using its learning capabilities can select best way of action [10].

In [11] Cognitive Multi-Agent System described as a model of real drivers that can give responses to traffic flow information. A review of CMAS showed that drivers after accepting information about route, departure time reply differently to traffic flow information. Closed-loop control of traffic network has some external values such as control inputs and disturbances. Behaviour of traffic flow depends on these two type groups (Figure 1):

- Control input;
- Disturbance [12].

Input variables directly come to actuators. These actuators (control devices) include traffic signs, variable message signs. It is possible to measure or detect external disturbances, but disturbance values cannot control. The main part of feedback control system is the control strategy. The control strategy controls inputs which measured by sensors. After that these data come to the surveillance that reinforces and stretches information in the required by control strategy and human-machine interface. The measurement information transfer to actuator and control strategy to provide actuator with task in real time. Traffic network feedback control system can operate in manual – human-machine and automatic – control strategy modes.

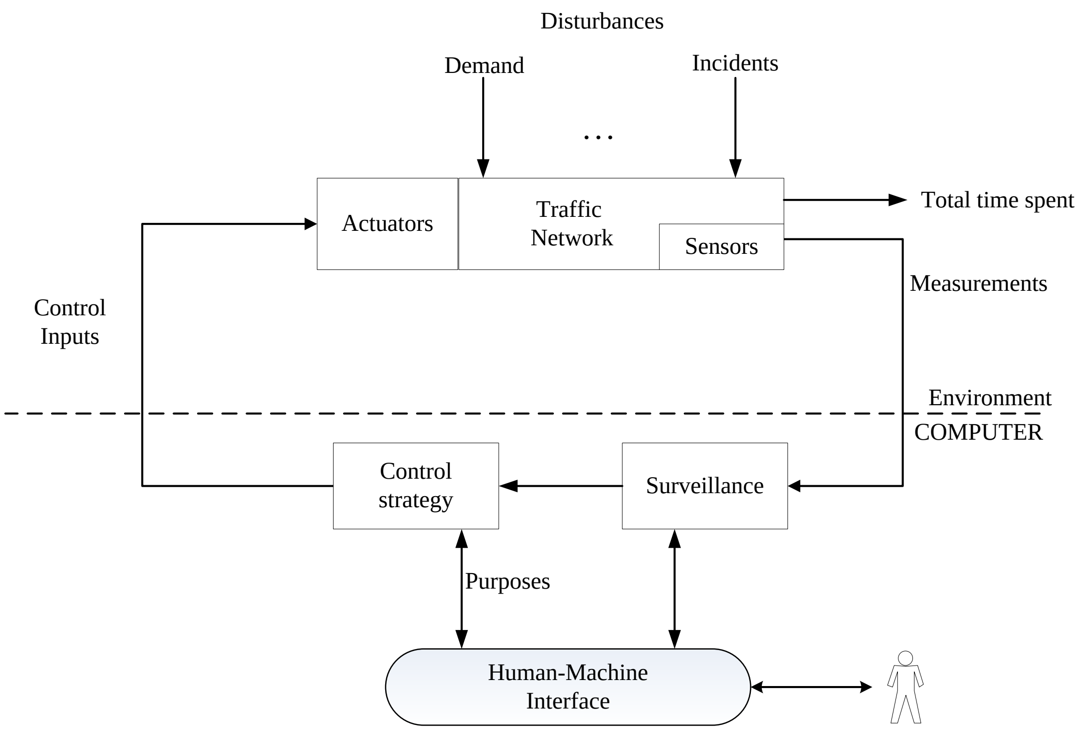


Figure 1. Traffic network feedback

In Figure 2 is illustrated a simple road intersection to compute traffic flows without turning left and right, where d_1 and d_2 are flows of arriving vehicles in direction north-south and east-west, respectively. The maximum oversaturation flow rate for d_1 and d_2 is s_1 and s_2 respectively, g_1 and g_2 are light phases of traffic light for both directions.

The average green light time is equals [12]

$$t_{gi} = t_c \frac{d_i}{s_i}, i = 1, 2, \dots , \tag{1}$$

where t_c – cycle time of traffic light signal changing.
Once arrival flows d_1, d_2 grow, we have

$$t_{g1} + t_{g2} > t_0 - L , \tag{2}$$

or

$$\frac{d_1}{s_1} + \frac{d_2}{s_2} > 1 - \frac{L}{t_c} , \tag{3}$$

where: L – the total lost time for acceleration and clearing.

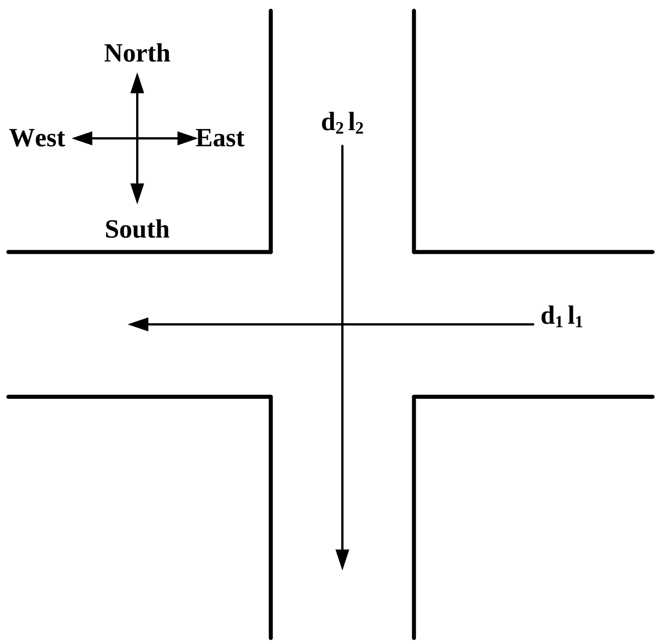


Figure 2. Simple road intersection

The sequence lengths l_1, l_2 at the intersection are designated as the state variables of the road traffic system with the following equations:

$$\dot{l}_i = d_i - s_i \frac{g_i}{t_c} , \quad i = 1, 2, \dots \tag{4}$$

The difference between arriving flow d_i and second term on the right-hand side of equation (4) designated as the rate change of the sequence length at the intersection. The second term on the right-hand side of equation (4) we can designate as control variables if there is no influence on the rate of arrivals. Therefore,

$$r_i = s_i \frac{g_i}{t_c} , \quad i = 1, 2, \dots \tag{5}$$

However

$$g_1 + g_2 = t_c - L \tag{6}$$

Substituting (5) into (6)

$$\frac{r_1}{s_1} + \frac{r_2}{s_2} = 1 - \frac{L}{t_c} \text{ or}$$
$$r_2 = s_2\left(1 - \frac{L}{t_c}\right) + \frac{s_2}{s_1} r_1, \tag{7}$$

which means: $r = r_1$. Substituting (5) and (7) into (4) we obtain the linear state equation of the system:

$$\dot{l_1} = d_1 - r \tag{8}$$
$$\dot{l_2} = d_2 - s_2\left(1 - \frac{L}{t_c}\right) + \frac{s_2}{s_1} r. \tag{9}$$

The equations (8) and (9) provide a basis for obtaining optimal control strategies of traffic light signals at intersection road with direction only straight ahead.

Let's consider intersection with turning left and right. The state equations for intersection with turning left and right (Figure 3) are obtained as the same for a simple intersection. The control variable is set to

$$r = s_{11} \frac{g_1}{t_c} \tag{10}$$

and the state equations are given by

$$\dot{l_{11}} = d_{11} - r \tag{11}$$
$$\dot{l_{12}} = d_{12} - \frac{s_{12}}{s_{11}} r \tag{12}$$
$$\dot{l_{21}} = d_{21} - s_{21}\left(1 - \frac{L}{t_c}\right) + \frac{s_{21}}{s_{11}} r \tag{13}$$
$$\dot{l_{22}} = d_{22} - s_{22}\left(1 - \frac{L}{t_c}\right) + \frac{s_{22}}{s_{11}} r\ . \tag{14}$$

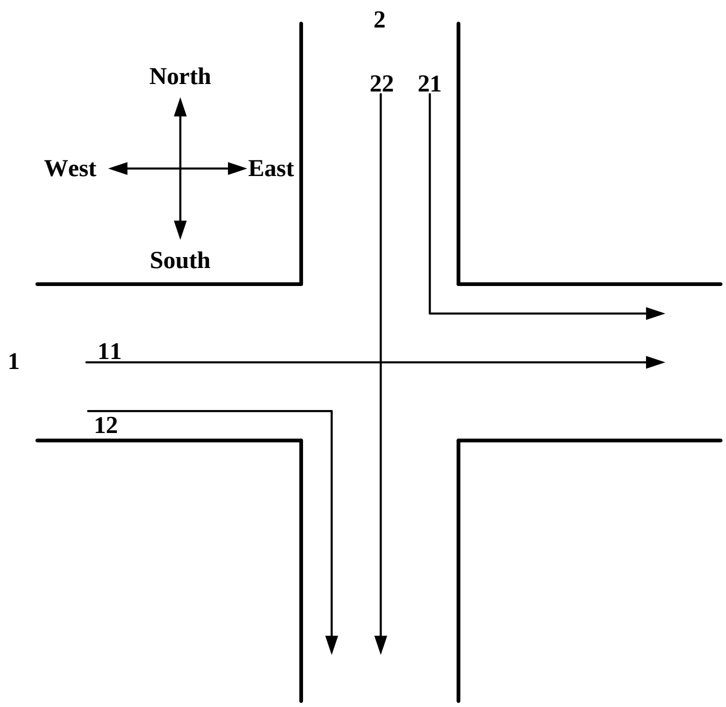


Figure 3. A complex oversaturated intersection

3. Components of traffic light control system

A block diagram of traffic light control system is illustrated in Figure 4. Microcontroller PIC 16F877A based traffic light control system consists of the following components:

- 5 V power supply;
- Microcontroller PIC 16F877A;
- Control switches (Transistor BC557 and resistor 1K);
- Binary Coded Decimal (BCD) decoders;
- 74LS47N decoders;
- Seven-segments display decoder;
- LED driver.

BCD converts one digital format into another format for 7-Segment Display Decoder which is suitable to display. BCD converter has Input lines (A, B, C, D) and Output lines (a, b, c, d, e, f, g) (Figure 5) [13].

LED drivers are used to control the traffic light units. Control switch consists of resistor and transistor. It is controlled by microcontroller and used to switch on or switch off 7-segment display.

Digit 7-segment is provided to show numbers, letters or even alpha-numerical characters in digital form. The unit comprises of seven segments in one single display package.

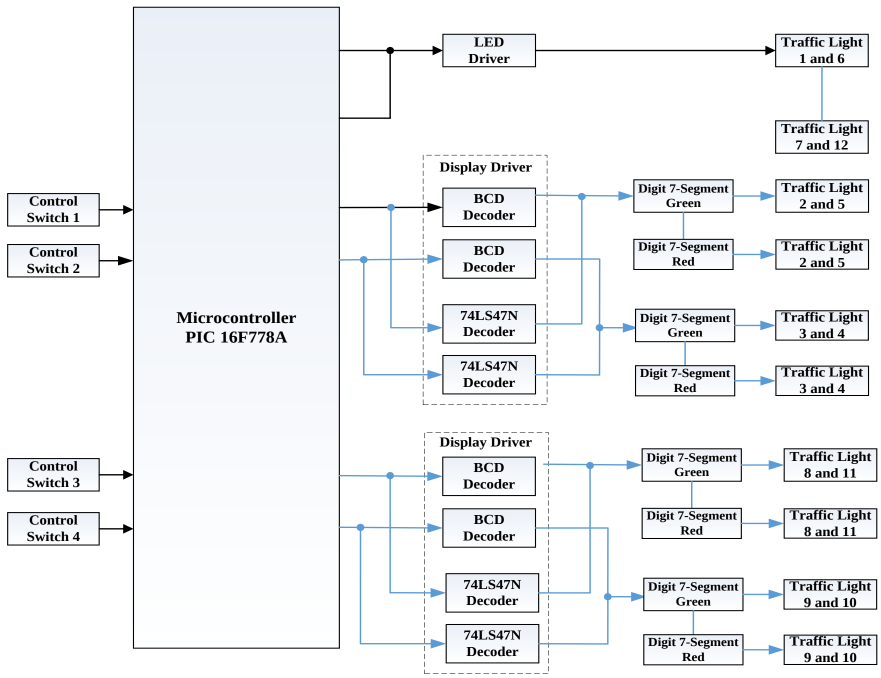


Figure 4. Block diagram of traffic light control system

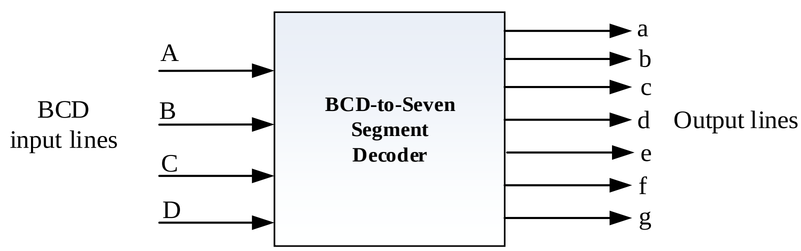


Figure 5. BCD-to-Seven segment decoder

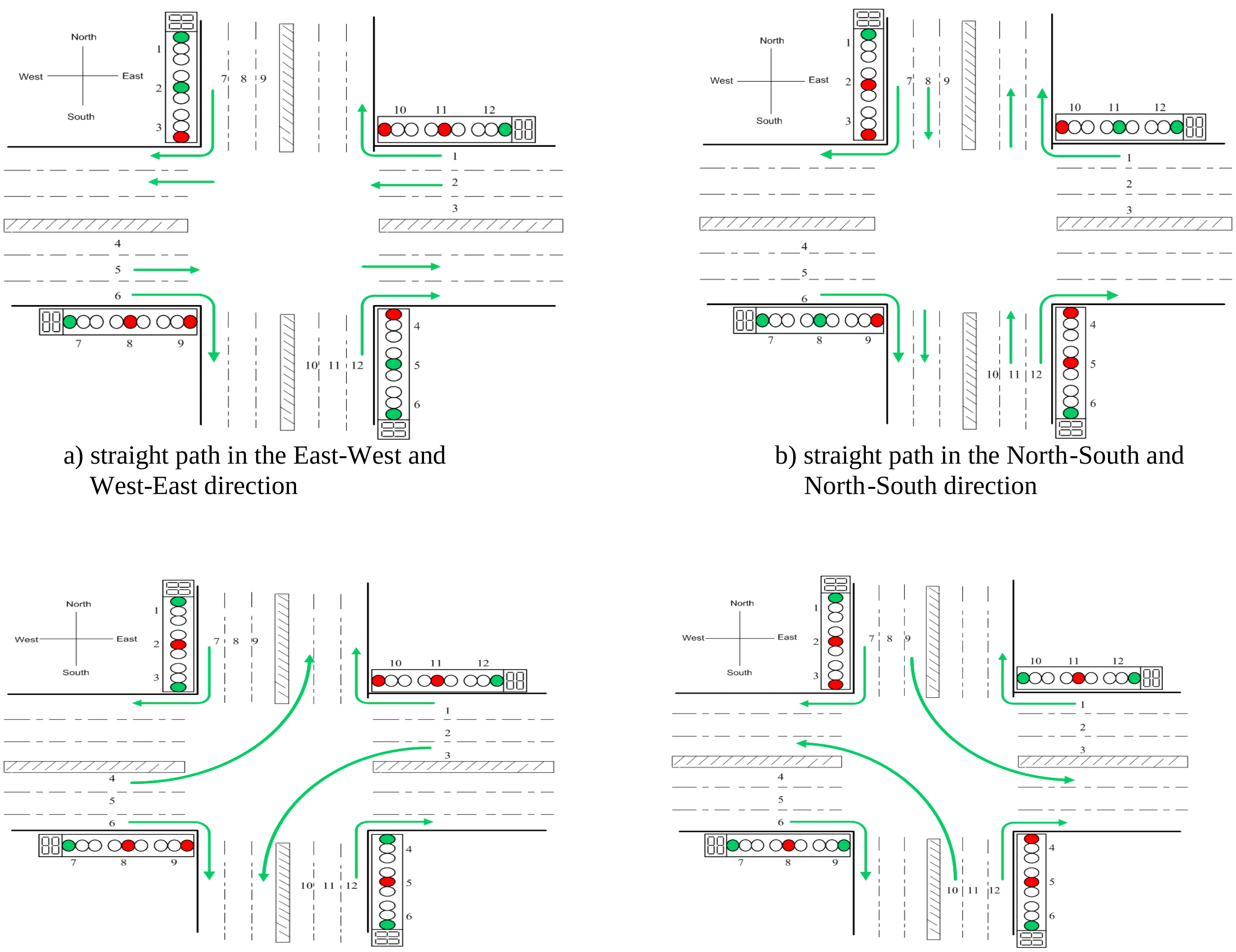
BCD to 7-segment Display Decoder and 74LS47 decoder illuminate on the display the correct combination of LED segments required numbers or HEX characters from 0 to 9 and A to F respectively.

A standard 7-segment LED display generally has 8 input connections, one for each LED segment and one that acts as a common terminal or connection for all the internal display segments. Some single displays also have an additional input pin to display a decimal point in their lower right or left hand corner [13].

4. Simulation and implementation of traffic light control system

The simulation of PIC 16F877A based traffic light control system is executed in Proteus Design Suite 8 software. We used Proteus Design Suite to build the model of traffic light control system for six way and four junction intersection and to implement simulation of the system.

Figure 6 illustrates traffic flow, layout of four-way road intersection. There are four states of direction for cars and each direction has two states, for example go to straight direction has North – South and South – North states, respectively turn left direction has East-South and West-North and so on. The directions to right turn (1,6,7,12) always are open for cars. Each lane direction has also three lines, East-West and West-East lanes have 1, 2, 3 and 4, 5, 6 lines; North-South and South-North lanes have 7, 8, 9 and 10, 11, 12 lines.



a) straight path in the East-West and West-East direction

b) straight path in the North-South and North-South direction

c) turning path in the East-South and South-West direction

d) turning path in the North-East and West-North direction

Figure 6. Traffic flow layout

Traffic lights for parallel paths (2 & 5, 8 & 11) go to straight and for parallel paths (3 & 4, 9 & 10) turn left are controlled by microcontroller using BCD-to-seven segment and 74LS47N decoders.

So, traffic lights for parallel paths 1 and 6, 7 and 12 are always open they directly connected to microcontroller.

The passing time of each parallel paths for go forward and turning left is 35 sec. Implementation of simulation, for example of paths go forward (2 & 5) is illustrated in Figure 7.

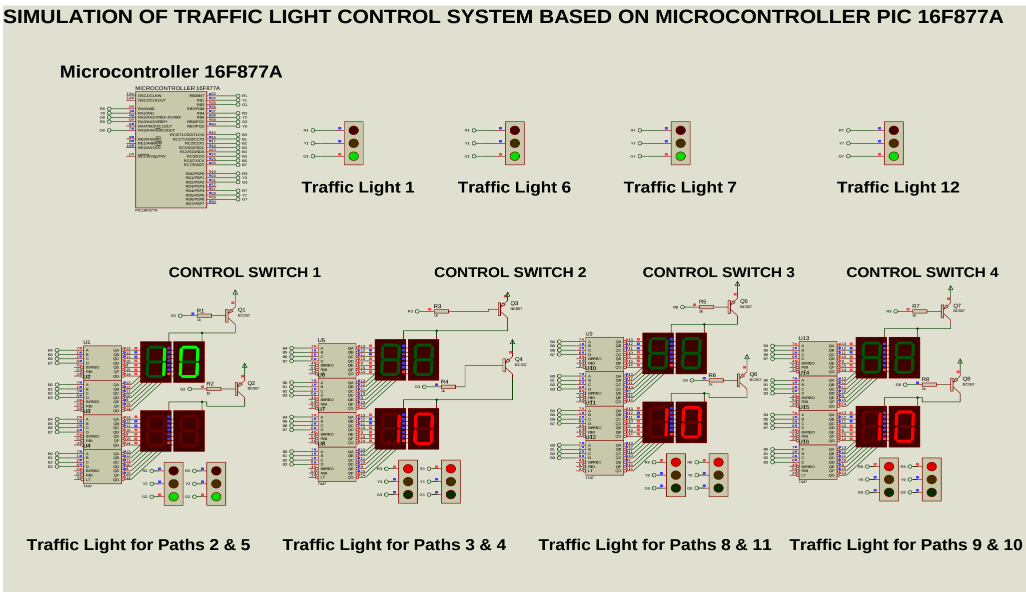


Figure 7. Traffic light is flashing green to go forward for paths 2&5

PIC 16F877A microcontroller and PICkit 3 programmer/debugger are utilized to execute in the prototype the control of traffic light. The program code for microcontroller realized in C++ on mikroC PRO for PIC software.

The system operates in two modes – normal and emergency. There are four control switches – CS1, CS2, CS3 and CS4 for emergency mode. Control switch CS1 is intended for path 2&5, CS2 – for path 3&4, CS3 – for 8&11 and CS4 – for path 9&10. Once control switches CS1 – CS4 pushed on triggered, emergency case for each control switch has executed. For example, if emergency case occurs in path 3&4 control switch CS2 push on triggered and road will open 10 sec. to pass for emergency cars. In Figure 8 is shown emergency case for path 3&4 is open.

Normal mode operation is applied when traffic congestion occurs in rush hours. In rush hours, the cars enlarge at the intersection road. Therefore, people waste more time than usual times. The traffic light is green setting time should be increased for paths with high traffic flow, respectively traffic light is green setting time reduces for paths with low traffic flow to prevent waste time of cars.

Let’s consider the system operation in normal mode using Table 1. Turn right direction for paths 1&6, 7&12 is active (value 1) always as Green, it means traffic light is not active as Red for them.

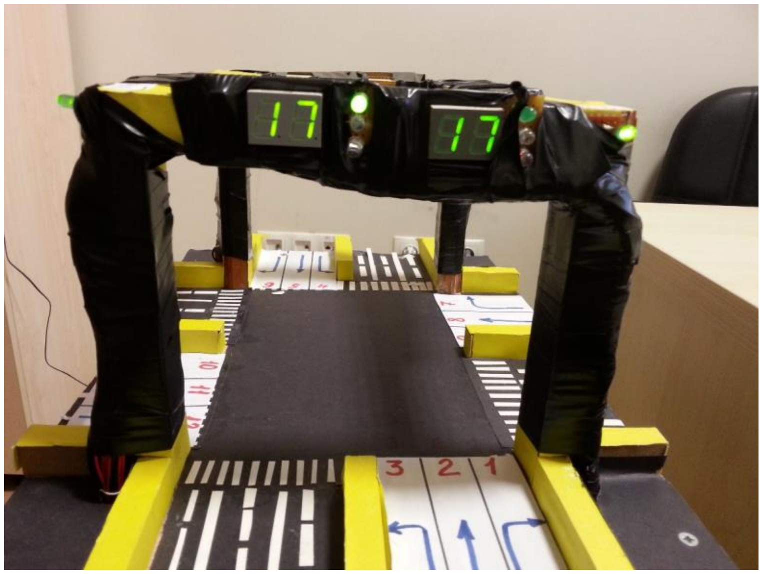


Figure 8. Emergency case for path 3&4 is open

Therefore, once parallel connected 2&5 paths are active as Green (value 1) for direction straight ahead during 35 sec., all another path are Red (value 0) in this time (Table 1). The demonstration of this state on prototype is illustrated in Figure 9. The cars can pass from 2&5 paths of intersection road during 35 sec., until traffic light is flashing Yellow. When traffic light is Yellow for 3 sec. direction straight ahead for paths 2&5 is closed (Figure 10).

Table 1. Traffic light is flashing Green for paths 2&5

Traffic light	Red	Yellow	Green
1 & 6	0	zero	1
2 & 5	0	zero	1
3 & 4	1	zero	0
7 & 12	0	zero	1
8 & 11	1	zero	0
9 & 10	1	zero	0

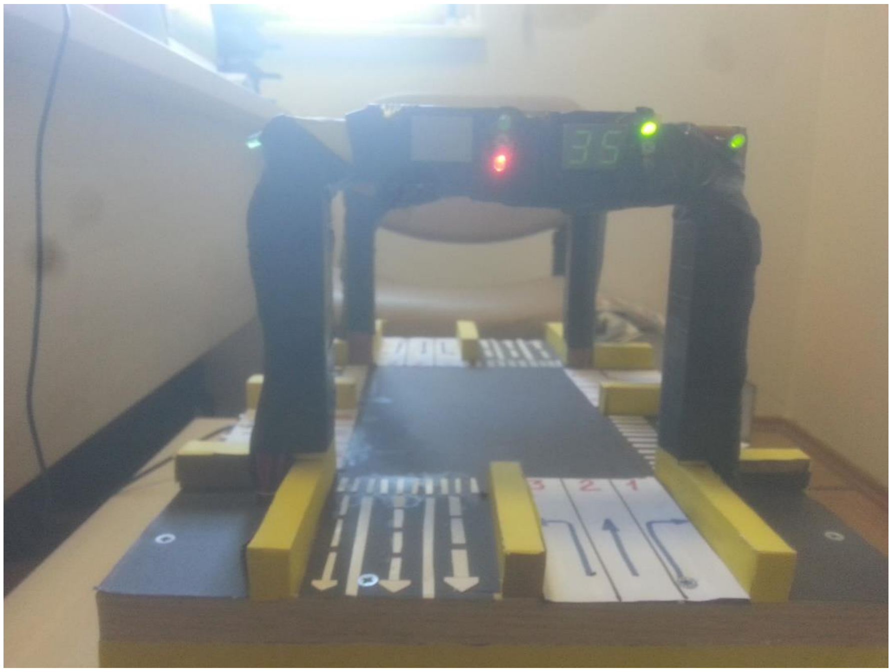


Figure 9. Traffic light is flashing Green for paths 2&5 straight ahead

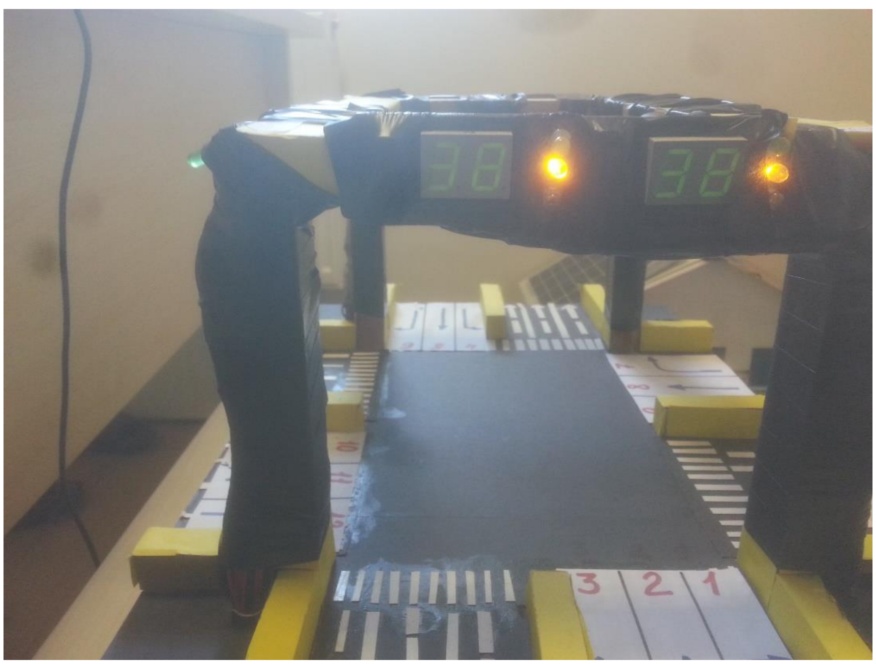


Figure 10. Traffic light is Yellow for paths 2&5 – straight ahead

The operation principle of traffic light for paths 8&11 (value 1) is the same as traffic light for path 2&5. (Table 2 and Figure 11).

Table 2. Traffic light is flashing Green for paths 8&11

Traffic light	Red	Yellow	Green
1 & 6	0	Zero	1
2 & 5	1	Zero	0
3 & 4	1	Zero	0
7 & 12	0	Zero	1
8 & 11	1	Zero	1
9 & 10	1	Zero	0

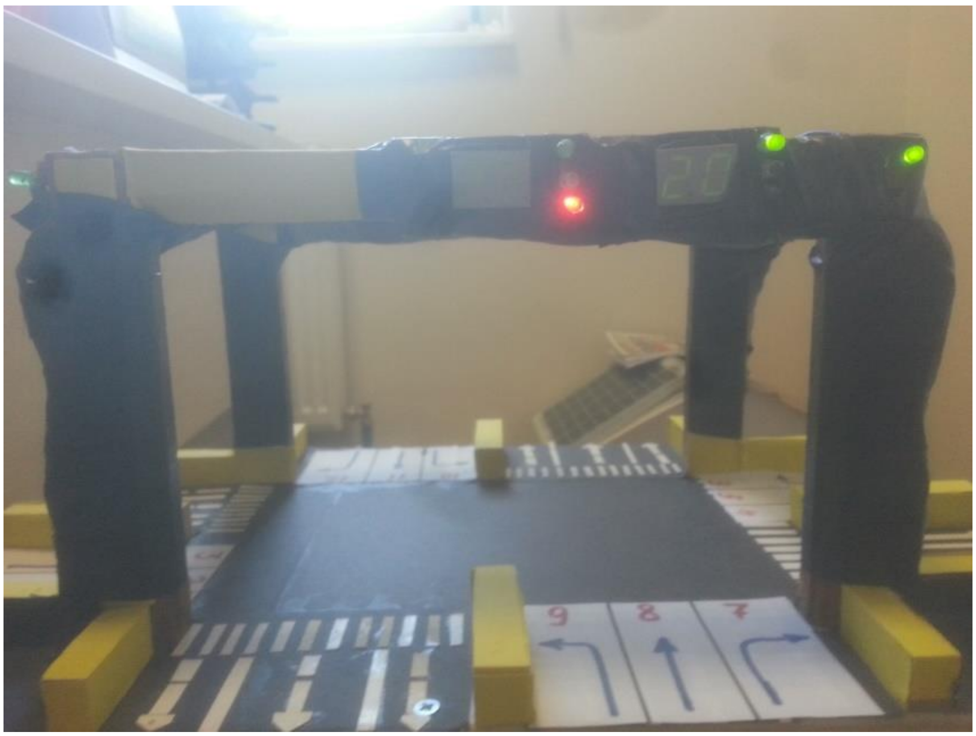


Figure 11. Traffic light is flashing Green for paths 8&11 – straight ahead

The operation principle of the traffic light for paths 3&4 and 9&10 turning left direction is the same as the traffic light for paths 2&5 and 8&11.

5. Conclusions and future works

The fast increasing number of passenger vehicles in urban cities and other urbanization activities has created a huge problem on Turkish metropolitan transportation systems.

This paper is dedicated to solve the problems of traffic congestion at intersection road. The microcontroller-based traffic light control system is developed for six way and four junctions at road intersection with arrowed signal for each direction.

The traffic light control system is designed to provide either normal or emergency mode cases for vehicles and reduce of traffic congestion at intersection road. The simulation of PIC 16F877A based traffic light control system is executed in Proteus Design Suite 8 software. Proteus Design Suite software applied to develop schematic diagram and PIC C compiler used is micro C Pro. The program code for microcontroller realized in C++ on mikroC PRO for PIC software.

There are several advantages of this system:
1. Simplicity, user friendly. Easily programmable.
2. Using of LEDs provide a longer service life, save a lot of energy and has less impact on the environment
3. Waiting time of cars at intersection reduces. So, it also reduces traffic congestion.
4. Gives a quick response to change in traffic, i.e. highly responsive.

In our future works we are planning to develop multi-agent based control of traffic road network including not only vehicles, also buses, pedestrain and bicycles in real-time. For this purpose we are going to:

- use cameras, loop detectors with GPS and Wi-Fi communication for traffic control system;
- employ reinforcement learning (RL) agent to optimize agent behavior;
- add to simulation platform the options which will give effects to define the occupancy of vehicle lanes on traffic network roads;
- develop the RL algorithm to provide communication between road intersections to make green ratio possible and delay time of vehicles should be depend on amount of traffic on the next intersection.

Acknowledgements

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