

SMART MAILBOX



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ABSTRACT

This project examines the methods of turning an ordinary mailbox into a smart mailbox. The goal of this project was to examine the existing technologies and modules to make a retro-fit device which could notify the resident of a house about the presence of mail in the mailbox. In addition to this, possible methods for detecting different kind of mail were explored.

The practical part of the thesis included range tests, power consumption measurements and an examination of the added features of commonly available RF modules. The test data was collected by connecting RF modules to Arduino. The costs of this project implementation were kept low so that the system would be useful for the home automation community and consumers. The project report is concluded with recommendations of usage and methods of implementation.

Keywords mailbox, IoT, wireless, home automation.

Pages XX pages including appendices XX pages

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21 pages including appendices 0 pages.

1 INTRODUCTION

In today's scenario, home automation is the new trend. From fancy lighting controls to energy saving applications, home automation is everywhere. It is in human nature to find the easiest way of doing things. This attitude drives innovation and promotes productivity. Smart mailbox is an important part of a future house where all deliveries are notified. This allows the user to track the delivered goods in real-time. It will also prove helpful for the elderly, people living in sparsely populated areas and farms with faraway mailboxes.

The project comprises of researching and comparing methods of detection of mail and data transfer from the mailbox to the house. In addition to it, battery technology and methods of power saving are explored. The research work is completed in three stages: market research for available technologies, experimental data collection, analysis of costs and comparison of solutions.

2 NEED OF A SMART MAILBOX IN FINLAND

Finland is a sparsely populated country and the population is spread all over its area. Long distances and declining mail volumes have forced postal service providers to move the mailboxes from house yards to street corners. These group boxes are sometimes as far away as 200 meters from the house. This causes inconveniences in bad weather especially for the elderly. In addition to it, online shopping is gaining ground in Finland which drives the need for smarter mailbox.

There are many benefits with a smart mailbox over a simple box. The biggest advantage is that it will save time for the consumers and help them track their deliveries. In addition to this, it will add value to the product of the manufacturer. Figure 1 shows a group of mailboxes in the Finnish countryside.



Figure 1. mailbox group (Yle news, 2016)

3 CHALLENGES IN MAKING A SMART MAILBOX

For the development and success of a commercial product, there are several hurdles to overtake. The biggest challenge is to make a product that is both cost efficient and robust. Moreover, it should be simple to install so that a layman can install it by himself on the mailbox. Following are the other major challenges listed in the development process of a smart mailbox.

3.1 Battery performance in cold weather

A major limitation in technology is our battery technology. The concept of electric cars has been around for decades, but the battery technology has not been good enough for such vehicles. Similar problems are faced by mountain climbers where their equipment and cameras stop working because of rapid battery drainage in the cold weather.

Living in Finland, we are aware of this problem when your car does not start on a cold morning because the battery has drained out. Low temperature slows down the chemical reactions happening inside the battery cells. The temperature in Finland can drop as low as -30 degrees Celsius in winter which can drain any normal chemical battery. In addition to this, a wire supplying power to the mailbox from the house would not be practical. For this reason, suitable battery selection is an important part of this project. Figure 2 shows the effect of temperature on battery performance.

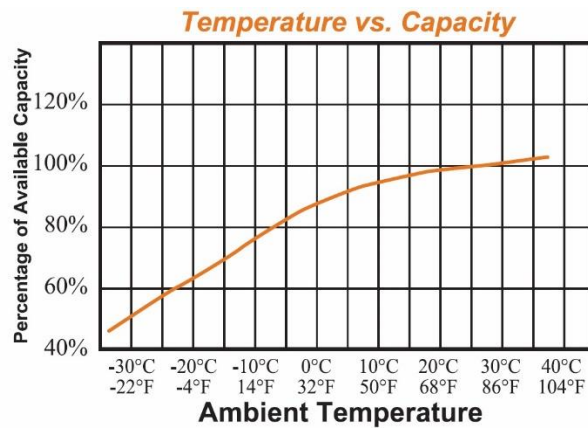


Figure 2 : Performance graph of acid battery (Rolls Battery Engineering, 2014)

3.2 Long distances

Long distance communication is not a problem if the device is provided with enough power. We can take as the example FM radios that can transmit voice over air to very long distances. FM transmitting stations usually have huge antennas with power consumptions of thousands of Watts. The challenge is to balance the power consumption and range of the radio link. Antenna design and direction also affects the range. However, in this project, only those antennae were examined here were compatible with the selected wireless module.

3.3 Variations in designs of different suppliers

To achieve market success, a consumer device must target as many customers as possible. This increases the sales prospects of the product and makes it economically viable. Different mailbox manufacturers have different designs for their mailboxes which makes it harder for a single device to fit on all mailbox types. It is extremely important to find solutions that can work with all mailboxes. However, there is one common trait of Finnish mailboxes that all of them are top loading. This makes it easier for the device manufacturer to develop solutions that are working on similar principles.

4 DEVICES AVAILABLE IN THE MARKET

The idea of automating the mailbox has been around for some time and there are some products available in the market. The problem with these products is that they are country specific and one product cannot target the whole market.

4.1 Working of Mail Chime

Mail Chime works by sending a wireless signal to the resident when the lid of the mailbox is opened. The black module attached to the lid holds the battery cell, wireless system and a magnetic sensor. The outdoor module always keeps checking its orientation using a built-in magnetic sensor. When the postman opens the box for inserting the mail, the lid and the attached outdoor module becomes horizontal. This is how it detects the mail delivery. Figure 3 illustrates the working of Mail Chime.



Figure 3: Mail Chime (Hanna Products, 2018)

4.2 Need for a different product

The above-mentioned device available in the United States is made for the front-loading mailboxes only. It needs to be modified if it needs to be fitted on a top loading mailbox. Moreover, it also has other limitations which makes it unsuitable for Nordic countries. Table 1 compares the features of the available device and the target device.

Table 1: analysis of availability and needs

	Mail Chime by Hanna products	Needs of Finland and Nordic countries
Range	30m maximum	200m
Working temp.	minus 5 to +40	minus 30 to +40
Detection method	magnetic	passive method/ less power consuming
Batteries used	Alkaline batteries	Cold operating Lithium cells

5 CONSTRUCTION AND IMPLEMENTATION OF THE DEVICE

For the development of any new product, the targets must be set according to the market needs. For this reason, the smart mailbox should have a range of at least 200 meters. Moreover, the batteries should last at least two months. In addition to this, the device should be able to be

retrofitted on all kinds of mailboxes. The implementation of a smart mailbox and the construction of device can be divided into five parts.

1. Mail delivery detection
2. Signal transmission and radio link.
3. Battery technology and power consumption.
4. Mail type detection possibilities.
5. Design and consumer product development.

5.1 Mail detection

Mail detection is the first step when making a smart mailbox. This can be done either by sensing the contents of the mailbox or by detecting other related mechanisms. One of the easiest ways to detect mail is to detect the opening of the lid of the box. It can be assumed that if the lid has been opened, there has been something delivered to the mailbox.

5.1.1 Sensor based detection

Sensors are the first issue that comes into your mind when there is a need of measuring some physical phenomenon. A motion sensor is the most common one of such applications. It works by absorbing the infrared signature of the surroundings and detects any changes of infrared in its field of view. However, this mechanism makes it unsuitable for our application because it cannot detect any inanimate objects. Figure 4 shows the working principle of a motion sensor.

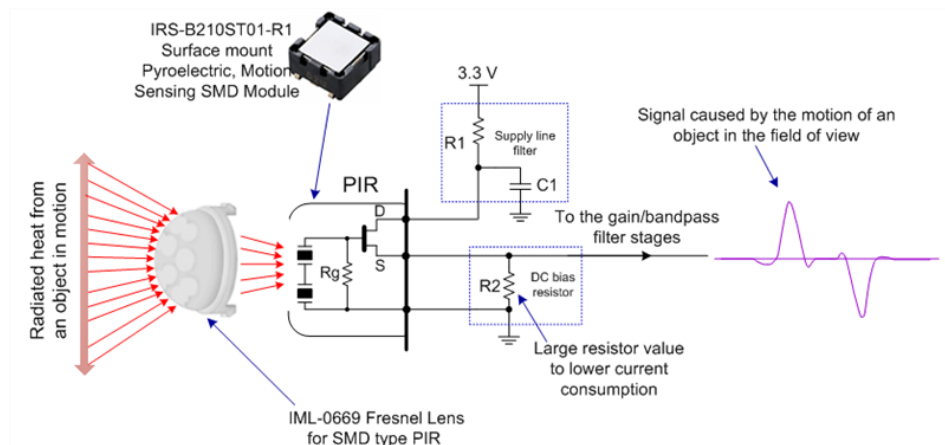


Figure 4: PIR sensor working principle (Texas Instruments, 2017)

For the smart mailbox application, a gyroscope sensor can also be utilized. It can sense the motion of the lid of the mailbox. Principally gyroscopes have broad applications and they are relatively small and inexpensive. Figure 5 illustrates the working of a gyroscope.

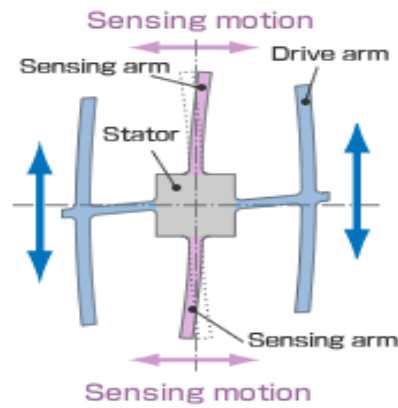


Figure 5: Gyroscope sensor (Epson Device,2018)

The use of an accelerometer is also an option for this application. The difference between an accelerometer and a gyroscope is that the accelerometer only detects the acceleration produced but a gyroscope can also detect specific directions. Both sensors are available as microchips and can be attached to the lid of the mailbox. However, the programming required for the gyroscope is more complex as compared to the accelerometer. Figure 6 shows an accelerometer available in the market.



Figure 6: Accelerometer (Markerlab Electronics, n.d)

Ultrasonic sensors are also an option. They work by the detecting reflection of ultrasonic sound waves. The time taken for the reflection can be used for detection of objects and their proximity. One of the most common is the car parking sensor. Ultrasonic sensor can be cleverly placed in the mailbox for the detection of mail. It can be placed so that the acoustic signature of the empty mailbox is different than the acoustic signature of a filled box. For instance, a letter or a cardboard present in the mailbox will reflect the sound waves different than the empty mailbox walls. Following image shows the working of an ultrasonic sensor.

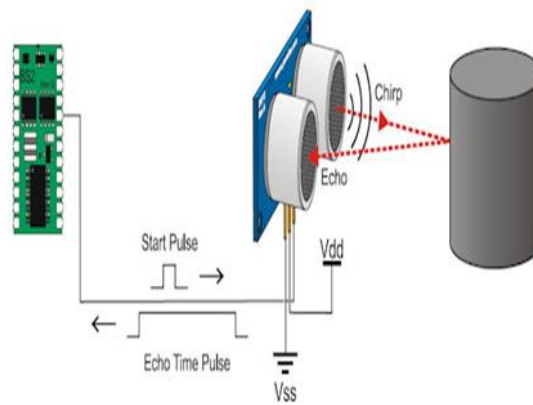


Figure 7: Ultrasonic object detection (Elprocus, n.d)

This sensor gives the opportunity to detect the mail inside the mailbox without considering the motion of the lid. The system can be programmed in a way that the micro controller wakes up from the sleep mode every half hour and uses a chirp of soundwave to detect the presence of mail. It then goes back to sleep for power conservation. A constantly working ultrasonic sensor will drain the battery in half a day which is not practical. The drawbacks of this system are discussed in detail in the end of the detection chapter.

5.1.2 Switch based detection

Normally closed switches can also be used for the detection of mail delivery. They need to be cleverly placed in the lid of the mailbox to detect the opening of the lid. This concept has been around for decades and it can be found inside refrigerator and elevator doors. Figure 8 shows the placement of a NC switch inside the mailbox.



Figure 8: detection switch inside a mailbox

5.1.3 Benefits and drawbacks

For the final selection, it was important to compare the pros and cons of both methods. For this application, we need to keep in mind the power consumption, cost and robustness of the system. Table 2 compares the pros and cons of both technologies.

Table 2: comparison between switch and sensor usage

Characteristics	Sensor	Switch
Idle mode power consumption	1-2mA	No power consumption in idle mode
Temperature range	-5 to 50 degree Celsius	-40 to +50 degree Celsius
Life cycle	5000 hours	10000-20000 operations
Cost	5-20 euros	0.1 to 0.5 euros

Use of constantly working sensors such as an accelerometer, a gyroscope and motion detectors is not practical. These sensors will drain the battery fast and are expensive as compared to the switch. The switch does not consume any power itself rather it just connects the wireless transmitter to the battery. However, the switch principally only detects the motion of the lid and not the mail itself.

The use of ultrasonic sensor discussed in chapter 5.1.1 is also suitable because the sensor does not need to operate continuously. It can work once every half hour for the detection of the mail. Nonetheless, it throws other challenges such as complexity of operation and inability to work universally on mailboxes of all shapes, sizes and materials. The ultrasonic sensor system architecture will also increase the interval of detection to half hour while a switch can detect instantly. For this reason, the switch is selected as the most suitable method of detection.

5.2 Wireless/radio transmission of signal

The most important part of the project was to find a suitable wireless technology. There are several ways of achieving a wireless link between the mailbox and the indoor notifier module. However, power consumption and costs play a huge role in the selection of technologies. Internet of things (IoT) devices are flooding the market and most of the developers are focusing on this technology. However, access to the internet is still a question for remote devices. These devices can only function near to our

houses where Wifi is available. A device that can work with a range of 200 meters is not possible with a regular household Wifi connection. Figure 9 shows the relationship between Wifi signal power and distance.

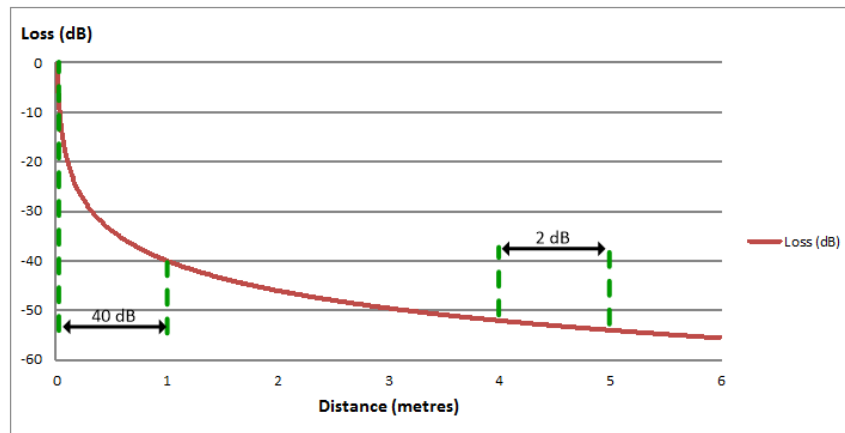


Figure 9: WIFI signal power loss (Ekahau Wireless design, 2015)

5.2.1 selection of RF module

RF based wireless devices can perform at a variety of ranges. The reason is that RF covers a broad spectrum of wave lengths and frequencies. The travel distance of a radio wave depends on many factors. This part of the project was covered by experimenting the use of a long-range wireless module named Semtech LoRa 1276. It is a transceiver module which means that it can either become a transmitter or receiver based on how it is programmed. For this application, two similar modules were used as transmitter and receiver. Figure 10 shows the integrated circuit chip of Semtech Lora 1276.

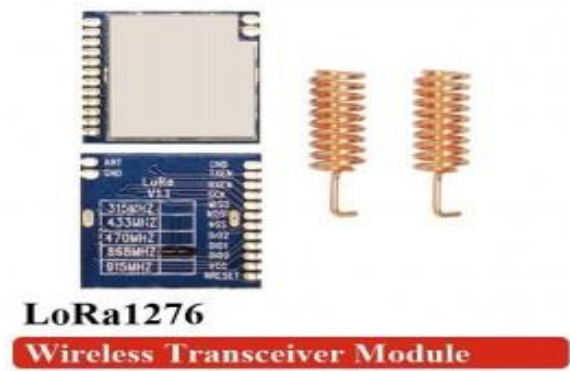


Figure 10: Semtech LoRa 1276 (Semtech, 2018)

5.2.2 LoRa 1276 test circuit

LoRa 1276 is specifically designed in a way that it gives the user control over data transmission rate, frequency selection and spreading factor selection. Following are the most common applications of LoRa modules:

- Automated Meter Reading
- Home and Building Automation
- Wireless Alarm and Security Systems
- Industrial Monitoring and Control
- Long range Irrigation Systems

For this project, an experiment was performed to measure the range of the system. Two 1276 modules were connected to two Arduino Uno boards. One of them was programmed as a receiver and other one was programmed as a transmitter. Following image shows the test circuit.

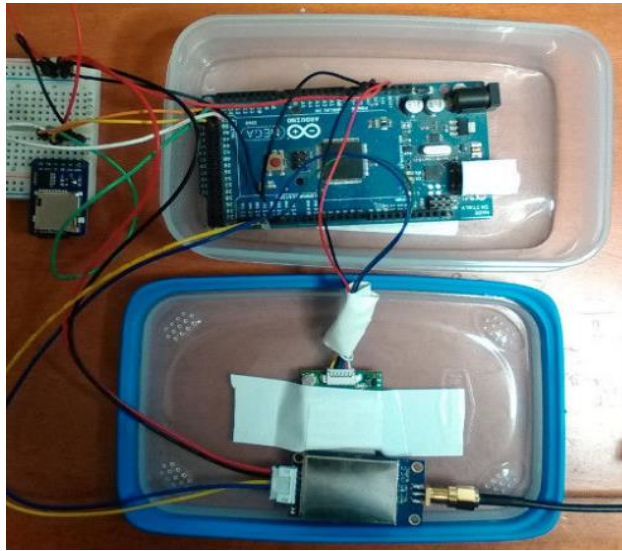


Figure 11: Arduino Uno and LoRa 1276 test circuit

5.2.3 Selection of Frequency and Bandwidth

LoRa modules offer many frequency selections. It can work from 137 - 1020 MHz. However, lower frequencies have certain advantages over higher frequency signals. Lower frequencies have better penetration power and more propagation as compared to high frequency systems. This makes lower frequencies ideal for our application. The only disadvantage is that the data transmission rate is lower than the higher frequencies. For the experiment 62.5khz and 125khz bandwidths were used. The experimental data collected is shown in Table 3.

Table 3: range and bandwidth experiment

supply voltage	Bandwidth khz	spreadin g factor	range measured(m)	power consumption(mA)
3.5	62.5	6	80	5.2
3.5		7	122	5.2
3.5		8	189	5.2
3.5		9	230	5.3
3.5		10	300	5.3
3.5		11	366	5.3

3.5		125		6		38		6.8	
3.5				8		81		6.8	
3.5				9		125		6.8	
3.5				10		154		6.9	
3.5				11		180		6.9	

5.2.4 Selection of Spreading factor

The biggest advantage of Semtech modules is that it allows the user to configure the spreading factor according to the needs of the user. The spreading factor can be defined as the ratio between the nominal symbol rate and the chirp rate. It represents the number of symbols sent per bit of information. In simple words, we can trade data rate for transmission range of the signal. Since the data is just one-bit signal coming from the mailbox, we can use the highest spreading factor to acquire the longest range. In Table 4 the available spreading factors that can be used are illustrated.

Table 4 : spreading factor and corresponding chips (1276 Datasheet, 2018).

SpreadingFactor (RegModulationCfg)	Spreading Factor (Chips / symbol)	LoRa Demodulator SNR
6	64	-5 dB
7	128	-7.5 dB
8	256	-10 dB
9	512	-12.5 dB
10	1024	-15 dB
11	2048	-17.5 dB
12	4096	-20 dB

5.2.5 Sleep mode and low battery notification

For the construction of a power efficient device, sleep mode configuration is very important. Lora 1276 module can be programmed so that it consumes minimal power while keeping the detection ports working. The current consumption in sleep mode is about 0.2uA. Sleep mode can be activated by using programming methods specified by Semtech in Lora 1276 Datasheet.

Another great feature of Lora device is that it can notify the user if the battery is running low. This can be done by setting a voltage standard in the program of the device. The device generates an interrupt signal if the voltage drops below that threshold. That interrupt signal can be received by receiver module.

5.2.6 placement of antenna

Range of wireless transmission greatly depends upon antenna design and placement. However, there are only two compatible antennas for Lora 1276 module. One of them is a simple spring and the other is 915Mhz 3dBi SMA Antenna. The latter was used for the range experiment done for this project. Antenna for wireless transmission must be placed outside the mailbox for maximum range. However, the antenna can be placed inside the box if the box is made up of plastic. For metallic boxes, the wireless transmission will not work if the antenna is inside the box. This is due to Faraday Cage effect. A faraday Cage is formed when a conductive material is surrounding an electromagnetic transceiver module. Faraday Cage blocks all the communication.

5.2.7 usage and regulations of frequency spectrum

Usage of frequencies for communication is regulated by law. It is to make sure that the interference caused by different electronic devices does not affect other services. The use of most radio equipment requires a radio licence from FICORA. Radio licences ensure that radiocommunication functions properly. Licensing also helps the authorities to manage the needs of the market.

5.3 GSM based text messaging system

It is also possible to notify the user by using a GSM module inside the mailbox. The GSM module can act as an alternate to the RF based system. GSM modules use a sim card to send text messages. There are many benefits of using text message system over RF modules. One of them is that it does not have any range limitations. Secondly, there is no need for an indoor notification module because the notifications can be received via SMS on mobile phone. However, the SMS subscription for the sim card inside GSM module would add to extra costs. Figure 10 shows a commonly available GSM module.



Figure 11: GSM module (Research Design Lab, n.d)

5.4 Battery technology

One of the most important part of the project was to find suitable batteries that would be easily available and operate well cold weather. For this application, Energizer Ultimate Lithium was chosen as the most suitable battery pack. It is cheap and operates well in extremely low temperatures. This battery costs two euros for one cell. A total of three cells were required for the smart mailbox application. Figure 11 shows the drainage curve of Energizer Ultimate Lithium.

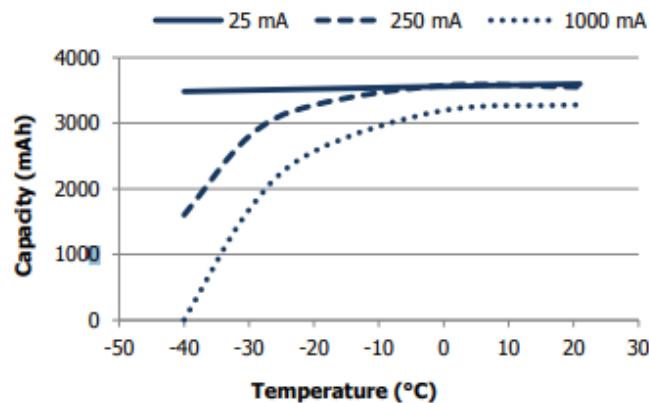


Figure 12: Lithium Disulphate battery drainage curve (Energizer,2018)

It can be concluded that temperature does not affect the battery performance if 25mA or lesser current is drawn. The maximum current required in our application is 20mA. Other characteristics of Energizer Ultimate Lithium are as follows:

- It is classified as a cylindrical Lithium battery.
- It is composed of Lithium and Iron Disulphide
- It can operate from -40 to +40 degrees °C.
- It has a shelf life of 20 years.

Newly developed lithium batteries have constant and more reliable current output characteristics. It means that the batteries will provide the same amount of current unless they are completely drained. Figure 12 shows the graph between voltage and current of a LiFeS₂ battery.

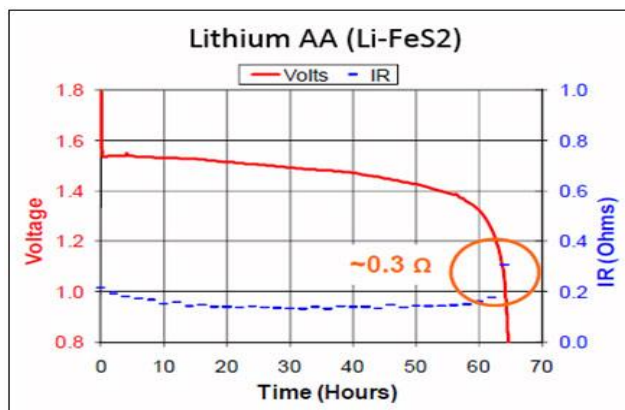


Figure 13: current supply curve of LiFeS₂ battery (Battery University,2018)

5.5 Detection of different types of mail

Detection of the type of mail received is a challenging task. This specific feature might not be a reason for someone to buy a smart mailbox device, but anything that adds value to a product must be considered. There are two ways of detection of mail type.

5.5.1 Use of strain gauge load cells

A strain gauge works by detecting any changes in the resistance of an electrical conductor. This change occurs as the ratio $\Delta R/R$ and it is proportional to the change in the length of the conductor $\Delta L/L$. The change in resistance is due to the change in the physical size or deformation of the conductor and an alteration in the conductivity of its material. Following image shows the working of a strain gauge load cell.

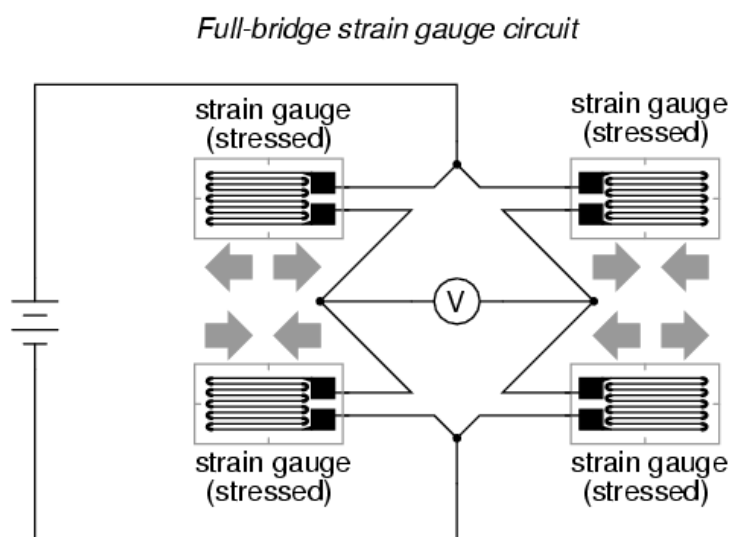


Figure 14: full bridge strain gauge (All About Circuits, n.d)

The simplicity of operation and cheap costs make it suitable for smart mailbox application. It can classify the delivered contents based on their weight. For example, a newspaper is much heavier than a letter. The device can be programmed to predict the type of mail received. However, the limitation is that if both are delivered together, this system will only show that it is a newspaper. All four strain gauges should be placed on the base of the mailbox and a flat cardboard should be placed to cover them.

5.5.2 Camera based image recognition

This method of mail detection is relatively expensive and complex, but it is very accurate. We can install a small pinhole camera on the inside of the mailbox and use image recognition techniques for mail kind detection. For a deeper understanding we need to examine the characteristics of an image. A digital image is a numeric representation, normally binary, of a two-dimensional image. These numeric representations can be processed

in the software by using programming techniques. Example of a digital image in the form of data is shown in the picture below.

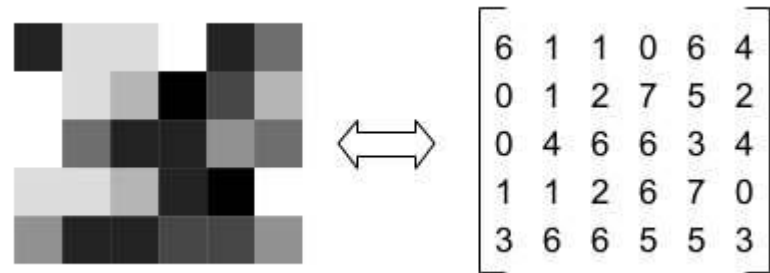


Figure 15: representation of image as data (Stackoverflow, n.d)

The most suitable method for the smart mailbox application would be to store sample data of different size of letters and newspapers. The software can then compare the collected data with the stored data to make predictions. In this case, most suitable way of comparing the data is to use edge or colour detection of the acquired image. It is important to note that a flash LED would be required with the camera to illuminate the interior of the mailbox. Following image shows a commonly available camera module.

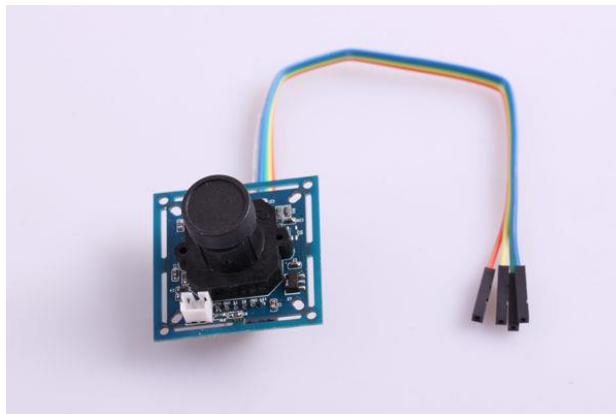


Figure 16: Ardu Cam (Instructables, n.d)

5.6 Indoor notification module

The indoor module of the smart mailbox consists of similar parts as the outdoor module. The only difference is that it has a notification light or bell instead of a detection switch. If mail is detected, the indoor device will blink the LED corresponding to the type of mail. Following image shows how indoor module would look like.



Figure 17: indoor module design concept

6 RECOMMENDATIONS

There are two possible ways of implementation of smart mailbox. Either it can be done by a company making consumer electronics or the existing mailbox manufacturers. The mailbox manufacturers have an advantage as they can adopt different architectures according to the application for cost effectiveness.

Usually during the construction of rowhouses, the contractor purchases and installs the mailboxes. These boxes are then placed together in the form of a group near the yard. They are usually from a single manufacturer for aesthetic and logistical reasons. Following picture shows a rowhouse mailbox group.



Figure 18: Grouped boxes at a rowhouse (Marsakari Oy, n.d)

This practice of one purchaser and one provider presents the opportunity for the provider to use a single transmission module for all the boxes. The most suitable in this case would be the GSM based text messaging system discussed in the chapter 5.3. Each box just needs an individual switch connected to the common transmission module. The transmission module checks which box has received the mail and sends a text message on the mobile phone of the respective house owner. In this way, the need of personal mailbox device and indoor module is eliminated. This smart approach will help the mailbox manufacturer win more customers and reduce costs at the same time.

However, for the existing grouped and separate houses, the best option is to use the RF based personal device with indoor and outdoor module. This is due to the reason that the GSM module is much more expensive than the RF module for an individual customer.

7 CONCLUSIONS

It can be concluded that it is economically and technologically viable to produce and implement smart mailbox. The benefits it provides outweigh the costs. Mailbox market is quite competitive and the companies making these boxes are always competing over designs. In my opinion, the first company to adopt smart mailbox will win over other companies in business. The consumers and the building contractors will choose the smarter version of the box and increase the sales of the respective company. In addition to it, the retrofit device also presents a good business opportunity.

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