Traffic Light with Inductive Detector Loops and Diverse Time Periods

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Abstract. Designing a traffic light system can be a challenging task. Several factors should be taken into account. Neglecting some of these factors can cause the traffic light to be inefficient by harming the flow of the traffic, increasing the carbon emission and even trigger off unnecessary vehicle accidents. This paper presents a scheme for a practical intelligent traffic light design.

Keywords: Traffic light, State Machine, Inductive Detector Loops

1 Introduction

Traffic lights have been becoming more sophisticated since their invention at 1868 [1]. The new generation of traffic lights is called "intelligent traffic lights" and it contains digital electronic units derived from common computers [2]. Traffic lights are one of the oldest safety apparatus for transportation [3]; however, traffic lights can have both positive and negative effects on transportation safety; particularly traffic lights can increase the chances for rear end vehicle accidents [4]. Computed collision detection simulations can help deciding whether to install a traffic light in a questionable intersection [5,6]. Yet, when the new autonomous vehicles will be widespread, these decisions may be changed [7,8,9].

2 Traffic Light Model

We consider an intersection of two roads and a controllable traffic light system is in charge of the lights on all of the intersection corners. In Israel most of the major roads are North-South; therefore we consider the North-South road as the major road and the East-West road as a minor road. Accordingly, we gave the North-South road triple time period.

In countries where the traffic goes on the right side of the road, the right turns are easier; because they do not interfere with the traffic from the opposite direction. In Israel vehicles go on the right side of the road; therefore, the left turns are more problematic. There are two possibilities what to do when the left turns get the green light:

1. Let two left turns from opposite directions to go together as they will not intrude into each other's path.
2. Let the traffic comes from one side and goes straight or goes left to be in motion together.

We have chosen the second option.

As the traffic of the left turns is sparse, we consider Inductive Detector Loops [10,11] installed under of the left turn lanes pavement. If the detector does not indicate a vehicle in the turn left lane, the green light for this turn will be skipped in this iteration.

The state machine for this traffic light is depicted in Fig. 1.

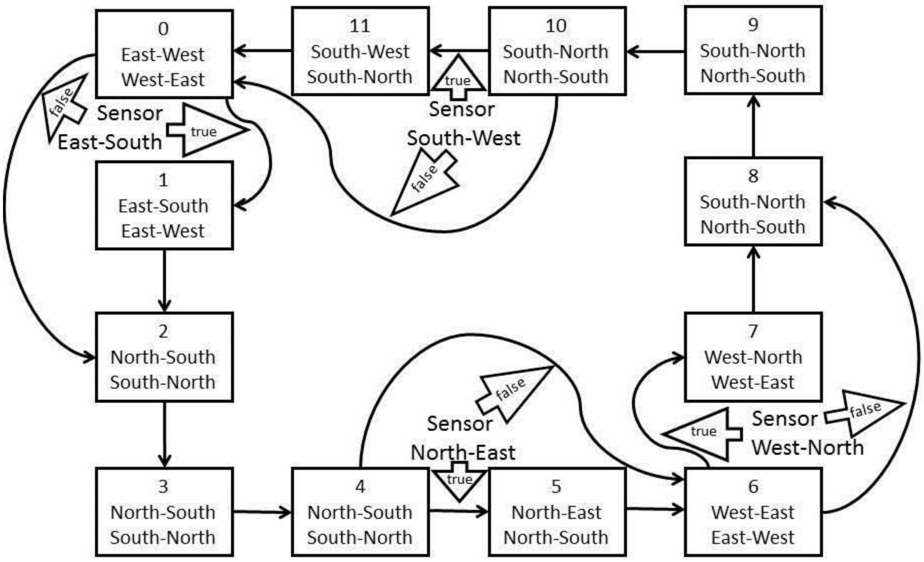

Fig 1. Description of the states in the traffic light.

3 Controlling the lights according to the states

The lights are decided only according to the states. The inputs from the Inductive Detector Loops have an effect only on the next state decision. This is actually the different of Mealy machines [12] and Moore machines [13]. In Mealy machines, the input has a direct effect on the output, whereas in Moore machines the input affects the output only through the selection of the states. In view of that, our machine is a Moore machine.

We use Karnaugh maps [14] to find the simplest functions for implementing these circuits. As can be seen in Fig. 1, we have 12 states numbered from 0 to 11, so we need $\lceil \log_2 12 \rceil$ flip-flops to implement this state machine i. e. we need four flip-flops. We have denoted these flip-flops as A, B, C, D. Four flip-flops will give us 2^4 states but as a matter of fact only the first 12 states are needed. The other states are considered as "don't care" as denoted by "X". We have considered green light as "1" and red light as "0".

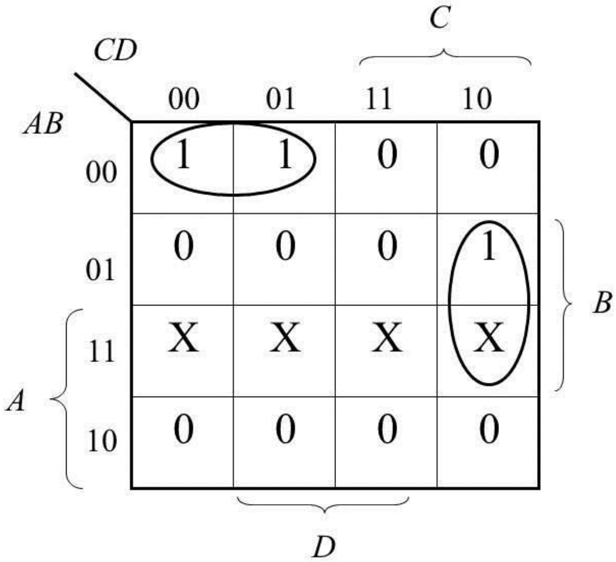

Fig. 2. Karnaugh map for East-West direction.

The first traffic light we take is for the East-West direction. The Karnaugh map for this direction is depicted in Fig. 2 and according to this map the minimized Boolean function for this direction is

$$East - West = \bar{A}\bar{B}\bar{C} + BC\bar{D}$$

According to De Morgan's laws it can be also expressed as:

$$East - West = \overline{A + B + C} + BC\bar{D}$$

The implementation of this Boolean function can be found in Fig. 3.

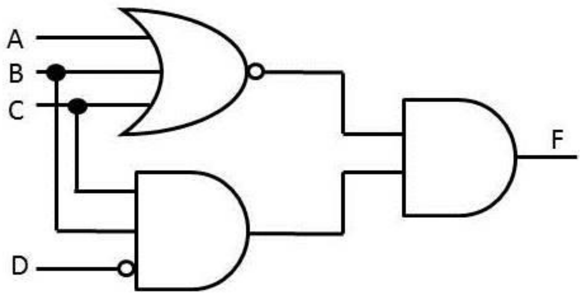

Fig. 3. Gate implementation for the circuit of East-West direction.

Unfortunately we do not have enough space in this paper to detail all the traffic lights; however, the chosen traffic light can clearly point up the system configuration.

The next state functions are more complicated because we have four input lines and four flip-flops, so in total we have eight lines entering into the circuit functions, which are too much for a Karnaugh map. So, we will have to minimize the functions by the Boolean Algebraic laws.

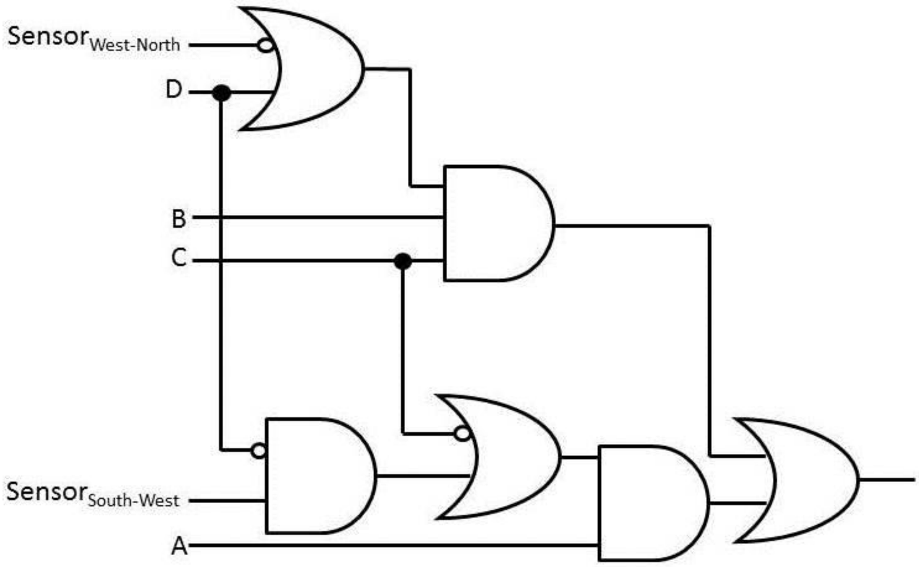

Fig. 4. Gate implementation for the circuit of next value for flip-flop A

The first next function we take is the next value for flip-flop A. We consider standard Edge-Triggered D flip-flop, so the function is:

$$A_{next} = \bar{A}BC\bar{D} \cdot \overline{Sensor_{West-North}} + \bar{A}BCD + A\bar{B}\bar{C}\bar{D} + A\bar{B}\bar{C}D + A\bar{B}C\bar{D} \cdot Sensor_{South-West}$$

The first product in this function assumes that the current state is 6; however, adding states 7, 14 and 15 will make no harm, because from state 7 we always go to state 8 regardless of the sensors and in state 8 flip-flop A should contain "1". States 14 and 15 do not exist, so we don't care what the value of flip-flop A will be in these non-exist states, therefore we can minimize the first product to:

$$BC \cdot \overline{Sensor_{West-North}}$$

The second product assumes that the current state is 7, but again we can add state 15 that do not exist and this addition will help us to minimize the product to:

$$BCD$$

The third and the forth products assume that current state is either 8 or 9. Here, we can add state 12 and state 13 that do not exist and by this to minimize the third and the forth products to:

$$A\bar{C}$$

The last product assume that the current state is 10; however, adding states 8, 12 and 14 will make no harm, because from state 8 we always go to state 9 regardless of the sensors and in state 9 flip-flop A should contain "1". States 12 and 14 do not exist, so we don't care what the value of flip-flop A will be in these non-exist states, therefore we can minimize the first product to:

$$A\overline{D} \cdot Sensor_{South-West}$$

Consequently, the next function of A should be:

$$A_{next} = BC \cdot \overline{Sensor_{West-North}} + BCD + A\bar{C} + A\overline{D} \cdot Sensor_{South-West} =$$

$$A_{next} = BC(\overline{Sensor_{West-North}} + D) + A(\bar{C} + \overline{D} \cdot Sensor_{South-West})$$

We are not interested in the delay of the logic gates and the number of level that we should be passed until getting the result, because anyway the clock cycle is very long – few seconds; therefore, we focus on minimizing the number of gates, even if the result is more level of gates and an extra delay time. The implementation of this function can be found in Fig. 4.

Unfortunately here again we do not have enough space in this paper to detail all the next state functions; however, the chosen next state function can clearly point up the system configuration.

4 Conclusions

Vehicular safety equipment is divided into two general categories. The equipment within the vehicle [15,16,17] and equipment in the vehicle environment [18,19]. Traffic lights are one of the most important safety equipment in the second category. New approaches for traffic light configurations have been recently suggested [20]. These approaches can be implemented in a dedicated chip [21] or in a remote manner [22] and can have many benefits for many objectives like better traffic flow [23,24] or carbon emissions mitigation [25]. Our proposition in this paper can help traffic light designers drawing up plans for more efficient traffic lights.

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