Radio Frequency Based Street Light Management System

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ABSTRACT

This research was conducted to design and evaluate a street light management system based on radio controlled signals. An audio signal transmitted through a radio station was used as the control signal. Signal pattern was identified based on the frequency, duration and the order of the tones. PIC microcontroller was used to detect and identify the signal and to trigger power control module which controlled the street lamps. Using a radio station as the transmitter reduced the implementation cost is reduced while providing an optimal coverage for the signals.

Extra precautions were taken to reduce the misfiring and to increase the robustness against the factors such as power failures and power surges. Units were tested in the laboratory and are currently being tested for the outdoor environment and observed to be functioning properly under average conditions.

1. INTRODUCTION

Street lights are sources of lights which are used to aid the pedestrians and drivers during the night time by illuminating the streets and the surrounding. These lights serve a vital role by not only helping the drivers and pedestrians to see better but also to reduce some of the street crimes. However these lights use high intensity bulbs such as high wattage sodium and mercury lamps and consume large amount of power. It is estimated average annually usage of electricity for street lighting in Sri Lanka is of 150 GWh [2]. Having the street lamps switched on for an extra hour in a city can be considerable power wastage. Ceylon Electricity Board incurs a annual loss of Rs 2,673 million on account of the street lights which are not switched off on-time [2].Therefore it is necessary to control these lights effectively to guarantee the safety of the people while keeping the wastage to a minimum.

At present, most of the streets lamps are controlled manually. A single switch may control cascaded lamps in a street or in an extreme case each lamp may have a dedicated switch. This process is not only labour intensive but also inefficient. As an example Colombo Municipal Council at the moment has only 59 staff members to control large amount of street lights within the city limits while it is estimated that at least 80 employees are needed for the task. If it takes one hour for a person to complete the task, lamps at the end of the route would be switched on for an extra hour. But the most problematic scenario is when the shear negligence may lead street lamps to switch on throughout the day which is not a very uncommon sight.

Automating the light controlling system can solve most of the above mentioned problems while reducing the costs in long term. Automated street light control systems can be categorized as follows.

1. Timer based controlling
2. Ambient light based controlling
3. Remote controlling

Timer based controlling uses a real time clock (RTC) to determine when to switch on or off the lamps. This clock may be an internal clock which is builds in to the circuit, or it may use an external clock signal such as GPS clock time, to determine the time. Since different seasons have different times for sun rising and sun setting it is required to take these differences into account for an efficient controlling.

A light sensor based controller samples the intensity of the outside light level and determines whether if the light should be switched on/off. These controllers can compensate for the daily weather changes such as the cloudy sky since they rely on the external feedback. However these sensors are more prone to be misfired due to the collection of dust and rusting of the shields.

All the above mentioned automate methods have one disadvantage. They do not allow a human to micromanage the lighting. An example may be a decision to switch off street lamps from 1.00 a.m. to 3.00 a.m during a power shortage period. Although timer based controller may be programmed to do so it would require reprogramming all the devices which would be a major drawback.

A more convenient method would be to have a central place where all the lights can be management. Remote controlled light management was based on this concept. Remote controlling can be wire based, Infra Red (IR) based or Radio Frequency (RF) based. Wire based methods would require additional wiring to the street lamps which is an upgrade to the infrastructure and is costly. Further, damage to a single point along the line can cripple the full system. IR based methods only works for a short distance which makes them unsuitable for a wide area. Radio frequency based controlling eliminates all these disadvantages. However the conventional radio frequency controlling methods require a dedicated powerful transmitter to send the control signal. Objective of this research is to overcome this obstacle. Therefore it was decided to use existing radio transmission services as transmitters.

2. METHODOLOGY

2.1 System Overview

Street Lights management system consists of a central transmitter tower, which is a radio station, Signal receiver and decoder modules also known as the controller modules and the lamps themselves. Figure 1 Illustrate the overall design of the system.

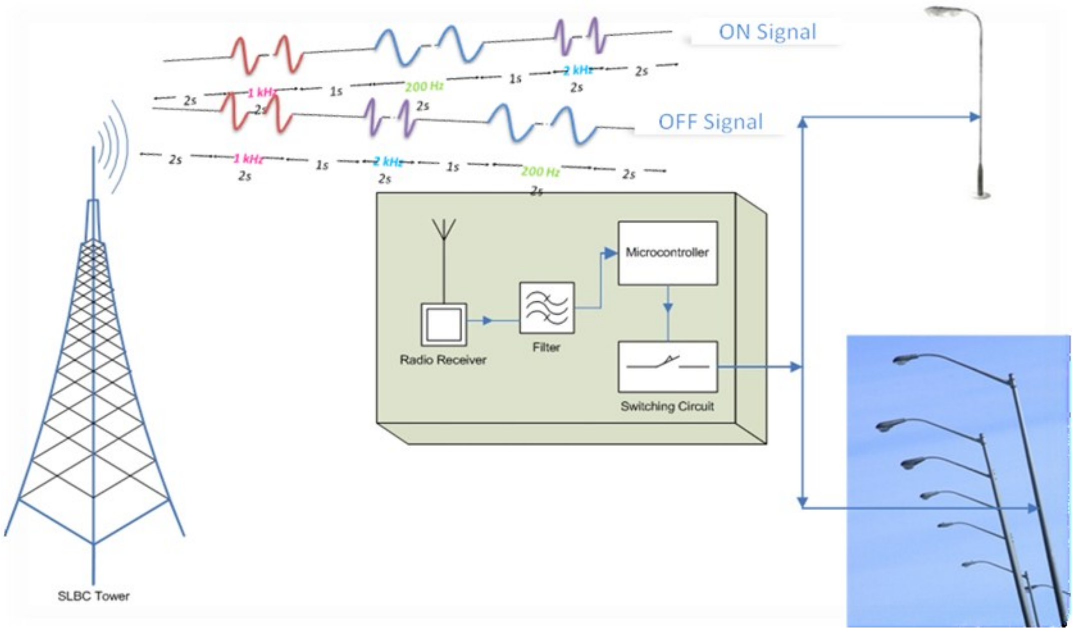

Figure 1: Overall design of the system

Switch of the street lamps is replaced by an electronic module which is referred as control unit. This unit mainly consists of a FM radio, a microcontroller and a latch switch which is connected to the street lamp. Microcontroller is capable of identifying the predefined controller signal from the audio signal received from the FM receiver and triggers the latch switch.

2.2 Control Signal

Control signal consists of a sequence of frequencies which are encoded to an audio pattern that can be transmitted through a standard radio channel. Several factors were to be considered when designing the control signal. Since the signal was transmitted using a system designed to transmit audio it was necessary to keep the signal in the audio range. Most of the other frequencies were filtered during the intermediate steps in the transmission process. As a result control signal is audible and it is necessary to minimize the interruption to the audience. This is handled by making the control signal brief and pure tone. Duration of the pattern was 7 seconds. Three base signals used were 200 Hz, 1 kHz and 2 kHz. Using pure tones reduced the distortion due to unequal equalizer settings. The final control signal was a collection of pure tones which was transmitted in a sequence with a predefined set of durations and intervals. It was artificially generated using a computer program. Control signal is illustrated in figure 2.

2.3 Measurements to Prevent Misfires

Unlike a dedicated transmitter which would transmit only the controller signals ,using an existing radio service exposed receiver to other audio signals such as music, news and advertisements. Hence it was necessary for the controller program to identify the controller signal from all other possible audio signals. Identification was based on following three key characteristics of the signal.

1. Frequency of the tones
2. Duration of the tones
3. Order the tones were received

For a control signal to be identified it is necessary to satisfy all the conditions, reducing the possibility of a false positive.

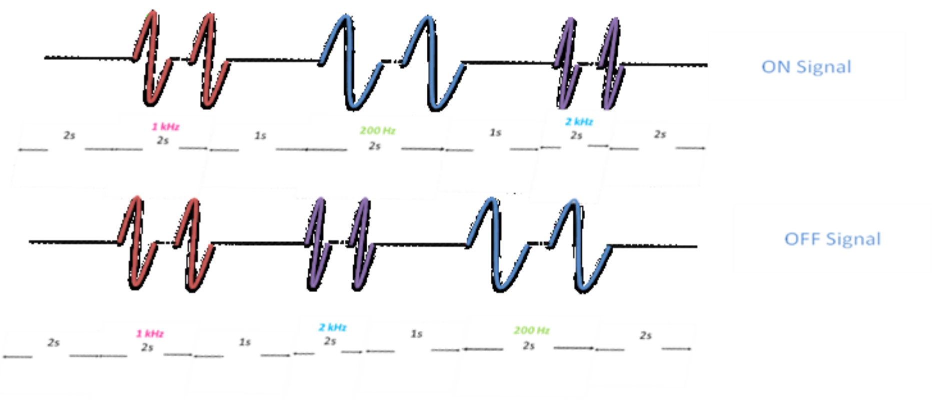

Figure 2: Control Signal Pattern

2.4 Transmission Process

Frequency Modulation (FM) band is chosen due to the availability of the RF receivers and the number of radio stations active. Standard frequency range approved by the Telecommunication regulation commission is 88 MHz to 108 MHz. Several test transmissions were carried out to determine the efficiency of the transmission process and was found to be highly successful. Signal was transmitted in raw wave file format as well as the compressed mp3 format and found to be effective regardless of the compression method. Audio sampling rate was 44,100 Hz with 16 bit resolution.

2.5 Electronic Circuit Block Diagram

Circuit was designed and implemented in modular architecture. Figure 3 illustrates the seven sub modules and their interconnections.

2.6 Power Supply Module

Power module is used to supply regulated low DC voltages required for other modules, including 12 V and 5 V. It was also designed to act as a protection unit. Since the unit would be directly connected to the national grid, possibility of a voltage surge is high. These surges can damage the electronics used in the controller. A surge protection unit installed in the power controller module filters power line voltage spikes.

2.7 Receiver Module

RF receiver used was an fm radio circuit designed to receive signals from 88 MHz to 108 MHz. Several modifications were made to the design to make it more robust. Most of the radio receivers used an inductor capacitor tank unit to resonate with the transmitted frequency [1]. By changing the capacitance and induction it was possible to tune to a different frequency. In early designs it was noted changes in temperature and humidity can affect the value of these components and hence can change the receiving frequency. Because the controller signal was transmitted from a fixed radio channel this was undesirable.

It was amended by using a solid state receiver with a digital tuning circuit. It was noted that changes in the environment had minimal effect on the frequency of these units. It was also necessary for the units to be properly initialised after a power failure. Microcontroller unit was used to handle the initialising process once the power returned. Captured audio signal was filtered from the noise and was amplified using the amplifier sub module.

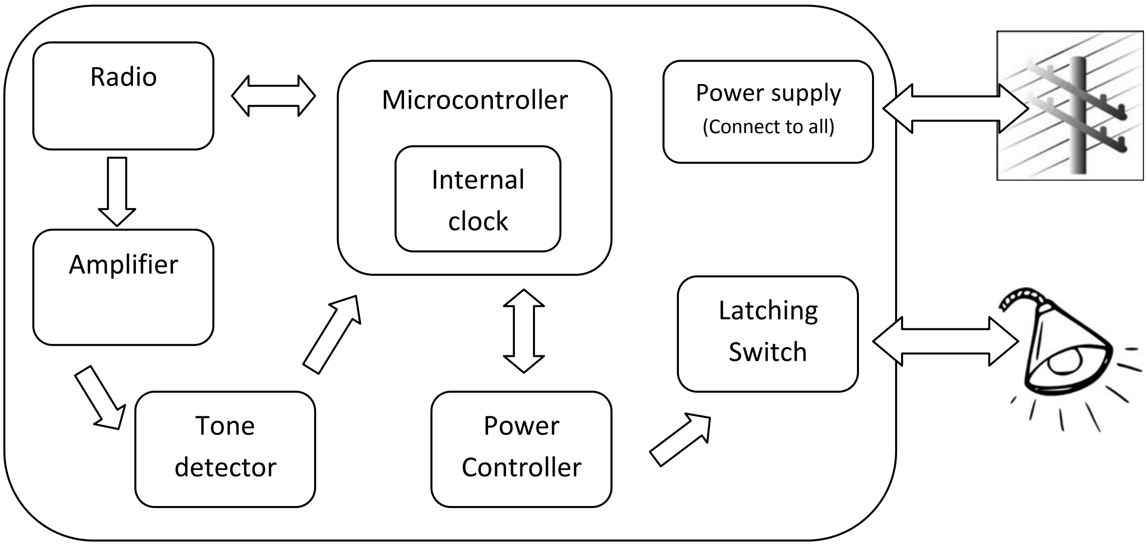

Figure 3: Design of electronic sub modules

2.8 Detecting Pattern

One of the key concepts in the design was the pattern detection. Control signal was identified using frequency of the tones, their durations, and the sequence of the tones. Since control signal consisted of pure tones it was logical to have three tone detector circuits with each one tuned for a unique frequency. Each time the audio signal contained the relevant audio frequency component these circuits would send a signal. Tolerance of 10% was provided to compensate for any abnormalities that may occur during the transmission and receiving process. A Schmitt lock on frequency was imposed and the results are illustrated in Figure 4.

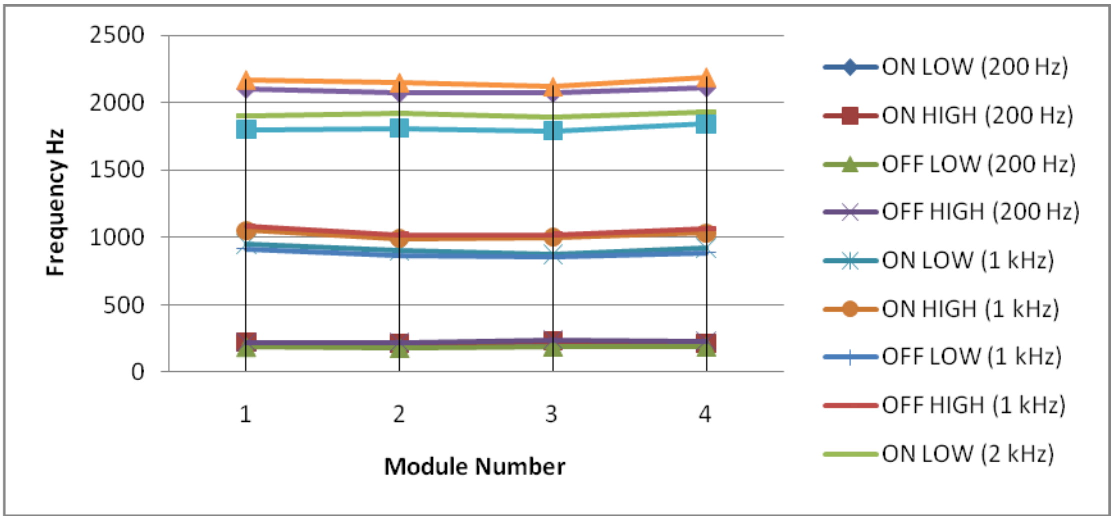

Figure 4: Tone detector frequencies

An internal clock inside the microcontroller unit measured the duration of each of the tone detector circuit's signals. Tone detectors were queried in 100 ms periods for the frequencies. This data was then used to detect the controller signal.

2.9 Microcontroller Module

Identification of the signal included several steps. If any of the steps failed it would be considered as a non control signal and system would return to the previous state. First step was the detection of silence to initialize the detector circuit to detection mode. This also prevented controller signal been mixed up with a fading audio from a previous track. Then 1 kHz signal of 1second period is detected by the microcontroller and the process continued. Since controller signal consisted only of a single frequency it was also confirming none of the outputs of other tone detectors are high. If so it would be considered as a misfire and system would reset. Tolerance of duration of a single tone was 20 ms. This was to minimize any cross fading effect and to handle any short period signal losses. Once the first tone was identified microcontroller would be detecting the second signal. This process was continued until either the controller signal was identified or signal resets. Once the controller signal was identified, using two special bits encoded to the signal, microcontroller would identify it as an on signal or as an off signal. This on/off signal was then communicated to the power controller sub module. Power controller sub module would send a signal to the switch the latch switch. Since the state of the latch switch is non volatile once the status change was made microcontroller can switch off the power controller unit. Another advantage of the latch contactor is, it would not reset during a power failure and would remain in the state until a controller signal is received making it more robust against power failures. The logic behind this process is illustrated in figure 5.

Identification of the signal was handled by a microcontroller. Selected microcontroller was from the PIC family due to the competitive price and the range of functions available. The program was written in language C.

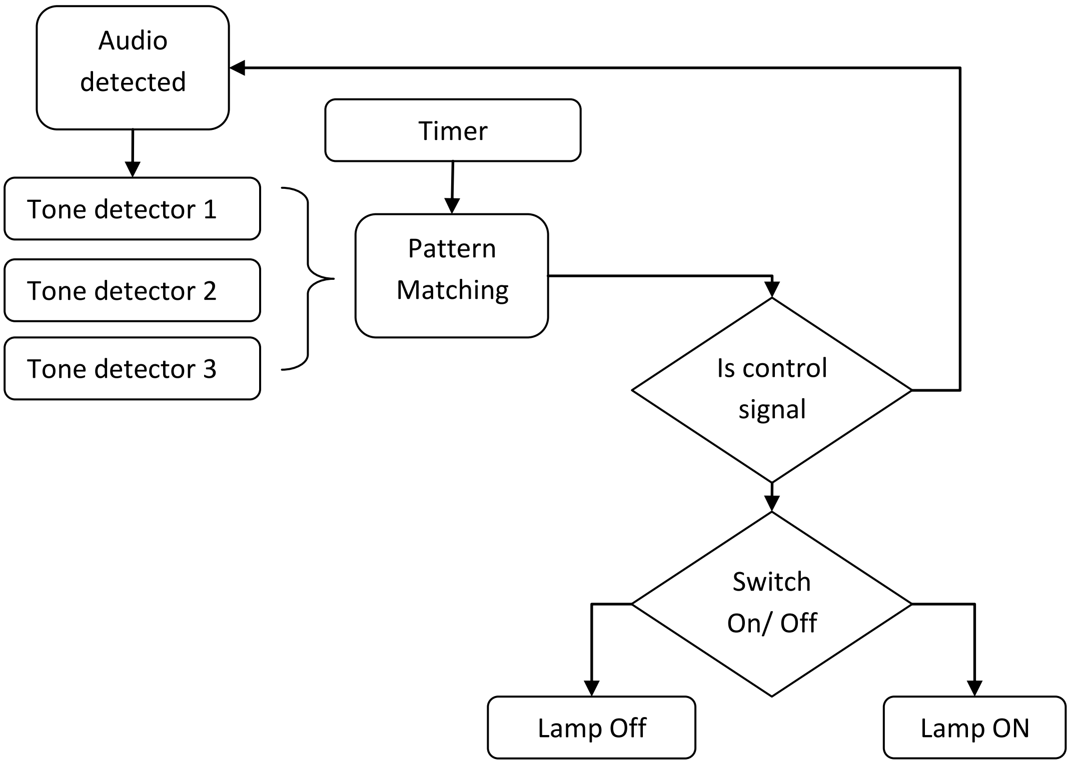

Figure 5: Flow chart of signal identification

2.10 Mechanical Design

Since this was an outdoor unit special care was taken designing the enclosure. It was designed to withstand extreme weather conditions while providing a good insulation for the internal electronics. It was also necessary to be economically feasible and environmentally friendly. The box design shown in Figure 6 was used as the prototype.

Figure 6: Controller unit inside the casing

3. RESULTS AND DISCUSSION

Four modules were tested in the laboratory and were found to be successful. They were put to continuous operation for over 96 hours and were found to be operating in the same efficiency without any noticeable change in frequency shifts, degradation of amplification or excess heating. Same modules were exposed to frequent power failure scenarios and all the units were found to be functioning properly even after multiple power failures.

Although frequency detection module shifted its detection frequency in extreme temperatures (60.0 ± 0.1) ^{o}C, it returned to previous value once the module returned to room temperature. By logging the temperature and the humidity inside the metal box it was found that the maximum temperature in side box was (39. 0 ± 0.1) ^{o}C. The temperature variation during a 24 hour period inside box was found to be in the range between (24.0 ± 0.1) ^{o}C to (39.0 ± 0.1) ^{o}C. All the modules were operating successfully in this temperature range. Modules were also tested against extreme humidity levels from (20 ± 1) % relative humidity to (70 ± 1) % relative humidity.

4. CONCLUSION

Main objective of the research was to develop a low cost robust street light management circuit which can be deployed island wide. Use of an existing radio station had make is possible to transmit a signal island wide without having to invest on a separate transmitter. A controller signal embedded as audio frequency was transmitted and was captured by a FM receiver. It was decoded for composition frequencies and the result was submitted to the microcontroller for the identifications for controller signals. Once identified a signal was used to control the bulb. System was tested for various conditions and was found to be practical and reliable.

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