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Abstract. This paper presents the sliding gate opener system that android smartphones can remotely control using a Bluetooth connection. The gate opener is driven by 12-pole single-phase induction motor of permanent-split-capacitor type (PSC motor) coupled with right-angle worm gear and rack-pinion power transmission. To obtain subjacent velocity of the gate opener, worm gear which has a 50:1 speed ratio has been selected. The wiring of PSC motor installation is designed so that the PSC motor can rotate either forward or in the reverse direction by using contactors arrangement which is controlled by Arduino microcontroller module. Moreover, the microcontroller module has been wired with Bluetooth transceiver HC-06 enabling it to communicate with other devices using a Bluetooth connection. The microcontroller module has been programmed so that the gate opener movement can be remotely governed from android smartphones and can be controlled at the site (local-control) by operating a set of pushbutton switches mounted onto the door of the control panel which is placed near the motor installation site. In addition, there are 2 limit switches installed at the ends of the gate opener movement to give information to the microcontroller to stop the motor automatically when they are touched by the gate opener. The functional test has been conducted on the sliding gate opener system and the result shows the gate opener movement can successfully be controlled locally through pushbutton switches and remotely using an android smartphone with a distance of up to 8 meters.

INTRODUCTION

The industrial control technology has been adapted to residential applications to provide comfort to family members and simplify many tasks at home. Some activities that are usually done in manual way have been transformed to be executed automatically by extensive use of electricity and electronic control system. Automatic washing machine for laundry and automatic dishwasher for cleaning food utensils are two examples to mention. Another task at home that has attracted engineers to discover such simple method of execution is the activity to open and close the entrance gate.

Based on its mechanism, there are 2 types of gate opener used in residential applications: swinging-arm opener and sliding opener. To automate the opening/closing process, the electric actuator must be geared to the gate opener, thus different mechanism requires different type of electric actuator as well. By using electric actuator, a weighty gate opener will be easily driven to open or to close with little effort of the operator.

Many researchers have proposed their ideas in relation with gate opener automation system. Khreasarn and Hantrakul have added remote-control feature to existing gate entrance system, so the gate opener can be controlled from far distance by smartphone with bluetooth connection [1]. Notice that the gate entrance system was previously operated using RFID identification. Pospisilik et. al have proposed GSM network and arduino platform to control swing-arm gate opener movement [2]. This system offers bi-directional communication between the user and the gate controller via text messaging service (SMS). Majcher has proposed to use programmable logic controller (PLC) to control sliding gate opener system [3]. He made a model of the system that was controlled by Siemens PLC and the commands to open and close the gate originated from a set of pushbutton switches connected to PLC's input module. Muthmainnah and Afiq have proposed to control the sliding gate opener system from android gadgets using Wi-Fi connection [4]. They made miniature of the system consisting of Arduino microcontroller, Wi-Fi module, DC motor as actuator and some sensors to create smart gate system.

In this paper, the sliding gate opener system is controlled by Arduino microcontroller module and possess 2 modes of control, local-control and remote-control. In local-mode, the movement of gate opener is commanded by a set of pushbutton switches wired closely to the input channels of microcontroller. And also, there are 2 limit switches wired to the microcontroller input channels to detect ends of gate opener movement. Contrarily, in remote-mode, all operation commands to the microcontroller, such as open/close/stop the gate opener, will come from android smartphone that connected to the microcontroller in wireless using Bluetooth protocol. The transition between local to remote control or vice versa is done by operating a selector switch that wired closely to the input channel of microcontroller. However, the default setting of the control system is remote-control. Providing local-control feature gives advantage because, the gate opener still can be controlled from on site, in case troubles happened to the smartphone, such as the smartphone experiences low-battery conditions. Another feature that makes this research differing than others is about the actuator we choose. The permanent-split-capacitor motor (PSC motor) is used to drive gate opener mechanism. This motor is selected because of some reasons. First, it is a single-phase AC motor, so it is suited with the electricity available at home. The second, PSC motor has low maintenance cost, because it does not have brushes, so no need regular components replacement like happened to DC motors. And the third, the speed of PSC motor is nearly constant from no-load to full-load conditions, so speed control is not required, thus this factor will simplify motor controller configuration.

DESIGN CONSIDERATIONS AND METHODOLOGY

The sliding gate opener system consists of 3 main parts, which are an electric motor with its power transmission apparatus, the motor controller and the smartphone. Electric motor together with its power transmission kit will drive the gate opener to open or to close the gate, thus electric motor must be able to rotate either in forward or in backward direction. The role of motor controller is to control the operation of electric motor based on commands from pushbutton switches and commands from the smartphone. Since the motion of electric motor reflects the movement of the gate opener, the motor controller is also named the gate controller. The key component of the gate controller is an Arduino microcontroller equipped with Bluetooth transceiver module. The microcontroller is programmed in a manner so that it can perform either remote-control or local-control based on the state of the selector switch. The smartphone functions to govern the microcontroller from remote location by using special application software. The application software is configured applicable only for smartphone with android operating system.

Design of Drive System

The sliding gate opener is driven by single-phase induction motor of permanent-split-capacitor type (PSC motor) through a mechanical power transmission set which consists of right-angle worm gear speed reducer and rack-pinion gear assembly. The PSC motor shaft is coupled with the input shaft of speed reducer and then its output shaft directly drives the pinion gear. Rack-pinion gear assembly converts rotational motion at pinion gear to linear motion at the rack. Finally, the rack is bolted to the sliding gate opener. Speed reducer translates the angular velocity of the motor shaft to a lower value at its output shaft depending on its speed ratio. Sliding-gate-opener drive system is illustrated in Fig.1.

The objectives of drive system design are to determine power and speed ratings of PSC motor and speed ratio of worm gear based on the velocity of gate opener and radius of pinion gear. The gate opener is assumed to have 2 wheels as shown in Fig.2. Notice that the number of wheels is not limited to 2.

The force required to slide the gate opener is calculated as follows [5],

$$F_{gt} = f \frac{m \times g}{R_w} \tag{1}$$

where F_{gt} in Newtons, f is rolling friction coefficient (inches), m is mass of gate opener (kg), g is gravitational acceleration (m/s^2), and R_w is radius of wheel (inches). The coefficient of rolling friction has been empirically determined for different materials, and can vary by the speed of the wheel, the load on the wheel, and the material the wheel is contacting. The coefficient of rolling friction for different materials at speed of 3 mph is presented in Table 1 [5].

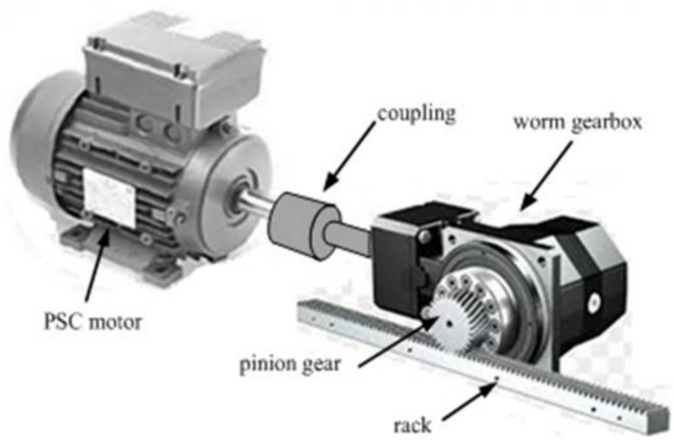

FIGURE 1. Main components of sliding-gate-opener drive system

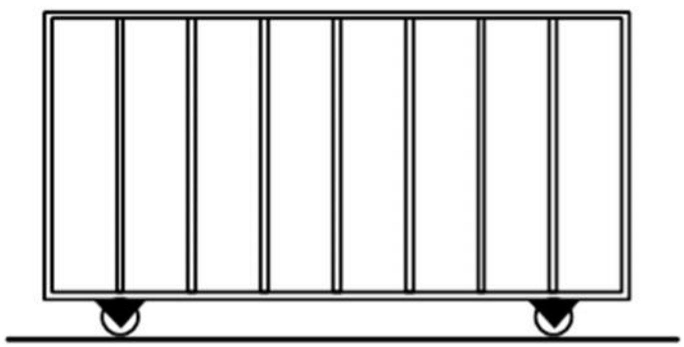

FIGURE 2. Gate opener with 2 wheels

TABLE 1. Coefficient of rolling friction for different materials at speed of 3 miles-per-hour.

Tread Material	Floor Material	Coefficient of Rolling Friction (inches)
Forged Steel	Steel	0.019
Cast Iron	Steel	0.021
Hard Rubber	Steel	0.303
Polyurethane	Steel	0.030 – 0.057
Cast Nylon	Steel	0.027
Phenolic	Steel	0.026

The required torque at pinion gear to drive the gate (T_p) is determined using the equation below,

$$T_p = r_p \times F_{gt} \tag{2}$$

where r_p is radius of pinion gear (metres). The unit of T_p is N.m.

The speed of pinion gear (n_p) is calculated as follows,

$$n_p = \frac{60}{2\pi} \times \frac{v_{gt}}{r_p} \tag{3}$$

where v_{gt} is the velocity of the gate (m/s). The unit of n_p is rpm.

The output power of worm gearbox (P_{wg}) is determined using following equation,

$$P_{wg} = \frac{2\pi}{60} \times T_p \times n_p \tag{4}$$

where P_{wg} is in watts.

Minimum power of PSC motor is calculated as follows,

$$P_m = \frac{P_{wg}}{\eta_{wg}} \tag{5}$$

where η_{wg} is efficiency of worm gearbox.

The speed of PSC motor (n_m) in rpm is determined as follows,

$$n_m = m_{wg} \times n_p \tag{6}$$

where m_{wg} is speed ratio of worm gearbox.

Design of Contactors Circuit and Its Controller

The PSC motor is assembled of 2 main parts: stator and rotor. The stator of PSC motor consists of machine frame, stator core and stator windings. There are 2 windings found inside the stator: main winding and auxiliary winding. Both windings are inserted into stator slots and placed in a way that the magnetic axis of each winding differs 90 degree of electrical angle. In order to produce revolving magnetic field, the main winding current and auxiliary winding current must have 90 degree phase difference. To achieve this, the capacitor is wired in series with auxiliary winding. The rotor of PSC motor is of squirrel cage rotor.

PSC motor must be able to rotate either in forward or in backward direction. To achieve the requirement, 3 contactors (K1, K2 and K3) are wired as shown in Fig.3. The operation of contactors is explained as follows.

1. When pushbutton switch ‘OPEN’ is pushed, then contactor K1 is energized, so all main contacts of K1 will close and current flows in the auxiliary winding from B1 to B2.
2. Then followed with de-energizing contactor K3 and energizing contactor K2, so all main contacts of K3 will open and all main contacts of K2 will close and current flows in the main winding from A1 to A2.
3. Both currents (main winding current and auxiliary winding current) together with windings distribution along the stator slots will generate revolving magnetic field in the air gap. Interaction between revolving magnetic field and current in rotor conductors will produce electromagnetic torque at rotor conductors, making it to rotate in forward direction driving the gate opener to open the gate.
4. When the gate opener arrives at the end of its movement, it will touch a limit switch. This action will affect all contactors to de-energize, causing their main contacts to open, cutting currents to stator windings and the motor will stop.
5. When pushbutton switch ‘CLOSE’ is pushed, then the contactor K1 is energized, so current flows in the auxiliary winding from B1 to B2.
6. Then followed with de-energizing contactor K2 and energizing contactor K3, so current flows in the main winding from A2 to A1.
7. Both currents (main winding current and auxiliary winding current) will produce rotating magnetic field that rotate in reverse direction, driving the gate opener to move backward closing the gate.
8. When the gate opener arrives at the end of its movement, it will touch a limit switch. This action will cause all contactors to de-energize and then stop the motor.
9. If pushbutton switch ‘STOP’ is pushed, then all contactors will de-energize cutting all stator currents and the motor will stop.

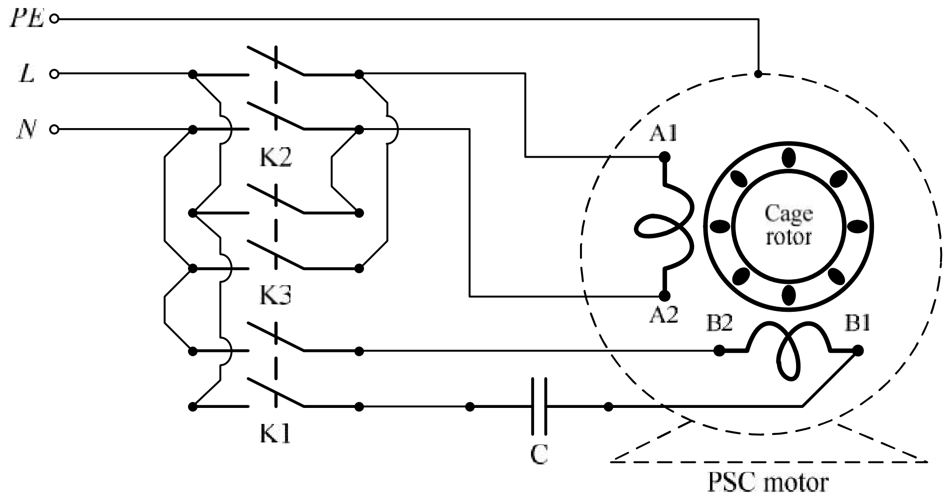

FIGURE 3. Power circuit of PSC motor

The operation of contactors is controlled by Arduino UNO microcontroller. There are 6 digital input devices wired to the input channels of microcontroller: selector switch (to transfer between remote-control to local-control or vice versa), pushbutton OPEN, pushbutton CLOSE, pushbutton STOP, limit switch 1 dan limit switch 2. Also, there are 3 output devices wired to microcontroller output channel, they are coil of contactor K1, coil of contactor K2 and coil of contactor K3. There is a circuitry as an interface between input devices and microcontroller input channel and a circuitry as an interface between microcontroller output channel to output devices as well. Both interfacing circuits use optocouplers to isolate input/output devices to microcontroller input/output channels. Moreover, there is a bluetooth transceiver module wired to serial communication channels of microcontroller to provide serial communication between microcontroller and android smartphone. Connection diagram of input/output devices to microcontroller input/output channels is shown in Fig.4.

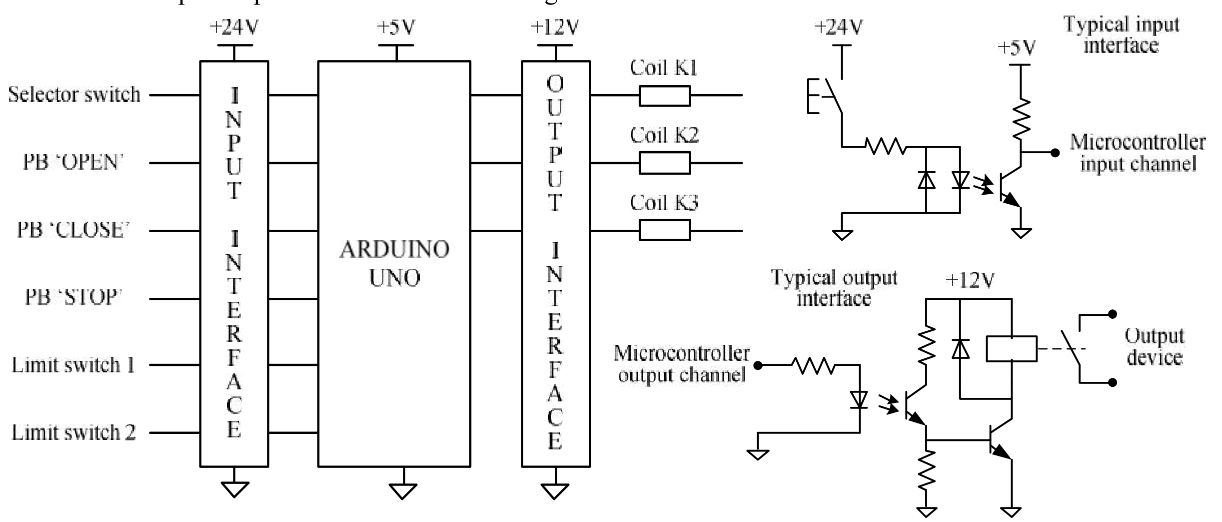

FIGURE 4. Connection diagram between I/O devices to Arduino UNO microcontroller I/O channels

Figure 5 presents wiring diagram between the microcontroller and the bluetooth transceiver HC-06. Though bluetooth connection can have capability to establish 2-way communication in half-duplex mode, the communication between the smartphone and the gate controller is designed to operate in one direction (simplex mode), that is from the smartphone to the gate controller. In this case, the smartphone acts as a bluetooth transmitter sending command signal to its receiver which is the gate controller.

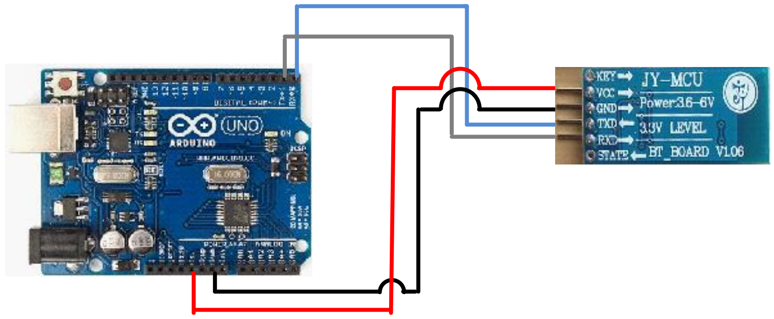

FIGURE 5. Arduino UNO microcontroller wired with Bluetooth module HC-06

Design of Remote Controller Application Software on Android Smartphone

The application software to establish communication between android smartphone and microcontroller is designed using App Inventor. App Inventor is a web application integrated development environment originally provided by Google, and now maintained by the Massachusetts Institute of Technology (MIT). It uses a graphical user interface (GUI), which allows users to drag and drop visual objects to create an application that can run on android devices. The photograph of application software for sending commands to the microcontroller is shown in Fig.6.

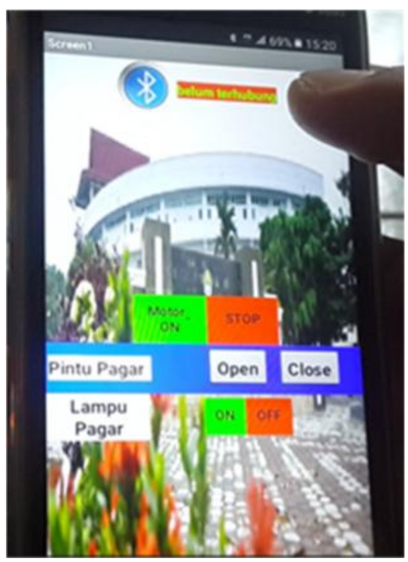

FIGURE 6. Visual of application software for sending commands to the microcontroller

Functional Test Setup

The functional test has been conducted on the sliding gate opener system to measure maximum distance of which the smartphone able to control the gate controller. The complete set of the system is assembled and energized and the application software is installed on android smartphone as well. The operator will operate all buttons provided in the screen of the smartphone and observe the response of the gate opener. The distance between the operator and the gate opener system is made to gradually farther, in 1 meter each step. Firstly, the operator is positioned at the gate site, this position is set as zero distance. The operator then operates all buttons on smartphone screen and checks the response of the gate opener system. And then the operator moves to the next position, 1 meter away from the first location, doing the same actions as he did before. The operator continues to the next position until the distance where the smartphone can not control the gate opener anymore. The functional test setup is illustrated in Fig.7. Notice that x is the distance between the gate controller and the smartphone.

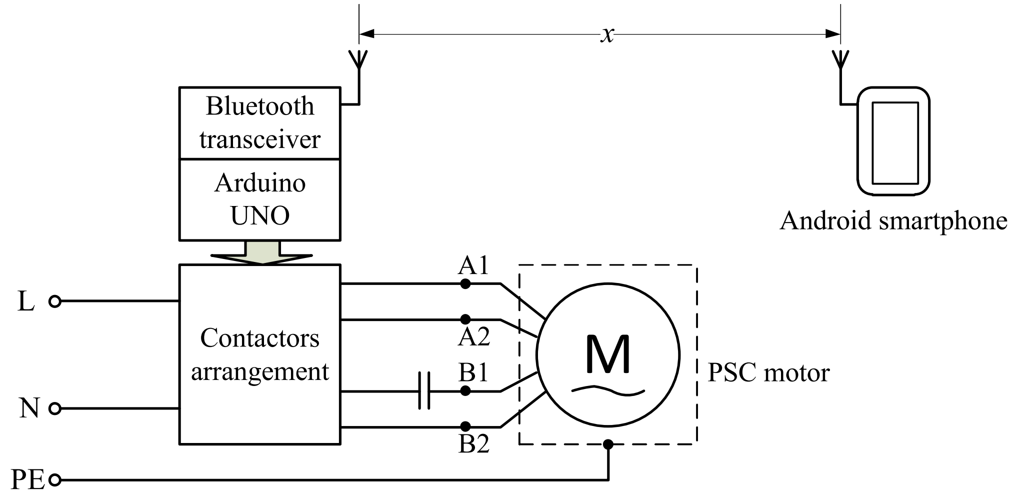

FIGURE 7. Functional test setup to measure controllable range of remote-control mode

RESULT AND DISCUSSION

The project is aimed to build the prototype of sliding gate opener system, so the size of the gate system is smaller than those in use in residential applications. However the size that we choose can still represent all conditions found in the application and operation of sliding gate entrance system.

The width of the gate entrance is 600 mm and the gate opener is designed to slide at velocity of 20 mm/s. This value is too slow compared to standard speed of European sliding gate opener, which is 200 mm/s [6]. However it is reasonably applicable for the prototype size. The PSC motor is selected so it can handle weight of gate opener up to 500 kg. The gate opener is equipped with 4 wheels made of cast nylon with radius of 1 inch. Based on Table 1, the coefficient of rolling friction between wheels and steel floor is taken as 0.027 inch. By using (1), the force required to slide the opener is 132.3 N. The radius of pinion gear is 0.02 m, so by using (2), the torque required by pinion gear to drive the opener is 2.646 N.m. Based on (3), the speed of pinion gear is 9.55 rpm. By using (4), power output of worm gearbox is 2.65 W. From (5), by assuming 70% gearbox efficiency, the minimum power of PSC motor is 3.79 W. From (6), by using 50:1 speed ratio gearbox, the speed of PSC motor is 477.5 rpm. The PSC motor that has 12 poles has been selected to drive the opener, because it has synchronous speed of 500 rpm.

The 12-poles PSC motor is rarely available in the marketplace, so a 2-pole PSC motor is dismantled and rewound to obtain 12-pole configuration, and also the capacitor has been replaced with different capacitance value. The developed diagram of stator coils for 12-pole PSC motor is shown in Fig.8. Notice that A1 and A2 are terminals for main winding, whereas B1 and B2 are auxiliary winding terminals. PSC motor with its new winding configuration after assembled is shown in Fig.9.

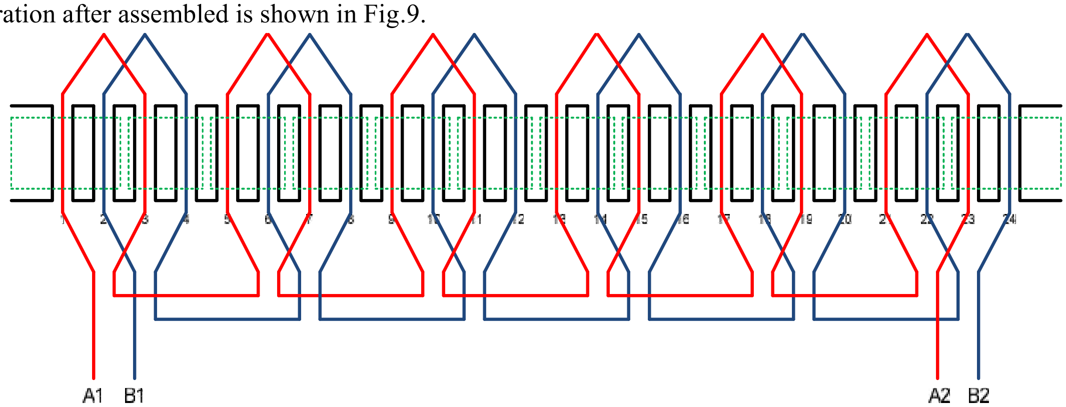

FIGURE 8. Stator coils arrangement for 12-pole PSC motor

FIGURE 9. PSC motor with its new windings configuration after assembled

The complete set of sliding gate opener system is shown in Fig.10. The system then undergoes functional test to determine maximum distance of which the smartphone still able to take control the gate opener. The result of the functional test is presented in Table 2.

FIGURE 10. Sliding gate opener system together with the smartphone as its remote controller

TABLE 2. Functional test result.

No.	Distance between the gate and the smartphone (metres)	Controllability
1	1	controllable
2	2	controllable
3	3	controllable
4	4	controllable
5	5	controllable
6	6	controllable
7	7	controllable
8	8	controllable
9	9	uncontrollable
10	10	uncontrollable

Based on Table 2, maximum controllability distance of the smartphone is 8 metres, although the bluetooth connection can have communication range up to 10 metres [7]. In fact, the maximum communication range will vary depending on obstacles (person, metal, wall, etc.) or electromagnetic environment as reported in [8 – 11]. Though they are interesting topics, the analysis of bluetooth transceiver sensitivity and bluetooth link budget analysis are beyond the scope of this research.

CONCLUSION

The prototype of sliding gate opener system which can be remotely controlled by android smartphone has been built in this research. The controller that controls the operation of sliding gate opener system (or named the gate controller) uses Arduino Uno microcontroller module. The communication between the gate controller and the smartphone is established by Bluetooth connection in simplex mode, where the smartphone acts as transmitter and the gate controller acts as receiver. In addition, the control system also provides local-control so the gate controller can control the operation of gate opener locally through operating pushbutton switches which are mounted on the door of control panel placed at the drive system site. Transition from remote-control to local-control or vice versa is commanded by a selector switch which is wired to input channel of Arduino microcontroller. However, the default setting is remote controlling. Local-control functions as back-up control in case troubles happened with the smartphone. Furthermore, there are 2 limit switches installed at ends of the gate opener movement to stop the motor automatically when they are touched by the gate opener. Yet, the motor can be stopped anytime either remotely or locally by pushing STOP button on the smartphone screen or on the door of control panel. Moreover, the gate opener is driven by 12-pole PSC motor and coupled with 50:1 speed reducer gearbox to obtain subjacent speed at pinion gear so the gate opener velocity fulfills the requirement. In addition to its working voltage which is the same as available at home, PSC motor has been selected due to its low maintenance cost and its constant-speed characterictic.

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