Smoke alarm detection, broadcast notifications and social implications

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Abstract

Changes in population demographics and lifestyle choices have led to an increased risk of higher mortality from house fires. The current average of 27 house fire related deaths per year is likely to be exceeded in the following years. The aging population with its natural increase in age related hearing loss and the younger demographic only having mobile phones and no land-lines means there is a need for alternative warning methods of smoke alarm activation. This project develops a proof of concept application that runs on a smart phone and detects an activated smoke alarm. If there is no response by the occupants automatically trigger an alarm to a predefined contact group. This application can reduce the possibility of death or injury by persons unable to respond to an activated alarm.

1 Introduction

The increasing availability of programmable mobile devices, smart phones in particular, creates new opportunities. These devices can be used for various context dependent computation, data gathering and tracking. Many smart phones offer today Internet and GSM connectivity together with a range of sensors that can be used for improving quality of life, well-being and safety.

There is an rapidly increasing proportion of the population that is at higher risk in the event of a smoke alarm activation, this is due to a number of factors:

1. an aging population increasingly living alone [1],
2. age related hearing loss in the frequency range of the smoke alarms [2],
3. increases in no land-line connection to residences [3],
4. the anecdotal perception of the high cost of off site monitoring of alarms.

These factors combined have somewhat reduced the value of the work undertaken in the last 10 years to get smoke alarms into residences. Mobile smart phones are an increasing part of the market. By developing a smoke alarm detection application that can be deployed on a mobile device the risks to the population of adverse effects from fires can be reduced at little or no cost to the public. The application provides a verification of actual fire situations to emergency authorities by the independent verification process.

In New Zealand there is on average 27 house fire related deaths per year [1]. Age-specific mortality rates were highest for adults ≥ 65 years and children < 5 years. Age-standardised rates showed a threefold increased mortality for Maori compared with non-Maori [4]. While the greater proportion of these deaths may have occurred in households that have no smoke detection, some are due to the people not hearing the alarm. The use of a mobile device such as a cell phone that can detect an activated smoke alarm and if there is no response by the occupants automatically trigger an alarm to the emergency services could reduce the house fire related mortality. The application strength is not only notification to the emergency services, but also to neighbours and care-givers of a given person. We explore these aspects later in the document.

2 Background

2.1 Environmental factors

New Zealand housing stock has a high proportion of dwellings that are built of wood [5]. The housing is predominantly low density, this sets up situations where fires occurring in such buildings are less likely to be noticed by other than the occupier and also will have a rapid spread. Smoke detection systems are essential and important in the management of fire risk in these homes. Currently the major type of smoke detector in New Zealand homes are the battery powered ionising or optical smoke detectors. These detectors are inexpensive and are able to be place anywhere. One of the shortcomings of these systems is that they have to have their batteries replaced at regular intervals [6]. It is rare that this type of detector is remotely monitored, and the system relies on occupant hearing the alarm and reporting the event to emergency services. Most smoke alarms available in New Zealand resonate in the range of 2 to 4 kHz. Coincidentally, it is also the frequency band most effected by age related hearing loss[7]. Sprinkler based and mains powered smoke and CO_2 systems are rarely installed, possibly due to the relatively old housing stock and the high cost of installing and maintaining these systems. Fire detection alarms are not mandatory in New Zealand homes although there is a high proportion of the housing stock that has at least one alarm [4]. False alarms are an issue with the basic smoke alarms used in households with up to four out office alarms proving to be false, they can be set off with steam or smoke from cooking when no actual fire is present.

2.2 Human factors

Human factors are a major influence in the ability of the smoke alarm to warn occupants of a potential fire. The primary one being the replacement of the batteries and testing of the devices, there is also the issue of disabling the device due to multiple false alarms[8]. Response to the alarm can be affected by a number of factors, such as: hard-of-hearing, children, older adults, young adults, alcohol, mentally or drug impaired. New Zealand fire mortality statistics show that the very young and the elderly are most at risk [4]. The young adult is a risk also due to alcohol or drug impairment, and the naturally risky behaviour of the young adult [9].

2.3 Mobile devices

Many modern smart phones such as Android[1] and Apple[2] phones are equipped with microphones that can be used to detect sound in the local area. This detected sound can be processed and analysed by the device and used to identify sounds. The devices also have built in GPS units[3] that can make the device aware of its geo-spatial location.

Smart phones have built-in accelerometer and GPS units and they act primarily as a communications device (that can be used in multiple different ways: SMS, phone call, or a data connection). Modern smart phone devices are flexible enough to be re-purposed for other tasks such as motor vehicle crash detection [10], portable ophthalmology examinations [11], and potentially many other health monitoring applications.

3 Principal Research Hypothesis

We propose that mobile devices can accurately discriminate smoke alarm warnings of standard home smoke alarms available in New Zealand from the general day to day household sounds. The discrimination will be to at least the 99.9th percentile (1 in 1000). This discrimination is to the detection of the alarm not that there is a fire. Based on the fire alarm detection, the device can autonomously, if not instructed otherwise by the owner, notify care givers, neighbours and emergency services about the alarm.

4 Scope of the Research

Development of a proof of concept application on a mobile device, that will reliably detect the majority of domestic smoke alarms in New Zealand and be able to give location aware warning to emergency services in the event the user is unable to respond to the alarm.

5 Importance of the Study

With an increasing number of households not having land-line capability and the younger demographic predominately using cell phone technology[12] there is a need to provide automated alarm connectivity for households without 3rd party alarm connections. These alarm connections are expensive and generally are outside the financial reach of the demographic most at risk, those ≥ 65 and low decile households. Alarms currently available in the market today have centre frequencies in the range of two to four kilohertz, this is the frequency range most effected by age related hearing loss. The elderly are already over represented in house fire mortality statistics[4]. New Zealand has a rapidly aging population, a population that increasingly lives in single person dwellings[1]. This will lead to further increases in the fire fatality statistics for this demographic.

6 Similar Studies

There appear to be no similar studies into the detection by mobile devices of smoke alarms. There are however algorithms used to detect and identify songs, or sound. These use spectral

[1] `http://www.google.com/phone/detail/nexus-one`
[2] `http://www.apple.com/iphone/`
[3] Global Positioning System – a system used to locate the device.

fingerprinting of songs that is then compared to a central database [13]. Fingerprinting is a common method of analysis of songs. These fingerprints are hash mapped [14] which provides a fast access comparison path. While this is more complex than is required for detection of the smoke alarms, the same principle will be used.

7 Design concepts

7.1 Smoke Alarms

The two most commonly recognised smoke detection technologies are ionisation smoke detection and photoelectric smoke detection.

Ionisation-type smoke alarms have a small amount of radioactive material between two electrically charged plates, which ionises the air and causes current to flow between the plates. When smoke enters the chamber, it disrupts the flow of ions, thus reducing the flow of current and activating the alarm.

Photoelectric smoke detection is generally more responsive to fires that begin with a long period of smouldering. Photoelectric-type alarms aim a light source into a sensing chamber at an angle away from the sensor. Smoke enters the chamber, reflecting light onto the light sensor; triggering the alarm.

The alarm mechanism on all commonly available alarms use high output piezoelectric buzzers. These buzzers have a defined fundamental frequency with even harmonic overtones. The sound pressure output is in the range of 65 to 108 decibels (dB).

7.2 Alert systems

Direct communication with emergency services of an alarm while desirable, is not practical. False alarms account for 90% of all alarm activations [15]. For this reason the alert system is based on the neighbourhood watch concept instead. A group of neighbours would be listed in the phone as contacts in the event of a fire. On an alarm activation the phone would group text all the people in the fire contacts list. This can be extended to care givers and supervisors of group homes etc. The people on the contact list can then ascertain the status of the person who has activated the alarm and if needed, call the emergency services.

The use of SMS messaging is the most practical method of mass communication with the contact list. A potential risk for this method of communication is that it has only best effort quality of service and cannot be guaranteed to provide a timely service. Direct voice conference calls are not easily implemented on mobile devices. While there are conference call facilities on mobile devices they are not a free service and require to be set up by a telecommunication provider.

For our proof-of-concept implementation we have used smart phone system equipped with the Android operating system and application framework. Android is an open platform widely used in a number of modern smart phones, tablets and some netbooks. Figure 1 demonstrates the elements involve in the communication chain. A smoke alarm gives off an audible warning, this warning is captured by the mobile phone application which analysis the sound to decide if it is a true alarm. After deciding the alarm is valid, it activates a warning on the phone if the user does not respond in 60 seconds it texts via Short Message Servicing (SMS) all the people in the fire contact list.

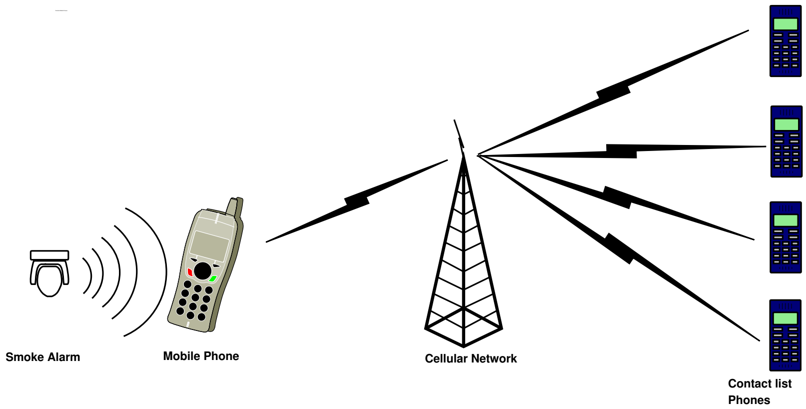

Figure 1: Communication Concept.

7.3 Application logic

To reduce the possibility of false positive alarms, when the analysed frequency transform of the sound matches a alarm pattern in the database the incoming signal is sampled a further 10 times this reduces the chance that other background noise could have the same fundamental an overtone frequencies. In normal music and day to day sounds it is rare to get exactly the same frequencies occurring over time.

A 60 second delay is started when an alarm is detected this is to give time for the user to react to the alarm and terminate the automatic sending of the text messages.

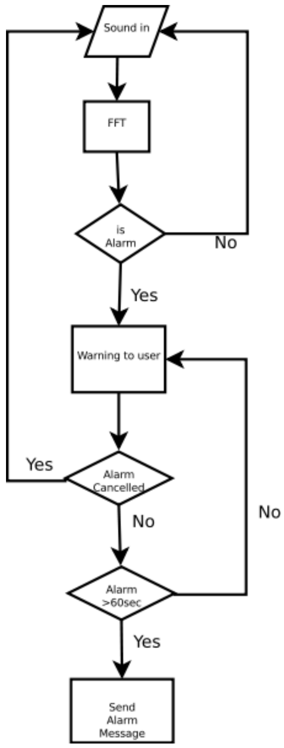

Figure 2: Flow diagram of alarm triggering.

7.4 Application architecture

Some elements of the application architecture are built into the Android phones, elements such as contact lists and SMS messaging. The application links into these existing elements to provide required services.

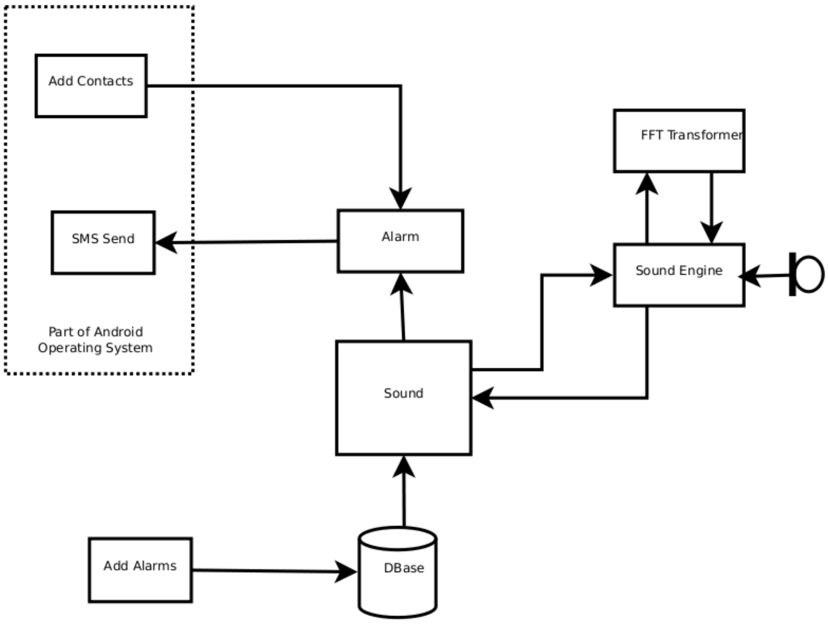

Figure 3: Design Concept.

7.4.1 Sound engine module

The heart of the application lies in the sound engine. This module sets up and reads in the audio from the microphone. The module then sends the sample to the FFT for processing, the returned FFT data is the used by the sound engine to ascertain the fundamental and first overtones of the sample. The result is then compared against the existing database of alarms and if there is a match is streamed through the audio buffer which is sampled and the sample sent to the FFT module. After frequency transformations the resulting data s sent back to the sound engine for further processing. The transformed data is filtered to establish the fundamental and first overtone frequency of the sample. These values are then compared with the database of alarms. If there is a match ten times in a row an alarm message is passed to the sound module .

7.4.2 FFT module

This module takes the captures sound sample, performs a Fast Fourier Transform on it an returns the result to the sound engine.

7.4.3 Sound module

This module provides a basic front end to the application (Figure 4a), it gets all the alarms from the database (to reduce access times) and starts the sound engine module (Figure 4b). It has a special menu system that allows for entering the new alarms and exiting the application(Figure 4c).

(a) At Startup (b) Running (c) Menu

Figure 4: Sound module front end .

7.4.4 Alarm module

This module is started when an alarm occurs, the module displays a flashing message on the screen to warn an alarm is detected. If after 60 seconds the alarm cancel button has not been pressed, the module looks up all the fire contacts in the contacts list and sends these to the SMS module (Figure 5).

7.4.5 SMS send module

This API is part of the Android version 2.1. The alarm module sends the fire contact list to the SMS module which then sends all the messages.

7.4.6 Add alarm module

The 'Add alarm module' records the smoke alarm and saves it to an SQLlite database. There are options to store the alarm type and the address location of the alarm to the data base as well (Figure 6).

7.4.7 Add contacts module

The built in phone contacts module of the Android Version 2.1 operating system was used. A contact type “Fire“ is made and the contact phone details added. This is then checked in an alarm situation and used as a contact group list (Figure 7).

Figure 5: Alarm module display.

Figure 6: Add alarm module display.

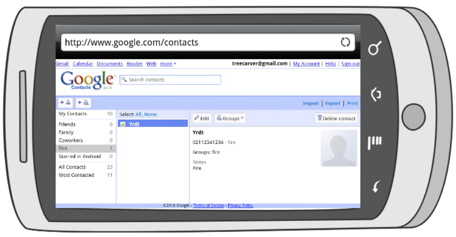

Figure 7: Add contacts module display.

8 Results

8.1 Base Frequencies

An analysis of smoke alarms supplied by the New Zealand Fire Service showed that all of the alarms used high frequency piezoelectric crystals, ranging in fundamental frequency from 2953Hz to 3468Hz. Although there are Low frequency (under 500 Hz) alarms on the market overseas there were none in the alarms supplied.

Alarm	Model	Fundamental Freq	1st Overtone Freq
Orca	M2354	2953	4238
Orca	OM196	3013	4165
First Alert	ESBA1	3234	4500
First Alert	11SAG0TTCAUS	3265	
Wormald	WRS001PH	3156	4180
Safelines	PR1211	3390	4650
Familyguard	F9888DCAUS	3468	4803

Table 1: Alarm Fundamental and 1st Overtone frequencies

8.2 Minimum sound threshold

Testing Equipment:

- Sound level meter Radioshack cat no 33-2050.
- Noise generator: Toshiba M110 computer with Audacity®1.3.12-beta

Sound level meter Radioshack cat no 33-2050.
Test settings : sound pressure level (SPL), 'A' weighted, fast response.
Test protocol:

- Phone and SPL meter 500 mm from sound source
- Measure ambient noise
- Start application
- Using 1 kHz tone start at ambient noise level, increase level till alarm triggers.
- Using 2 kHz tone start at ambient noise level, increase level till alarm trigger.
- Using 4 kHz tone start at ambient noise level, increase level till alarm trigger.
- Using 8 kHz tone start at ambient noise level, increase level till alarm trigger.

The application was tested to find the minimum sound threshold that would reliably trigger the alarm.
Ambient noise level: 62db

Frequency	Threshold
1kHz	65db
2kHz	65db
4kHz	67db
8kHz	68db

Table 2: Alarm trigger threshold.

8.3 False triggering

Testing Equipment:

- Sound level meter Radioshack cat no 33-2050.
- Noise generator: Toshiba M110 computer with Audacity®1.3.12-beta

Test settings : sound pressure level (SPL), 'A' weighted, fast response.

Test protocol:

- Phone and SPL meter 500 mm from sound source.
- Set volume to average threshold detection level 8.2.
- Start application .
- Play music tracks.
- Set volume to average threshold detection level + 20db 8.2.
- Play music tracks.

For the detector to be successful it should be immune to false triggering by sounds other than alarms. For the purpose of this test a range of music was played at the average threshold detection level and at 20db above threshold. Table 3 shows the range of music used and the results of the testing.

Average threshold detection level: 65db

				Alarm Triggered	
Genre	Title	artist	Time	Threshold	+20db
Slide Guitar	Nobody hold me close	Dave Hole	3.51	No	No
Death Metal	To the Wall	Sepultura	4.55	No	No
Jazz	Maple leaf rag	Chris Barber	4.35	No	No
Classical	L'Elephant	Saint Sauns	11.25	No	No
Blues	Black satin	Katie Webster	3.57	No	No

Table 3: False trigger test.

8.4 Discrimination in noisy environments

It is important that the application is able to detect the smoke alarms when in noisy environments. The purpose of this test is to ascertain the minimum difference in sound levels between background noise and the alarm sound to cause reliable triggering of the alarm.

For this test the same protocol as used in Section 8.3 with the ambient threshold replaced with music. The average SPL values were set at 60db, 70db, 80db and 90db. The alarm tone was triggered below the test threshold and the raised until the alarm triggered.

Background Noise (db)	Alarm Trigger value (db)	Difference (db)
60	66	6
70	75	5
80	87	7
90	97	7
Mean		6.25

Table 4: Alarm Trigger above background.

It can be seen from Table 4 that at all SPL levels there was little variation in the trigger level above the background noise. This constant alarm trigger threshold value gives confidence that the alarms are detectable in all high noise level environment as long as there is a minimum of 7db difference in alarm SPL.

9 Discussion

There is good discrimination between alarm activations and the surrounding noise, even in very noisy situations there is no false positives. The detection algorithm is sensitive and will activate the alarm at only 6db above the ambient noise level.

Continuous sampling of the microphone to ensure detection of all alarm events reduced the battery life of the phone substantially. There was insufficient time to evaluate the current drain of the application and this will need to be investigated further.

Continuous sampling for alarms was successful but at the cost of very high processor overhead, instead of continuous sampling it would significantly reduce the processing cost if a 5 second snapshot of detection occurred every 30 seconds. The interval between samples would have to be carefully considered to trade off between improved processing and the increased risk of greater fire involvement.

A further improvement in the processing costs could have been gained by the reduction of the 16kHz sampling rate of the audio to 8 Khz , however, because of the Nyquist criteria of FFT this would then reduce the detection to just the fundamental frequency as the first overtone frequencies would be outside the FFT window. Future analysis should be done to see if it would give acceptable results at this lower frequency.

The Android SMS API made it difficult to easily set up fire contact groups, for this reason the fire contacts were set-up using google contacts that were then shared with the phone. The latest API update has apparently rectified this problem.

10 Conclusion & Future work

10.1 Conclusion

We have successfully shown that detection of smoke alarms by mobile phone is possible, mobile phones can be reliably used detect smoke alarms and warn owners and remote contacts of a alarm situations. The alarms are detect reliably even in situations where there is high ambient noise. A weakness of the system is in the processing overhead used to constantly monitor the audio input of the phone. This application demonstrates the mobile phones ability to be used as a advanced warning device in the event of a smoke alarm activation, its automated group alert system reduces the chance of harm to people who have not been able to respond to an alarm.

10.2 Future Work

There are two major areas to be investigated further. The primary one is the implementation of the sound engine and the FFT transform to run as stand alone background tasks. These background tasks will call foreground task only when interaction with the user is required. This will improve the overall architecture and design of the system. It should also improve the battery consumption and overall responsiveness of the system.

Secondly, further research needs to be done on how often the input should be sampled and if the sampling rate of the data can be lowered without reducing the reliability of the detection. This has implication in the battery usage.

Further improvements to the Group Contacts module should be made using the latest API, to allow adding both current address book contacts and new contacts to the 'Fire' group in a integrated user friendly interface.

A geolocation module was originally envisaged for this application, but problems with getting the GPS to work reliably inside multi-story dwellings and with dwellings that have metal roofs meant there was insufficient time to get this feature working. The acquisition time of the GPS is too long in the event of an alarm activation so location will have to be already cached on the phone. Implementation of location awareness by use of GPS should be implemented. There are constraints on the use of GPS inside dwellings due to signal level problems that need to be overcome. Consideration of coarse location detection by cell tower triangulation combined with cached GPS location data is a possible solution to the problem that should be investigated.

This application has only proved the proof of concept of the detection of smoke alarms using the microphone input of mobile devices. The concept should be expanded to allow for input from blue-tooth ,wireless devices and the current 434Mhz Rf links.

While using the application on a mobile device allows for portability, a fixed location device that is mains powered would overcome many of the problems. A fixed location device should be constructed and trialled in a number of test situations such as rural locations and single person dwellings.

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