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Abstract: This paper describes a smart bushfire monitoring system that can provide an early warning message in case of a bushfire. The system utilises short message service through global system for mobile (GSM) communication technology as a medium of communication. The device is composed of a temperature and humidity sensors that are connected to a microcontroller. The microcontroller also interfaces with a GPS receiver to report the module position and a GSM module to communicate the sensory information. This message can then be collected by either another mobile phone or SMS server for further action or processing. The details of the device architecture, developed algorithms, and performance are provided.

Keywords: bushfire; global positioning system; GPS; global system for mobile; GSM; microcontroller; remote monitoring.

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1 Introduction

Bushfires are a serious natural disaster around the world. The devastating effects of these fires around the world are reported in a number of United Nations publications (Holmgren, 2007; Goldammer, 2001; Holmgren, 2006). These fires tend to start during summer due to a number of factors (Willis, 2004) which brings huge losses to lives and properties, in addition to a significant damage to the environment and wildlife.

Before 2001, major Australian bushfires did cost A$2.5 billion dollar and resulted in the death of around 250 people (Commonwealth of Australia, 2001). In January 2003, another bushfire disaster happened in Canberra (Esplin et al., 2003). During the following eight years, Australia has experienced three devastating bushfires. On February 2009, the terrible Victorian bushfires, also known as the Black Saturday bushfires, did cost a total of 173 lives and more than 500 injuries (Suter, 2009).

In order to prevent bushfires from occurring or minimise their negative impacts, accurate and early detection of any bushfire is essential. Nowadays, there are numerous bushfire alarm and monitoring systems that vary in terms of their structure and principle of operation. The development of a bushfire alarm system is affected by technological progress. The used approaches spans from using human beings to detect bushfire to using computers and satellites to monitor the possible occurrence of these bushfires. As a result, bushfire alarm systems become more and more efficient and reliable. However, although bushfire monitoring systems have improved constantly, they still have different shortcomings and limitations. More research and efforts are needed to develop an efficient and economical bushfire alarm system.

It is believed that the incorporation of the proposed system with current and new homes can result in a much smarter home or properties that can inform their owners or an authority in case of fire or bushfire. It can be argued that current alarm system can do some of these functionality, however the proposed system can be tailored to a number of communication mediums without the needed for extra cost, which is usually associated with monitoring services.

In the Section 2, we review current approaches to bushfire monitoring systems and the pros and cons of each of these approaches. Then, based on the research gap statement in Section 3, we present the proposed device architecture in Section 4. This is then followed by a description of the developed algorithms for this device and the continuous monitoring approach. An overall device performance is discussed in Section 6. This will be followed by a conclusion.

2 Review of current bushfire monitoring systems

In the following subsections, we will briefly review the common approaches to monitoring and detection of bushfires.

2.1 Word-of-mouth bushfire monitoring system

The word-of-mouth bushfire monitoring system is widely used in the world (Abarquez and Murshed, 2004). It is a human community based bushfire detection system, which utilises interpersonal communication to transmit bushfire information. Research by the United Nations points out that many human communication chains can be formed through interpersonal communication (United Nations DRO/22/76 Division, 1986). These chains would become active in the case of important events. Therefore, if a bushfire occurs, a warning message is conveyed through human communication chains and reaches a fire service department or an emergency centre. The features of this system are listed in Table 1. The pros and cons of word-of-mouth bushfire monitoring system are summarised in the Table 2.

Table 1 Characteristics of word-of-mouth bushfire monitoring system

Monitoring channel	*Communication medium*	*Communication technology*
Human being	Human communication chain	Telephone Telegraph Radio Fax

Table 2 Pros and cons of word-of-mouth bushfire monitoring system

Pros	*Cons*
System is easy to develop	Send inaccurate alarm message
System does not need maintenance	Alarm message might not be sent in time
	Possibility of missing an alarm message
	The detail information such as location, temperature cannot be announced precisely and punctually

2.2 Fire watch-towers bushfire monitoring system

When bushfire detection system is mentioned, fire watch-towers are most likely to leap to mind (Luke and McArthur, 1978). Bushfire watch-towers are constructed in a pyramidal shape to provide stability, with a cabin at the top, where an observer is located to spot fires. The towers are usually 10–20 m high and constructed on flat-topped hills, or 30–40 m high are commonly used on fairly flat terrain to provide a good view over the surrounding tree cover. Some equipments are provided in the cabin to facilitate detection, recording of information and communication. When observers detect a fire, they guide the pointer of the azimuth angle and report to a forest division or forest enterprise office by telephone or radio transmitter (Luke and McArthur, 1978). The working processes of this system are described as follows:

- an observer detects a fire and notes the azimuth angle of the direction of the fire, then a warning massage is sent to the forest division or the forest enterprise office by telephone or radio transmitter
- the office determines the place of fire by using the forest map.

The characteristics of this fire monitoring system are showed in the Table 3. The pros and cons of fire watch-towers monitoring system are listed in Table 4.

Table 3 Characteristics of fire watch-towers monitoring system

Monitoring channel	*Communication medium*	*Communication technology*
Bushfire watch-towers and observers	Human being (observers)	Telephone Radio Fax

Table 4 Pros and cons of fire watch-towers bushfire monitoring system

Pros	*Cons*
Early detection of fires	Bushfire watch-towers cost is high
Better visibility system for detection fires	The range of operation of the tower is limited (~18 km)
	Observers may send inaccurate alarm message
	Observers only send azimuth angle to the office, so the office needs to determine the place of fire, so some time is wasted

2.3 Ground and aerial patrol bushfire monitoring system

Ground patrolling is carried out by foresters and temporary fireguards. These people undertake forest fire detection, protection and control all round, in addition to their normal and regular duties (Chung and Kim, 2008). A patrol personal communicates the information to a base station, e.g., fire watch-tower, regularly. Therefore, when a bushfire occurs, the patrol personal is in radio contact with fire towers and their headquarters (Luke and McArthur, 1978). Aerial patrolling requires hiring an aircraft to watch from the air. Although such approach is expensive, it is commonly used for enhancing other methods of detection (Luke and McArthur, 1978). Aerial patrolling is usually used for special purposes, such as to provide an additional detection during fire danger periods. The main working processes of this system starts by the ground or aerial patrolling detection for bushfire, then report to fire watch-tower or forest enterprise office using a radio. The features of this bushfire detection system are listed in the Table 5. The pros and cons of ground and aerial patrol bushfire monitoring system are listed in Table 6.

Table 5 Characteristics of ground and aerial patrol monitoring system

Monitoring channel	*Communication medium*	*Communication technology*
Patrol aircraft	Human being (observers) Fire watch-tower	Radio

Table 6 Pros and cons of ground and aerial patrol bushfire monitoring system

Pros	*Cons*
Ground patrolling is more efficient	Alarm message might not be sent in time
Aerial patrolling can detect much larger areas	Aerial patrolling is very expensive and cannot keep flying all day long
	They require a sufficient number of individual sightings

2.4 Satellite-based bushfire monitoring system

A recent report (Li et al., 2005) indicates that systems based on space technology can efficiently monitor bushfire because they can locate fire quickly and precisely, in addition to providing extra information, such as temperature. Most of these systems mainly depend on satellites, which include remote sensing technology such as infrared technology (The Institution of Engineers Australia – Victoria, 1998). Thus, they are called satellite-based bushfire monitoring systems. Usually, such system consists of two components, satellite and communication network. Their operation process is portrayed as follows (United Nations DRO/22/76 Division, 1986). A satellite will monitor ground from space through embedded sensor network, if bushfire is detected, the satellite will activate bushfire warning sirens. Then, warning messages will travel outwards via communication network, for instance, satellite-computer linkages, ground receiver station, aircraft receiver station, and sea receiver station. Finally, warning messages will be sent to an official department. The characteristics of satellite-based bushfire system are listed in the Table 7.

Table 7 Characteristics of satellite-based monitoring system

Monitoring channel	*Communication medium*	*Communication technology*
Satellite with sensor network	Communication network	Satellite-computer link ages
		Ground receiver station
		Aircraft receiver station
		Sea receiver station

Due to these characteristics, satellite-based bushfire monitoring system has some merits and shortcomings, these are summarised in Table 8.

Table 8 Pros and cons of satellite-based bushfire monitoring system

Pros	*Cons*
Can send warning message in time	Complicated system structure
Improve reliability of warning message	Complex construction
Provide detail information of bushfire	High establishment cost
Provide accurate information of bushfire	High maintenance fees

3 Gap statement

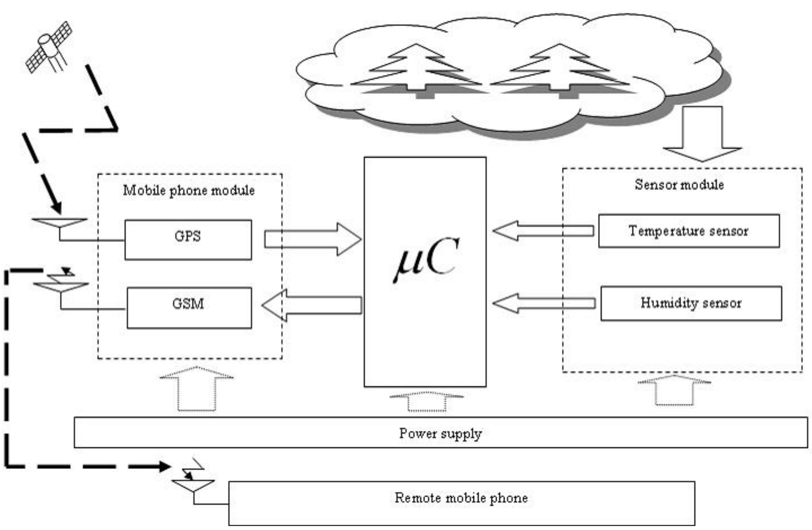
As we can see from the above review, existing bushfire monitoring systems have unique shortcomings. The word-of-mouth bushfire monitoring system and fire watch-towers bushfire monitoring system are not reliable, while ground and aerial patrol bushfire monitoring system are costly to build and maintain. However, they have a high efficiency in detecting and reporting a bushfire. As the need for efficiency and accuracy is increasing, the monitoring system becomes more complicated and more difficult to implement. In addition, as the cost for building such a bushfire monitoring system is increasing, we are proposing the development of a new low cost device that is based on off-the-shelf components and requires low maintenance and cost when compared with ground and aerial patrol bushfire monitoring systems.

Therefore, this paper addresses these needs by the development of a high efficiency, low cost, and easy to built bushfire monitoring system. This bushfire monitoring system can effectively detect bushfire, and send warning information precisely in time.

4 Device architecture

The block diagram of the proposed device is depicted in Figure 1. In this diagram, the microcontroller is used as a control centre that interfaces with a sensor module and a mobile phone module. The humidity and temperature data detected by sensors are collected by the microcontroller regularly. If the input data exceeds a predefined threshold, the microcontroller reads the location information from the global positioning system (GPS) receiver and controls the GSM modem. The collected information in terms of humidity, temperature and location are sent in SMS format to another mobile phone or SMS server. The used microcontroller is PIC16F877A (Microchip Technology Inc, 2003), which has a number of interfaces and flash memory.

Figure 1 System block diagram



The sensor used in this device is a single chip multi-sensor SHT75 (The Sensirion Company, 2004). The sensor can measure both the relative humidity and temperature with high accuracy and wide measurement ranges that meet the system requirements. The used mobile phone module has a combined GSM modem and GPS receiver. The GPS receiver is utilised to obtain the location information and the GSM modem for transferring temperature, humidity and location information to the remote mobile phone in SMS format.

Because the microcontroller has only one inbuilt universal synchronous-asynchronous receiver/transmitter (USART) interface, and there is a need to interface with the mobile phone module that requires two separate USART interfaces, one for the GSM modem, while the second for the GPS module, with a multiplexer was built using tri-stat buffer to select between them. A remote mobile phone or an SMS server is used to receive SMS, which contains the temperature, humidity and location information for further action or processing.

5 Algorithm description

As mentioned earlier, the proposed device is capable of collecting environmental and GPS information from both sensors and GPS module, and sends them in a SMS format through GSM modem. Therefore, the device combined algorithm and software can be divided into four parts: main program, sensor routine, GSM routine, and GPS routine.

- The ‘main program’ is very important in the software because it is the backbone program and determines what should be done and when. Therefore, the main program will affect the system performance and decide whether the expected system functions can be achieved. The flowchart that describes the operation of main program is shown in Figure 2.
- The ‘sensor routine’ controls the needed communication between the microcontroller and temperature and humidity sensors, which has a serial interface. However, this interface is not compatible with any of the inbuilt interfaces in the microcontroller, so this routine provides a software method to accomplish the data communication between microcontroller and sensors. According to the sensors manual (The Sensirion Company, 2004), the communication process can be described as follows:
    1. issue ‘transmission start’ sequence
    2. set measurement resolution as 8-bit, 12-bit or 14-bit
    3. send measurement start command to measure temperature or relative humidity
    4. wait 11 ms, 55 ms, or 210 ms for 8-bit, 12-bit, or 14-bit resolution, respectively
    5. detect measurement completion signal from sensors, and prepare to receive data
    6. receive data starting from most significant bit (MSB) to least significant bit (LSB)
    7. issue communication completion signal to terminate data transmission.

The flowchart of sensor routine is shown in Figure 3.

Figure 2 Main program flowchart

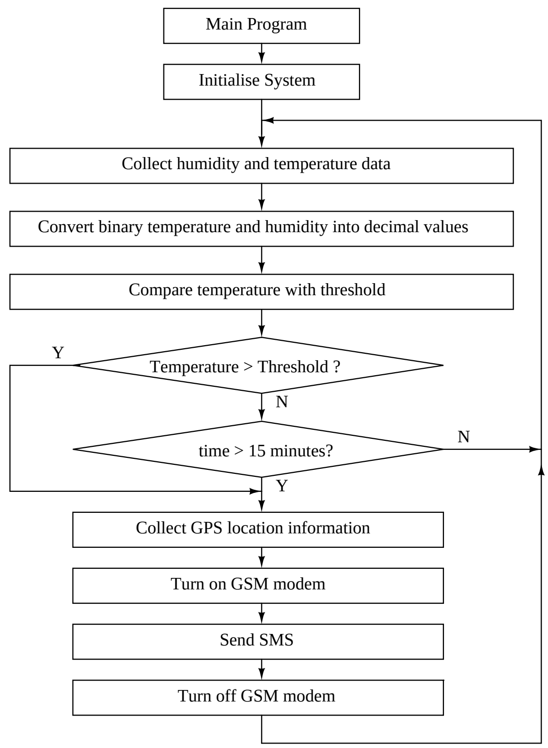
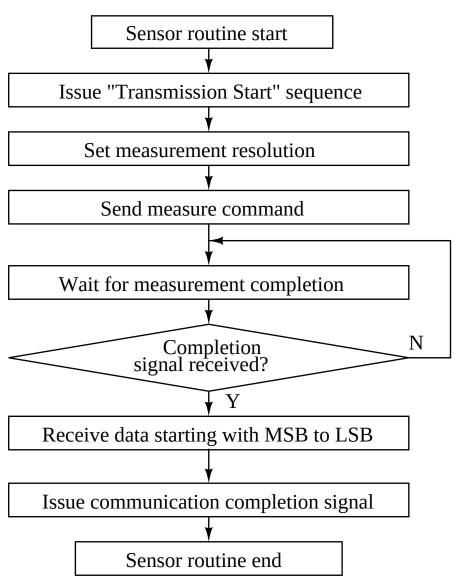


Figure 3 Sensors routine flowchart



- The ‘GSM routine’ is responsible for controlling the GSM modem to send SMS. In order to control the GSM modem with the microcontroller, AT commands should be sent from microcontroller to the GSM modem. These commands can be used to control the dialling function, SMS function, and GSM modem switching OFF. According to the FALCOM Manual (FALCOM Company, 2005) the syntax of AT commands for sending SMS and GSM modem turn OFF are shown in Table 9.

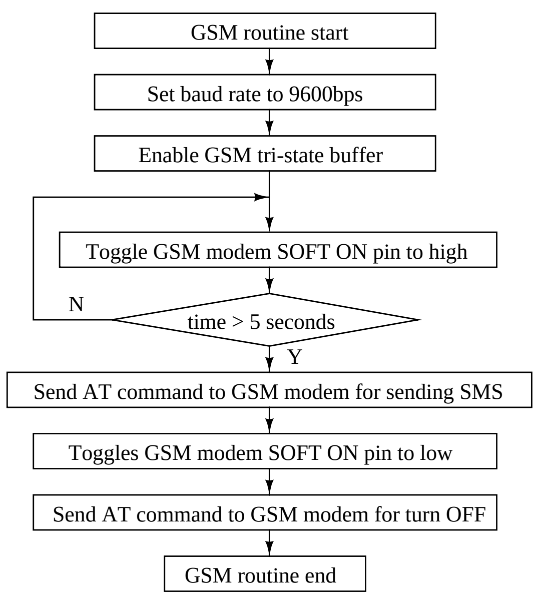
Table 9 AT commands for sending SMS and GSM modem turn OFF

Option	*Command*	*Syntax*
Send SMS	`+CMGS`	`AT+CMGS={Mobile Phone Number} <CR>} {SMS Contents} Ctlr-Z`
GSM modem turn off	`+CFUN`	`AT+CFUN=0 <CR>`

Source: From FALCOM Company (2005)

So, to control the GSM modem from the microcontroller, each character of AT commands is represented by ASCII codes. Therefore, in order to correctly send the needed AT commands, 90 microcontroller RAM words are defined as GSM data buffer to combine the ASCII codes before sending them to the GSM modem. Moreover, the GSM routine was used to control the turn ON of the GSM modem to send the SMS, and turn it OFF after the message has been sent, this was achieved through controlling SOFT ON pin provided by mobile phone module. The method described in the FALCOM Manual (FALCOM Company, 2005) to turn ON the GSM module is to set the SOFT-ON pin high for five seconds, while the turn OFF can be accomplished by pulling SOFT-ON pin low and sending the GSM modem turn OFF and AT commands. The flowchart of the GSM routine is given in Figure 4.

Figure 4 GSM routine flowchart



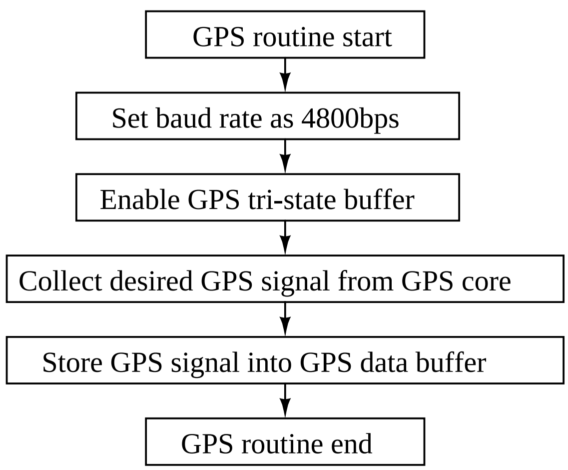
- The 'GPS routine' aims at obtaining the location information from the GPS module. It is necessary to understand the output message format of the GPS core. The GPS module part of C2D-SI is capable of providing data in the NMEA-0183 protocol. The baud rate supported by NMEA-0183 is 4800 bps, and all messages of NMEA-0183 are ASCII codes. Each message begins with a dollar sign ($) and ends with a carriage return and a linefeed (<CR><LF>) A brief description of NEMA-0183 output messages is listed in Table 10 (FALCOM Company, 2005).

Table 10 NMEA-0183 output messages

Option	*Description*
GPGGA	Time, position and fix type data
GPGLL	Latitude, longitude, universal time clock (UTC) time of position fix and status
GPGSA	GPS receiver operating mode, satellites used in the position solution and dilution-of-precision (DOP) values
GPGSV	The number of GPS satellites in view satellite identification numbers, elevation azimuth and the signal-to-noise ratio (SNR) of the receiver signal
GPMSS	SNR, signal strength, frequency and bite rate from a radio-beacon receiver
GPRMC	Time, date, position, course and speed data

Source: FALCOM Company (2005)

Figure 5 GPS routine flowchart



In the proposed device, we have elected to use GPGLL keyword because it provides latitude and longitude information. The process for collecting GSP information is as follows:

1 obtain each message by polling ASCII codes that start with a dollar sign and ends with a carriage return

2 obtain the desired signal by polling ASCII codes of GPGLL keyword

3 repeat collection of GPS information until the GPGLL data sequence is obtained.

During the operation of the GPS routine, USART baud rate should be set to 4800 bps and the tri-state buffer for the GPS should be enabled. The data received from GPS module are stored in the GPS data buffer, which consists of 90 microcontroller RAM words, then sent after that. The flowchart of GSP routine is shown in Figure 5.

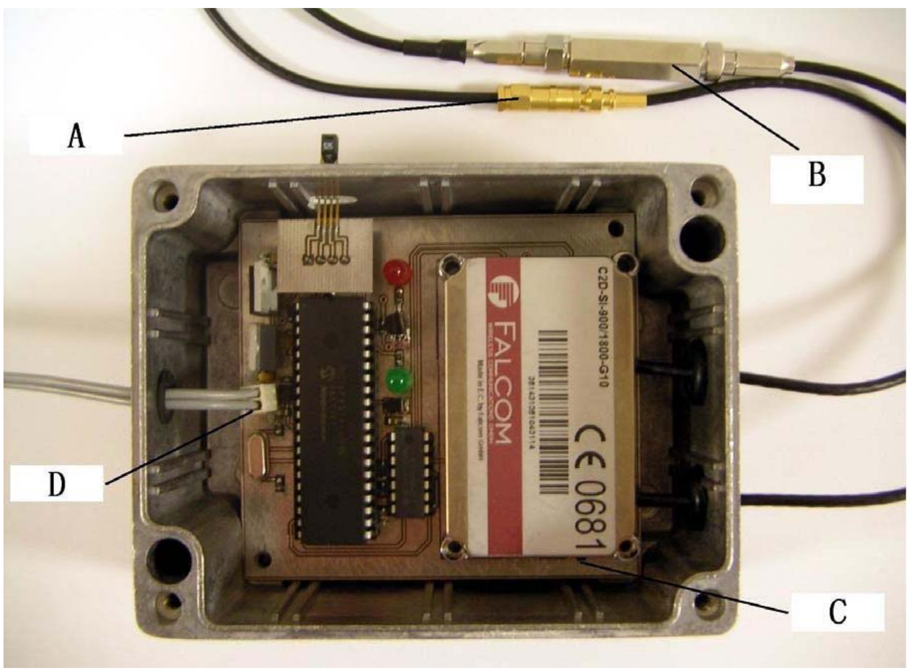
6 Overall device performance

In the following subsections a description of the interface, specifications and operation are discussed.

6.1 Interface specifications

The final device is shown in Figure 6. The dimension of the device is 90 mm × 115 mm × 55 mm. The interface specifications are listed in Table 11. This bushfire monitoring device is able to send relative humidity, temperature, and location information to the remote mobile phone.

Figure 6 Final bushfire monitoring device (see online version for colours)



Notes: Labels A, B and D refers to GSM, GPS and sensors connectors, respectively, while C refers to the combined GPS/GSM module.

Table 11 Interface specifications

Option	*Description*
Interface A	GPS 50 Ohm, MCX male
Interface B	GSM 50 Ohm, SMA-FME
Interface C	SIM card reader
Interface D	Power supply (7–17 Volts)

Source: FALCOM Company (2005)

6.2 Operation process of the product

The SMS format includes the following information: device identification – ID, temperature, relative humidity, and GPS location information. A message will be sent to the remote mobile phone/SMS server around two minutes after the module is powered ON. Then, the GSM module is switched OFF after ten seconds. After that, the microcontroller will keep scanning the received humidity and temperature data from the sensors, once the microcontroller detects that collected data exceed a predefined threshold it will enable the communication with GPS receiver to record the location information and combines it with the collected sensory information to construct the SMS message. The GSM module will be switched ON, and send the collected information. In case of no fire, the sensory information are collected every 15 minutes and sent to another mobile phone or an SMS server, however, in case of bushfire this information will be collected every two minutes. An example of the message format is shown below.

```
#ID:9999999;
TEM:011C;
HUM:075%RH;
GPGLL,3455.1035,S,13836.3379,E,050848.046,A*2B
```

All messages are ASCII codes. Each message begins with a hash (`#`) and ends with a carriage return and a linefeed (`<CR><LF>`) Following the hash is the device identification number – ID number, temperature, relative humidity, and GPS location information. Extra information can be added by assigning it unique keywords, and end it with a semicolon and linefeed. A brief description of keywords in the output message is listed in Table 12.

Table 12 Description of keywords in the output message

Option	*Description*
`ID`	Identification number. The system allows the identification of millions of devices
`TEM`	Temperature with the unit of degrees centigrade
`HUM`	Relative humidity
`GPGLL`	GPS signal format including latitude and longitude. It is compatible with NMEA-0183 GPS output messages

6.3 Power consumption issue

The sources of power consumption are: the microcontroller, humidity and temperature sensor, mobile phone module and tri-state quad buffer. The significant amount of this power is consumed by the microcontroller as this component stays ON all the time. Further minimisation of this power can be achieved by utilising the sleep mode in these microcontrollers or through using a much low power microcontroller device. In this device, the total power dissipation when sending an SMS is 1.9 Watts, while when the GSM is OFF, the power drops to 1.1 Watt. As the GSM module will be turned ON for a short period every 15 minutes, in no-bushfire mode, the average power consumption will be low.

6.4 The benefits of the proposed bushfire monitoring device

The benefits of this bushfire monitoring device are:

- *Low cost:* The cost for building this module is less than AU$500. The only major cost component is the combined GPS and GSM module that are used to send the sensory and location information. In this example, we have set the frequency of data collection to 15 minutes, however such period can be adjusted to reduce the maintenance cost and the device power consumption.
- *Wide usage:* This bushfire monitoring system can be implemented in any place where exist a coverage of a GSM network which is where we usually have lives and properties that need protection.
- *Easy exchange of information:* The alarm message is transmitted to the mobile phone or a SMS server, hence a fully automated process with no people involved.
- *High efficiency:* It only takes several seconds to switch on the GSM module and send a SMS.
- *It can be easily built:* The proposed bushfire monitoring and detection system uses using off-the-shelf components such a microcontroller (PIC16F877A), a three-state buffer, a GSM module and a humidity and temperature sensors. Hence easily built at a reduced cost.

A comparison between the different bushfire monitoring systems and the proposed system is given in Table 13. The table shows that the proposed system allows for better communication of the warning messages with less errors as it does not rely on human being. Also, the proposed system can operate independently and self sustained in terms of needed energy and can operate for a number of days using energy collected using its solar panel. Furthermore, the system is a low cost and requires low running cost as the amount of data communicated in the proposed system is very small. Leading to high efficiency and more accurate exchange of information. The only limitation is that the proposed system requires the availability of mobile phone coverage, in such case, satellite mobile phone can be used. However, such approach will dramatically increase the cost of such system.

Table 13 A comparison between different bushfire monitoring systems and the proposed system in this paper

	World-of-mouth	*Fire watch tower*	*Ground and aerial patrol*	*Satellite-based system*	*Proposed system*
Monitoring channel	Human being	Fire watch towers and observers	Patrol man aircraft	Satellite with sensor network	Remote monitoring system
Communication medium	Human communication chain	Human being (Observers)	Human being (Observers) Fire watch tower	Communication network	GPRS communication network
Communication technology	Telephone Telegraph Radio Fax	Telephone Telegraph Radio Fax	Telephone Radio	Satellite-computer linkages Ground receiver station Aircraft receiver station Sea receiver station	Mobile phone GPRS modem
Pros	Easy to develop Does not require maintenance	Early detection Good visibility	Ground patrolling is more efficient Aerial patrolling can detect much larger areas	Can send warning message in time Improved reliability of warning message Accurate and detail information on bushfire	Low power dissipation Low cost Accurate easy exchange of information High efficiency Fully automated and low maintenance
Cons	Can result in an inaccurate alarm message Alarm message might not be sent in time Possibility of missing the alarm message Detail information such as location, temperature cannot be announced precisely and punctually.	High cost Limited range (~18km) Can result in an inaccurate alarm message Possibility of missing the alarm message Only azimuth angle is sent Time is need to determining the place of fire	Alarm message might not be sent in time Very expensive and limited to part of the day A sufficient number of individual sightings is required	Complicated system structure Very high cost High maintenance fees Bushfire has to be large enough to be detected	GSM network coverage is essential for this system Limited to place within a GSM network

7 Conclusions

In this paper, a low-cost, high-efficient bushfire monitoring device was presented. The proposed device consists of a microcontroller, mobile phone module, humidity and temperature sensors and a tri-state buffer. The monitoring information is sent to a remote mobile phone or SMS server. The device is flexible enough to allow the integration of other sensory information. In the presented device, we have used SMS, however, as we already have general packet radio service (GPRS) module integrated with the GPS and the GSM modules, it is possible to send collected sensory information through this protocol, resulting in further reduction in the maintenance cost. On the low power side, the overall power of the device can be further reduced by using a low power microcontroller in addition to a low power GPS/GSM module.

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