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Sliding Gate Opener System with Smartphone Control Using Bluetooth Connection

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Abstract— This paper presents the sliding gate opener system that android smartphones can remotely control using Bluetooth protocols. The gate opener is driven by a 12-pole single-phase induction motor of permanent-split-capacitor type (PSC motor) coupled with a worm gearbox and rack-pinion power transmission. The PSC motor installation is wired to rotate either forward or in the reverse direction by using a contactors arrangement controlled by the Arduino microcontroller module. Two limit switches are installed at the ends of the gate opener movement to inform the microcontroller to stop the motor automatically when the gate opener touches them. Moreover, the microcontroller module has been wired with Bluetooth transceiver HC-06 enabling it to communicate with other Bluetooth devices. The microcontroller module has been programmed so that the gate opener movement can be remotely governed from android smartphones and controlled at the site by operating a set of pushbutton switches mounted onto the control panel's door. The functional test has been conducted on the sliding gate opener system, and the result shows that the gate opener movement can successfully be controlled locally through operating pushbutton switches and remotely using an android smartphone with up to 8 meters.

Keywords— android, bluetooth protocols, microcontroller, sliding gate.

I. 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 two 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 two 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 protocols. 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

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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.

Referring to Britannica Encyclopedia [5], Bluetooth is a standard for short-range wireless radio frequency communication between electronic devices. Bluetooth was initially developed in the late 1990s by Ericsson, the Swedish manufacturer of mobile telephones, and soon achieved massive popularity in consumer devices. The term Bluetooth comes from Harald I Bluetooth, the 10th-century Danish king who unified Denmark and Norway. Since it operates on radio frequencies rather than the infrared spectrum used by traditional remote controls, such devices would not have to maintain the line of sight to communicate. Other key features of Bluetooth are low power usage-enabling simple battery operation- and relatively low cost.

Numerous researchers have utilized Bluetooth to implement their idea in wireless remote controls. For example, Jiang *et al*. have used Bluetooth to remote control their novel type of wireless ballastless fluorescent lighting system [6]. Lei *et al*. have used Bluetooth for their compact wireless electroencephalography (EEG) recorder for auditory brainstem response [7]. Another application of Bluetooth is for home automation, such reported by Husain *et al*. [8] and Rahayu [9]. In this research, we have used Bluetooth to remotely control the sliding gate opener system operation.

II. Design Considerations and Methodology

The sliding gate opener system consists of three 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.

A. 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. The main components of the sliding-gate-opener drive system are 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.

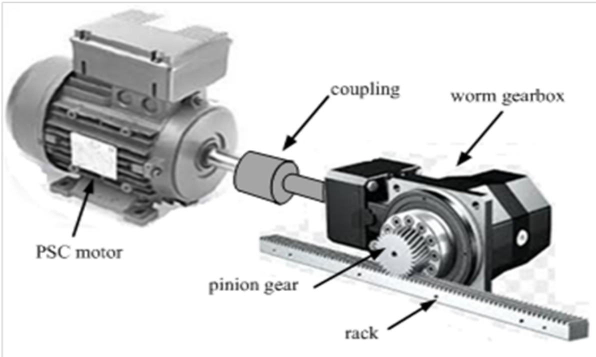

Fig. 1. Main components of sliding-gate-opener drive system.

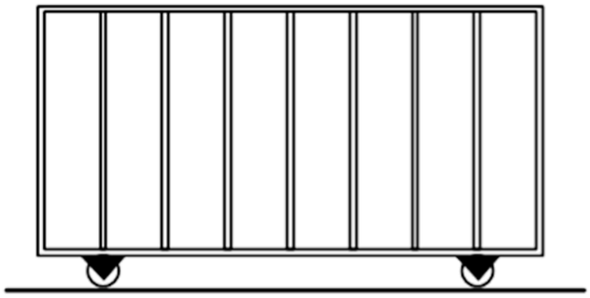

Fig. 2. Gate opener with 2 wheels.

TABLE I. 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 force required to slide the gate opener is calculated as follows [10],

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

where F_{gt} in Newtons, f is the rolling friction coefficient (inches), m is the mass of gate opener (kg), g is the

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gravitational acceleration (m/s^2), and R_w is the 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 [10]. 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 the radius of the pinion gear (metres). Notice, 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 the following equation,

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

where P_{wg} is in watts. The minimum power of the PSC motor (P_m) is calculated as follows,

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

where η_{wg} is the efficiency of worm gearbox. The speed of PSC motor (n_m) in rpm is determined as follows, where m_{wg} is the speed ratio of worm gearbox.

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

B. Design of Contactors Circuit and Its Controller

The PSC motor is assembled of two main parts: stator and rotor. The stator of the PSC motor consists of the machine frame, stator core, and stator windings. Referring to Fig.3, two windings are found inside the stator: the main winding (with terminals A1 and A2) and the auxiliary winding (with terminals B1 and B2). Both windings are inserted into stator slots and placed in a way that the magnetic axis of each winding differs 90 degrees of electrical angle. In order to produce revolving magnetic field, the main winding current and auxiliary winding current must have 90 degrees phase difference. Since the PSC motor is fed from single phase supply, to shift the current of auxiliary winding differs 90 degrees from the main winding's current, the capacitor is wired in series with auxiliary winding. The rotor of the PSC motor is of squirrel cage rotor.

The PSC motor must be operated to rotate either in a forward or backward direction. Such operation requires the arrangement of three contactors (K1, K2, and K3) wired in a way shown in Fig.3. Although the power circuit of the PSC motor installation uses 3-pole contactors, only two main contacts of it utilized in the power circuit. Notice that each contactor is drawn as two normally-open contacts with a coil that drives the contacts. The operation of the contactors is explained as follows.

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

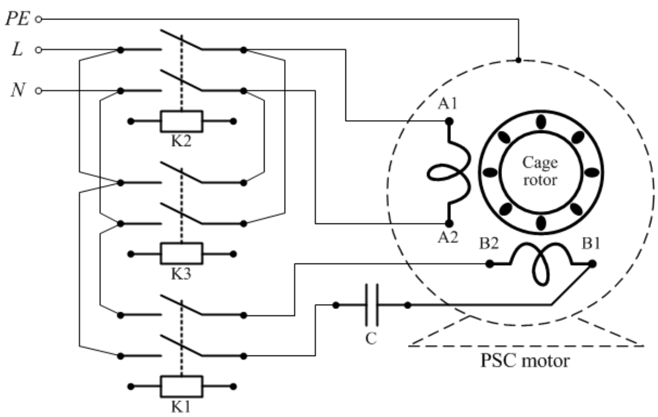

Fig. 3. The contactors' arrangement to drive the PSC motor either forward or in the reverse direction.

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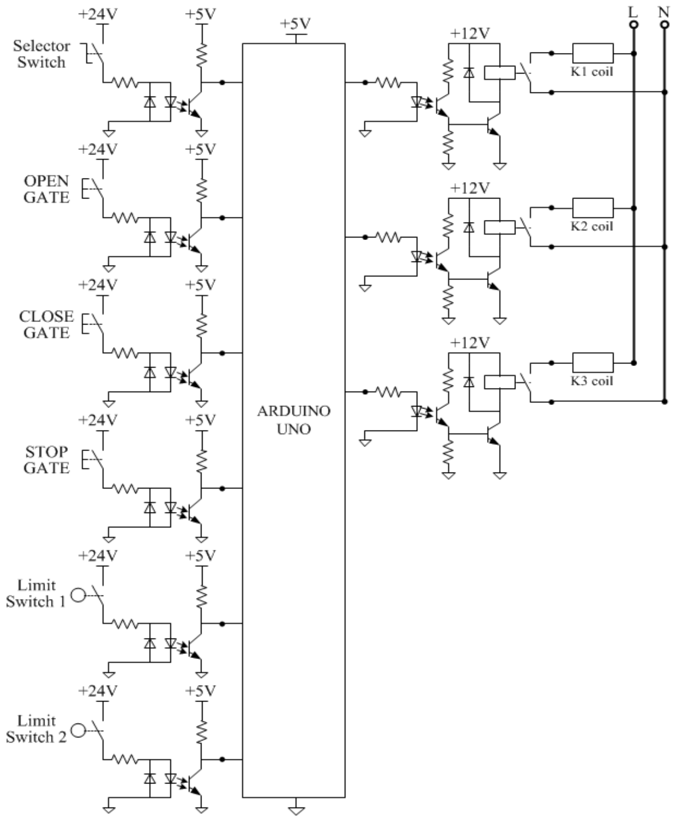

Fig. 4. Connection diagram between I/O devices and Arduino UNO microcontroller I/O channels.

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

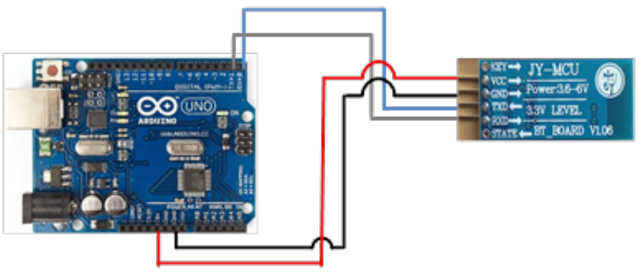

Fig. 5. Connection diagram between Arduino UNO microcontroller and Bluetooth module HC-06.

Fig. 5 presents a wiring diagram between the microcontroller and the Bluetooth transceiver HC-06. Though Bluetooth can 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 the command signal to its receiver, the gate controller.

C. Design of Remote Controller Application Software for Android Smartphone

The application software to establish communication between the android smartphone and the 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 the application software dashboard for sending commands to the microcontroller is shown in Fig.6.

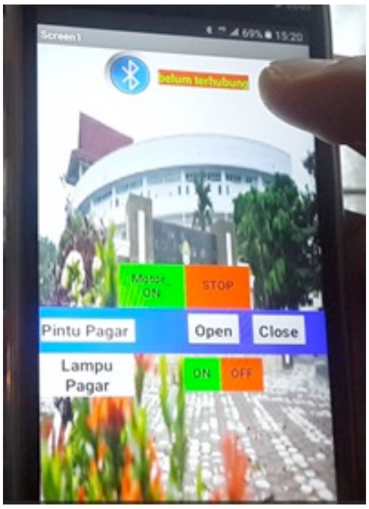

Fig. 6. Dashboard of the application software for sending commands to the microcontroller.

D. Functional Test Setup

The functional test has been conducted on the sliding gate opener system to measure the maximum distance the smartphone can control the gate controller. After the complete set of the system is assembled and energized, and the application software is installed on an android smartphone, the operator will operate all buttons provided on the smartphone's screen and observe the gate opener's response. The distance between the operator and the gate opener system is made to gradually farther, in 1 meter for each step. Firstly, the operator is positioned at the gate site, and this position is set as zero distance. The operator then operates all buttons on the smartphone's 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 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.

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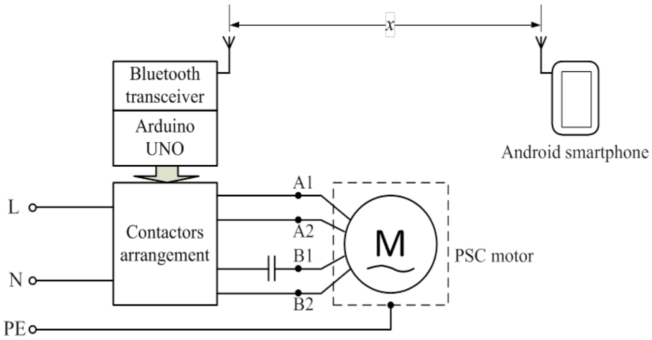

Fig. 7. Functional test setup to measure controllable range of remote-control mode.

III. 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 [11]. 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.

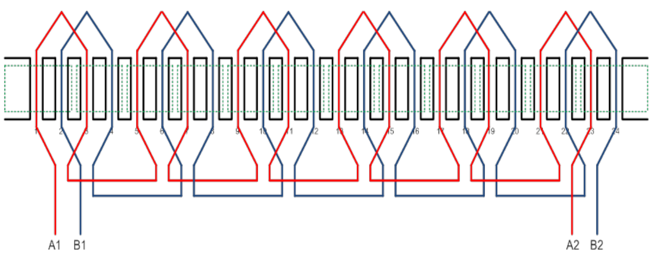

Fig. 8. Stator coils arrangement for 12-pole PSC motor.

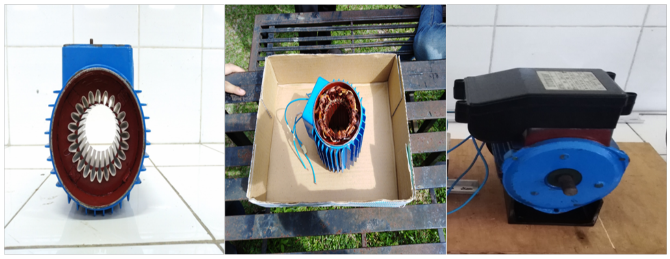

Fig. 9. PSC motor with its new windings configuration.

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.

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

TABLE II. 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 Bluetooth can have communication range up to 10 metres [12]. In fact, the maximum communication range will vary depending on obstacles (person, metal, wall, etc.) or electromagnetic environment as reported in [13 – 15]. Though interesting topics, the analysis of Bluetooth transceiver sensitivity and its link budget analysis are beyond the scope of this research.

IV. Conclusion

The prototype of a sliding gate opener system that an android smartphone can remotely control has been built in this research. The controller that controls the sliding gate opener system (or named the gate controller) uses the Arduino Uno microcontroller module. The communication between the gate

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controller and the smartphone is established by Bluetooth connection in simplex mode. The smartphone is a transmitter, and the gate controller is a receiver. In addition, the control system also provides local control so the gate controller can control the operation of the gate opener locally by operating the pushbutton switches, which are mounted on the door of the control panel placed at the drive system site. The transition from remote control to local control or vice versa is commanded by a selector switch wired to the Arduino microcontroller's input channel. However, the default setting is remote controlling. Local control functions as backup control in case troubles happen with the smartphone. Furthermore, there are two limit switches installed at the ends of the gate opener movement to stop the motor automatically when the gate opener touches them. However, the motor can be stopped anytime, either from a remote or locally, by pushing the STOP button on the smartphone screen or pushing the pushbutton STOP on the control panel door. Moreover, the gate opener is driven by a 12-pole PSC motor and coupled with a 50:1 speed reducer gearbox to obtain subjacent speed at pinion gear, so the gate opener's velocity fulfills the requirement. In addition to its working voltage which is the same as available at home, the PSC motor has been selected due to its low maintenance cost and constant-speed characteristic.

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