Design of railway signaling system using IR sensor as train detection

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Abstract. In this research would try to give contribution for researchers or academics about simulation of the railway signaling system. The model of railway system was built using miniature of track and train model. Small LED was used as a lamp signal. Point machine was moved by servo motor controlled by Arduino Nano. The last, track circuit was replaced by proximity sensor using IR transceiver. The result showed that the simulation could do some basic task which is occurred in railway signaling system. The design of system was created by FSM (Finite State Machine) method which would be implemented in PLC (Programmable Logic Controller). It consists of state diagram, declaration of inputs and outputs, generated logic equation, and finally is the written code in ladder logic diagram. Set route test also has been tried successfully and the lamp signal showed the color aspect correctly.

1. Introduction
Nowadays Indonesia start to build many of infrastructures. One of them is the development of railway industries to serve mass transportation such as MRT, LRT, and super high speed train. It begins from railroad infrastructure until the technology itself which can support railway signaling system. In the future, to anticipate the need of railway signaling engineer, then the research begins to learn and introduce how the railway signaling system is working.

The railway signaling system is an electronic system which connect some wayside equipment such as point machine, track circuit, signal lamp, and the interlocking system as its controller [1-3]. The safety factor is the most important thing that it should be guaranteed by design. The railway signaling system must check all of wayside equipment at the correct and safe condition. If sometime there is an error in one of the equipment, then the system will prevent the train not to move or stay in safe condition state.

The first design of system is only using single track with one train and the system also has several limited routes. Because it is our first time project, it still doesn’t have many complex features but in every semester the improvement will be made. The design was implemented using FSM (Finite State Machine). It was used because it was very simple and structural. The state chart of interlocking was created before the program or code (ladder logic) of it was put into PLC.

Some of previous researches about signaling of train have been done [4-11]. Many researchers have developed many technology methods in interlocking system or train detection to achieve the main purpose is safety. It was started from relay circuit until computer based interlocking. Today, the train control technology is also improved by the existence of IoT.
2. Method
This part will explain about the design method and what must be known before design is developed

2.1. Interlocking system
Interlocking system is a computerized system which controls and monitors the collection of objects in the railway [2]. The objects are:

- Signal Lamp
- Train Detection
- Point Machine

Figure 1 shows the railway signaling system which is collection of several objects and it is controlled by interlocking system.

![Figure 1. Example of interlocking application to guarantee train movement safe][1]

There are many routes that signalmen can set. The operator will choose where the entrance and exit point of route. All of conditions below here should be fulfilled if any route would be set [2].

- All of the track circuit should be in ‘clear’ condition. If there is any track circuit is not clear in the route, then the set route would not be accomplished.
- The point machine should be in appropriate position depending on where the set route is chosen. If the point machine is not in correct position so the system will automatically change the direction of point machine to another position.

2.2. FSM (Finite State Machine)
An FSM (Finite State Machine) is a mathematical model of computation for representation of sequential logic circuit with finite number of state [8]. In one time there must be only one state would be active. To design digital system circuit looks like the interlocking system, the FSM method is very suitable because it would make the program more structural and easier to understand.

There are two types of FSM [12]:

2.2.1. Moore state machine. The FSM is called moore state machine if the outputs depend only on the state condition.

2.2.2. Mealy state machine. The FSM is called mealy state machine if the outputs depend both the present state and inputs. Moore state machine looks simpler than mealy machine because the output is only a function of state. It could be said that the present state is alias of output.

2.3. Hardware design
There are several components which is needed to build the prototype of railway signaling system.
2.3.1. Layout and starter set of train model.

The track layout is developed like shown in figure 2. It has 3 station A, B, and C.

2.4. Signal lamp by small LED

The 3 aspects and 2 aspects lamp signal have different circuit. Demux circuit is used to reduce the number of used pin output in PLC. So, it doesn’t need 3 outputs pins, but only just 2 pins to control 3 aspects lamp.

- IR proximity Sensor for train detection.
- Motor Servo as Point Machine.
- PLC as Controller

2.5. Software design

The making of software of interlocking system has 3 steps process.

2.5.1. Define all of inputs and outputs. How many inputs, outputs, and states can be derived from figure 4. The table 1 shows list of inputs, states, and outputs that would be used in design. This table consists of variable’s name of input, output, state, and also their memory locations in PLC.
Table 1. List of input output table.

| Input            | Output              | State |
|------------------|---------------------|-------|
| 1. Track Circuit | 1. Signal Lamp 2 aspect | S00   |
| TCA1             | X1                  | C0    |
| TCA2             | X2                  | L1    |
| TCB1             | X3                  | C2    |
| TCB2             | X4                  | C3    |
| TCC1             | X5                  | C4    |
| TCC2             | X6                  | C5    |
| 2. Signal Lamp 3 aspect | S20 | C6    |
| LW2A             | Y6                  | C7    |
| IW1              | X7                  | Y8    |
| IW2              | X8                  | 3. Point Machine |
| 3. Set Route Button | W1               | W2    |
| SRAC             | X9                  | W2    |
| SRCA             | X10                 | W9    |
| SRBC             | X11                 | W2    |
| SRCB             | X12                 | W2    |
| 4. Start/Stop Button | START         | X13   |
| STOP             | X14                 |       |

2.5.2. State diagram. The state diagram or state chart below in figure 5 was designed based on the track plan at figure 4.

Figure 5. State diagram of interlocking for 2 routes.

2.5.3. Ladder logic diagram and logic equation. The logic equation is derived from state diagram at figure 5. There are divided into 2 equations as follows:

- State equation:
  \[
  S00 = \overline{STOP}(START + S00.S11.S12.TCC2 + S12.TCC2.TCA1) 
  \]
  \[
  S10 = \overline{STOP}.(S10.S11 + S00.SRAC.TCC2.TCC2.TCA1.IW1) 
  \]
  \[
  S11 = \overline{STOP}.(S10.TCA1 + S11.S12) 
  \]
The simulation was done by using free software for PLC simulation ‘Do – more Designer’. Before the implementation is made, the simulation of interlocking software has been done successfully. The simulation was done by using free software for PLC simulation ‘Do – more Designer’.

### Table 2. State and output relation.

| Sta | LA | LB | LC | LW1A | LW1B | LW2A | LW2B | W1 | W2 |
|-----|----|----|----|------|------|------|------|----|----|
| S00 | 0  | 0  | 0  | 0    | 0    | 0    | 0    | 0  | 0  |
| S10 | 1  | 0  | 0  | 0    | 0    | 0    | 1    | 0  | 0  |
| S11 | 1  | 0  | 0  | 0    | 0    | 0    | 1    | 0  | 0  |
| S12 | 0  | 0  | 0  | 0    | 0    | 0    | 1    | 0  | 0  |
| S20 | 0  | 0  | 1  | 0    | 1    | 0    | 0    | 0  | 0  |
| S21 | 0  | 0  | 1  | 0    | 1    | 0    | 0    | 0  | 0  |
| S22 | 0  | 0  | 0  | 0    | 1    | 0    | 0    | 0  | 0  |

### 3. Results and discussion

Before the implementation is made, the simulation of interlocking software has been done successfully. The simulation was done by using free software for PLC simulation ‘Do – more Designer’.

Figure 6 shows that the START button (X13) is pushed and it makes the system is ready now to accept another input. The variable X at the simulator is used as external inputs and the variable Y as external outputs. The state is coded by bit memory C. The table 1 could be reviewed to see more detail about the used variable. The ladder logic diagram in the simulator is refer to equation (4) until (14). For example, equation (5) could be generated to be like figure 7.

\[
S_{21} = \overline{STOP} (S_{20}. S_{21} + S_{00}. \overline{SRCA}. \overline{TCC1}. \overline{TCA1}. \overline{TCB1}. \overline{IW1})
\]

Figure 6. User interface simulation.

Figure 7. Example of ladder logic diagram for S10.
The design that we were done in here is much simpler than in the last research design in [9,11]. There is no complex calculation or complicated mathematical model to develop our interlocking system.

4. Conclusion
After design and simulation has been done, it can be concluded that the FSM method succeeds to develop an interlocking system. The FSM is very structural and organized so it’s suitable for train control design that uses so many inputs and output.

In the future, new researches will improve this first research for example are to make the track plan bigger or using double track with more number of train which can be operated

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