Portable Smart Door Lock

Hussain F. Alsaif, Mohammed A. Almaghrabi and Douglas E. Dow
Program in Electromechanical Engineering, College of Engineering
Wentworth Institute of Technology

Control of the lock for a door remains unsatisfactory for many people. The conflicting needs of security, convenience and retaining control, whether physically present or not, lead people to seek solutions beyond conventional methods. Certain available home security systems would meet the needs, but they are expensive, require professional installation, and are difficult to operate or maintain. Some of the more recently developed smart locks show promise as viable security systems, but lack some portability and control. The purpose of this project was to design and test modules for a smart lock system that can be monitored, controlled and moved within a building or between buildings. Components of the system included a wireless module, along with a motor and a gear mechanism as an actuator to function as the locking mechanism. A mobile app would be able to provide the user with control over the lock. The modules will be tested on a variety of key-lock assemblies to ensure compatibility with a wide range of doors. The state of the door will also be monitored and recorded.

Corresponding Authors: Hussain F. Alsaif, alsaifh@wit.edu.

Introduction

According to the FBI, a burglary takes place in the United States every 15 seconds. This implies that home security systems are underutilized for most cases either due to their cost or maintenance. In other situations, the security systems cannot be controlled from a distance or in a convenient way for non-experienced users. Smart devices usually refer to devices that interact with other devices or networks via different protocols such as Bluetooth or wifi. They also operate interactively to some extent. In this case, the smart door lock controller interacts with a smartphone and the locking mechanism. Some of the recently developed smart locks enable the user to partially control the lock, but they lack portability within a building and between buildings. Devices that are controlled wirelessly have been gaining market share across different fields such as home security and consumer electronics due to their flexibility and convenience. They are popular among end users as well as professionals. This type of systems is a part of the field of Internet of Things (IoT). This technology represents a building block for many recently developed automation systems including residential, commercial and home automation systems. Unfortunately, the replacement of existing door locks with newer automated ones represents a high expense to homeowners, limiting accessibility. In contrast, an affordable and user-friendly solution would increase accessibility and elevate the level of satisfaction for target users. One idea is a door lock that could be installed on an existing key-lock assembly without the need of professional help or risk of damaging the door.

Small scale applications require a particularly efficient use of space. For rotary movement applications, such as this project, the design ought to balance a tradeoff between the amount of torque required to turn the mechanism and the speed needed. A high torque is needed to ensure rotary motion for a wide variety of door locks. Consideration for a variety of ambient factors such as temperature, humidity and condition of the door lock is taken into account when choosing a motor for such applications. In many cases, the torque delivered directly by the motor may not be sufficient. This weakness could be alleviated by integrating gears either within the motor or constructing a gear box that supplies the needed torque using gear ratios such as 2.5:1 or 5:1.

The purpose of this project was to develop an affordable smart door lock that can be installed easily on a variety of doors, can be controlled over the internet and can be trusted for security. A prototype was developed that integrates a wifi module with a servo motor and a gearbox. A servo motor is a module that contains a regular dc motor along with a built-in gearbox and a potentiometer that is connected to a control circuit.

Materials and Methods

Design

In general, wireless and movement applications require strong and continuous power supply since the systems use power that would excessively drain batteries. This can be engineered in a variety of ways, one of which is to incorporate a sleep mode in the system that could decrease power consumption significantly and at the same time maintain functionality. Another approach is to utilize Pulse Width Modulation (PWM) in supplying the power to a load delivering recurring power pulses so that the load, receives the needed power and at the same time the power supply is maintained. Figure 1, shows a representation of how PWM would powers a load.

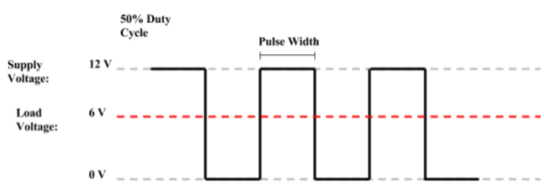

Figure 1: load voltage with relation to supply voltage in PWM.

This highlights that a supply voltage is passed only for half of the time period of the signal without compromising the performance of a load. In the model built for testing, PWM was utilized to conserve power as a duty cycle of 88.5% was passed to the motor. This means the motor is consuming power for 88.5% of the time only and is not consuming power for the remaining 11.5% of the time. For future development, a different motor could be utilized to improve power consumption. For example, a motor that can function properly on a 50-70 % duty cycle.

Affordability is another main objective behind designing this smart door lock constraining the design and limiting options in the rotary movement. In particular, powerful motors are highly priced reducing suitability. To supply the needed torque with a less powerful and less expensive motor, a gearbox of a 5:1 ratio was developed and integrated with the motor along with the locking mechanism 5 times the torque is supplied. The gearbox design was inspired by planetary gears concept and was implemented accordingly. Figure 2 indicates how the gearbox is attached to the motor and connected to the other group of gears including the main gear that will turn the locking mechanism highlighted in Figure 3.

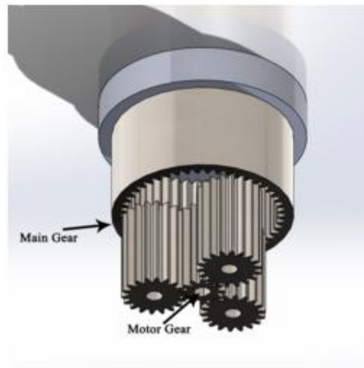

Figure 2: gearbox used to develop 5 times the motor torque.

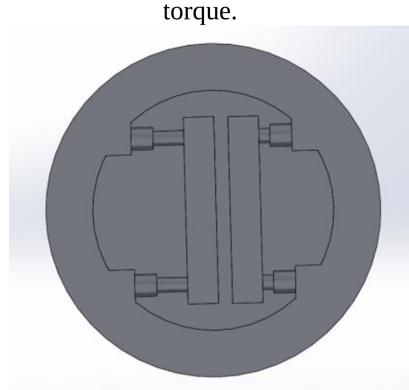

Figure 3: plan view of the locking mechanism where the key is held.

The design has the device equipped with strong rubber suction cups on the four angles surrounding the system's housing. They will be installed in the openings shown in Figure 4. Those suction cups are made from natural rubber that can be attached to wood, metal and glass.

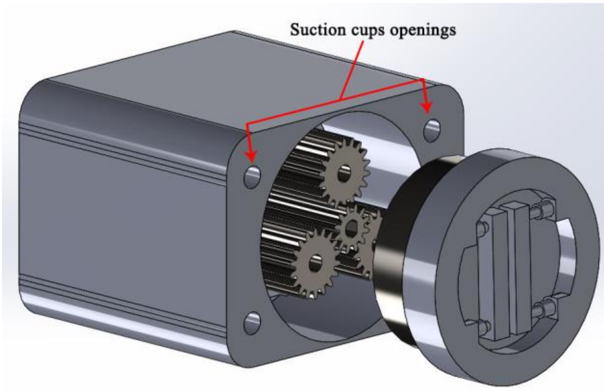

Figure 4: suction cups openings on the angles of the system's housing.

With these suction cups, the system is able to be attached and detached without damaging the surface of a door. Also, the locking mechanism is equipped with springs to compress on a door's key or a deadbolt turn-piece to provide additional support for the system to be fixed in place. These two aspects of the design achieve the desired level of portability and ease of installation for residential or commercial doors.

One of the main characteristics of the system is that it can be controlled via wifi. The flexibility of controlling the lock via wifi stems from the ability to lock or unlock a door with a push of a button on a smartphone without distance limitations. This is particularly useful for situations where the user needs to unlock the door without being at home, such as for a service personnel while at work. In this case, the smartphone communicates with the wifi microcontroller giving an order to unlocking the door. Since the system was designed to elevate the security of residential and commercial buildings, the user will be notified with any opening or closing of the door, in case it was not initiated by the user with the option of notifying authority immediately.

Assembly and Development

The smart lock prototype consisted of a wifi module, a servo motor, a 3D-printed housing and mechanism. This assembly will attach to the door's surface with suction cups. This setup is controlled with Blynk platform (Blynk, New York, NY), a third-party in the public domain that allows controlling of a variety of microcontrollers such as the one used in this project Esp8266 (Acrobotic inc, Pasadena, CA). Blynk can be installed on most smartphones. In addition, the wifi module was programmed using readily available public domain libraries including Arduino (Arduino, open source, www.arduino.cc) libraries as well as Blynk libraries such as <ESP8266WiFi.h>, <BlynkSimpleEsp8266.h> and <Servo.h>.

Testing Methods

Individual parts of the prototype such as gears were tested using Finite Element Analysis (FEA) in SolidWorks for stress, factor of safety and deformation scale (displacement). In particular, tests were carried out on the parts that are exposed to the most load such as the motor gear. Figure 5 and Figure 6 indicate the deformation scale and factor of safety (FoS) results of stress testing the motor gear respectively. Figure 5 shows the deformation scale of the motor gear, which is the displacement of the part in the three dimensions highlighting the possibility of interference between the motor gear and the other gears. Deformation scale is defined by the following equation:

$$Deformation\ Scale = \sqrt{U_x^2 + U_y^2 + U_z^2}$$

where U is the displacement in each coordinate

The test result indicated a displacement of 517 mm that may appear acceptable but for better reliability, further testing and development should be carried out. Figure 5 shows a FoS of 17, which is more than the recommended FoS of 2. FoS is defined as the stress over the cross-sectional area of a particular part.

$$FoS = \frac{Stress\ (\sigma)}{Area\ (A)}$$

where stress is defined as the force applied on a certain part divided by the area that force is acting on.

A structure with a FoS of exactly 1 would support only the design load and no more. Any additional load would cause the structure to fail. A structure with a FoS of 2 would fail at twice the design load. It can be inferred from Figure 6 that the sun gear could tolerate 17 times the load associated with the motor. This highlights the durability of the part that endures the highest amount of load indicating a better safety margin for the other parts that are not exposed to a similar load.

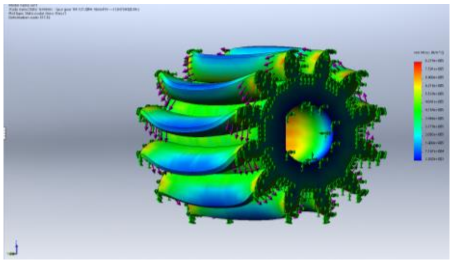

Figure 5: FEA test of the motor gear indicating a deformation scale of 517 mm

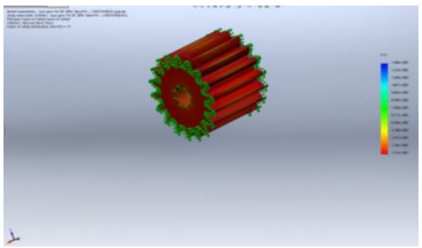

Figure 6: FEA test of the motor gear indicating a factor of safety of 17.

Support methodologies have been utilized in this system such as suction cups as well as the locking mechanism that attaches to a key or a deadbolt turn-piece to hold the weight of the system. The entire system is estimated to weigh less than 3.4 lb. Factoring motor's rotation, the system can be supported safely with the four suction cups that can tolerate 2.5 lb each. Furthermore, the system is estimated to cost less than 50 USD

Analysis

A prototype of a module that included the servo motor, the wifi module and the user interface in a smartphone was tested for clockwise and counterclockwise rotation simulating the locking and unlocking mechanism. The prototype module was powered using a bench power supply for testing purposes. In this test, the following parameters have been observed and recorded as shown in Table 1.

Table 1: results of the prototype test that includes different parameters of the waveform supplied by the wifi module.

Angle (degree)	Frequency (Hz)	V_{P-P} (V)	Duty Cycle (%)	Period (ms)
180	49.997	3.90	88.5	20.001
162	49.997	4.30	89.387	20.001
144	49.997	3.94	90.263	20.001
126	49.995	4.06	91.135	20..001
108	49.995	3.82	92.014	20.001
90	49.995	3.90	92.890	20.002
72	49.997	4.30	93.765	20.001
54	49.995	4.30	94.641	20.002
36	49.997	4.18	95.521	20.001
18	49.995	4.10	96.397	20.002
0	49.997	4.06	97.272	20.001

The results of Table 1 were observed to assess the optimal duty cycle of the motor in order to conserve power. In this case, 180º of rotation or more was required for the design purposes. The duty cycle associated with 180º of rotation is 88.5% as indicated in Figure 7. Figure 8 represents another sample obtained from the oscilloscope where the duty cycle failed to support the design aspect of saving power as much as the sample in Figure 7 did.

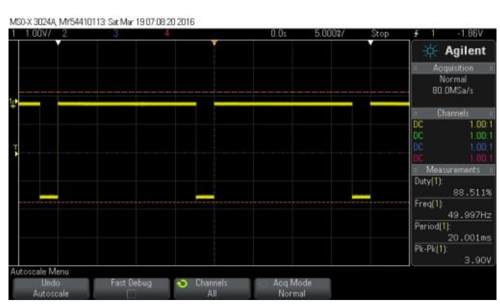

Figure 7: sample waveform indicating a duty cycle of 88.5%.

Figure 8: sample waveform indicating a duty cycle of 91.1%.

It was shown that a factor of 0.88 of the power supplied was used by the motor in Figure 6; that is the power was delivered 88.5% of the time and no power was delivered 11.5% of the time. Similarly, the power was delivered 91.1% of the time and was not delivered 8.9% of the time, in Figure 8, indicating that a duty cycle of 88.5%, as in Figure 7, is more efficient and conserves more power and therefore, for the purpose of this system, a duty cycle of 88.5% was deployed.

Conclusions and Future Directions

The early testing results appear to show that the design concept has promising functioning capabilities as indicated by the duty cycle of 180º shaft rotation, which is the needed amount of rotation to control a lock that contains a deadbolt turn-piece. Further testing and investigation are needed in order to determine the optimal amount of torque that can control most of the standard locks and at the same time avoid damaging the lock with excessive torque. In addition, evaluations have to be carried out to assess the fulfilment of the design for target customers. The prototype has to be integrated with standard key-lock mechanisms that require more than a 180º rotation. This can be accomplished with stepper motors or servo motors that were modified for continuous rotation.

In order to develop the security and efficiency of the smart lock, a timing algorithm will be developed so that the lock can be programmed to lock and unlock on certain times of the week. Also, upon changing the state of the lock without the knowledge of the user a message should be sent to the user with the choice of contacting authority. Furthermore, a strong encryption approach should be developed to make the lock even more secure for potential cybersecurity threats that represent concerns for commercial buildings. This needs an intensive research and implementation as IoT devices are usually vulnerable targets for cyber threats.

References

[1] "Crime in the United States." FBI, 2012. Web. 09 Feb. 2016.

[2] Il-Kyu, Hwang, and Baek Jin-Wook. "Wireless Access Monitoring And Control System Based On Digital Door Lock." IEEE Transactions On Consumer Electronics 53.4 (2007): 1724-1730. Military & Government Collection. Web. 4 Feb. 2016.

[3] T. Yokotani, "Application and technical issues on Internet of Things," Optical Internet (COIN), 2012 10th International Conference on, Yokohama, Kanagawa, 2012, pp. 67-68.

[4] K. Lingaiah: Machine Design Databook, Second Edition. Mechanics of Vehicles, Chapter (McGraw-Hill Professional, 2003 1994), AccessEngineering.

[5] F. A. Omondi, P. Shah, O. Gemikonakli and E. Ever, "A Framework for Energy Based Performability Models for Wireless Sensor Networks," Advanced Information Networking and Applications Workshops (WAINA), 2015 IEEE 29th International Conference on, Gwangiu, 2015, pp. 175-180.

[6] Arijit Ukil. “Security and Privacy in Wireless Sensor Networks.”395 – 418, 2010.