



ENGN2225 SYSTEMS DESIGN

Early Bushfire Detection System

Author

Yanny Xiaoyan Li

U5351844

Abstract

This report documents the systems engineering design process used to improve the current bushfire monitoring and detection systems by providing a more comprehensive and focused approach in data acquisition. The proposed solution exploits available mapping technologies and utilise a multiSPEC 4C sensor to detect hotspots, combined with senseFly's operating software. The final design also have applications to other areas of emergency response or disaster preparedness.

1 Background

Bushfires are common throughout Australia, resulting in significant economic, ecological and social costs each year to lives, infrastructure, ecosystems and property. Every year in Australia, economic damage associated with bushfire is estimated at \$337 million (NSW Government 2015a). The earlier the outbreak of a fire is detected, the size of the fire will be smaller when the initial attack response arrives, and consequently the greater the potential for the initial attack to be successful (Matthews et al. 2010). Therefore, an early detection of bushfire is critical to the success of subsequent actions to suppress them.

The client, NSW Rural Fire Service (NSW RFS) is a volunteer fire service that provides fire and emergency services to approximately 95 percent of NSW rural regions. The service spreads across NSW with a total of 48 rural fire districts or zones. The Fire Control Centres are the administrative and operational bases of coordination and management of local brigade responses to fire and other incidents. (NSW Government 2015a)

In order to improve the current bushfire detection system, many system approach tools are used as a method to understand the system as a whole. This portfolio investigates the most commonly used bushfire detection systems and recommends concepts to better align the early detection system to the needs of rural fire agencies in Australia.

1.1 Overview of Current Technologies

Existing bushfire detection systems rely on the use of fire towers, detection aircrafts and satellites, but they all have various shortcomings. Fire tower is the most commonly used detection system to gather weather information and assess bushfire condition. These towers are strategically located around the regions and require trained fire observers to scan the horizon for the first signs of fire (Bennett 2014). During bushfire season, fire towers require large number of human observers. Detection aircrafts, often known as spotter aircrafts, utilise infrared line scan or forward-looking infra-red (FLIR) instead of human observation (Matthews et al. 2010). Each aircraft has a unique and regular interval to detect smoke and communicate the message back to local fire control office. However, operation of spotter aircraft is often restricted due to controlled airspace and severe weather conditions. Satellites are also commonly used to detect hotspots in remote regions where the department manages millions of hectares of land. The satellite-based hotspots detection and mapping system in Australia is called Sentinel. Depends on the availability of satellites, hotspots information is able to update up to 4 times a day (Siqueira et al. 2014). Images were analysed by Geoscience Australia scientist to produce first maps showing the actual areas burnt, which will be used by managers in Fire Control Centres. Like most satellite-based systems, images captured by Sentinel has relatively low-resolution, which significantly limited the reliability of the system.

2 Evaluation of current systems

To improve the current bushfire detection systems, it is important to identify and emphasise the performance limitations of the current systems, and gain visibility at the early stage before the design configuration is generated. This would ensure the final concept addresses the main issues and leverages the best practices in the existing systems (Leonard 2001).

An evaluation matrix is used to evaluate the performance of current bushfire detection systems against a number of prioritised client requirement benchmarks. As shown in the Table 1, the satellite-based system out-performed the other two

systems due to its characteristics of minimal manpower and low on-going (maintenance) cost. Information collection and condition assessment in a satellite-based detection system are carried out automatically by computers. Therefore, satellite-based systems are more efficient and reliable than fire towers and detection aircrafts. Since detection aircrafts require fuel consumption and frequent maintenance, it has the highest on-going (maintenance and operation) cost. Maintenance cost of the satellites is covered by the Commonwealth government, and therefore very low on-going cost associated with the use of the system by any rural fire services in Australia (Siqueira 2014). Due to the fact that Sentinel is a national bushfire monitoring system that provides information about hotspots and is freely available to all emergency services in Australia including NSW RFS, the design configuration will focus on improving the performance of the Sentinel bushfire detection system. Some limitations of the Sentinel system will be addressed. Despite hotspots only updates up to 4 times each day, their location on any map (no matter how detailed) is only accurate to at best 1.5km (Siqueira 2014). In the light of these inefficiencies, a systems engineering approach is needed to reduce the gap in the flow of information and error in fire detection.

Table 1. Evaluation matrix, with some of the data provided by Matthew et al. 2010.

	Weight	TPM	Benchmark	Fire Towers	Detection Aircrafts	Satellites
Accurate fire detection	1	%	> 60%	~ 100 %	~ 100 %	~ 90 %
Accurate fire locations	2	km	≤ 2 km	~ 0.1 – 0.5 km	≤ 0.1 km	~ 1.5 km
Update frequency	3	Times/day	≥ 1	Continuous	≤ 5	4
Detection time	4	Minutes	≤ 200 mins	≤ 30 mins	≤ 30 mins	Almost instantly
Low manpower	5	Staff number	≤ 3	≥ 10	≥ 2	1-2
Low cost	6	On-going cost	≤ \$500/mth	≤ \$500 / mth	≥ \$500 / mth	~ \$ 0 / mth

3 Subsystems

3.1 Subsystems

Subsystem integration as the part of the systems engineering process that defines the system architecture, is used to understand the operation of Sentinel bushfire detection system as a whole and to identify where a subsystem could be altered or a new subsystem could be integrated. Methods used to define the system architecture are called the “functional allocation” and “subsystem interface”. The former utilises a top down tree diagram that partitions the system into subsystems. The later builds on this by using a subsystem interface diagram in which the interactions between selected subsystems are represented. (Leonard 2001)

3.2 Functional Allocation

The subsystem tree of the Sentinel bushfire monitoring system can be found in Fig. 1. Sentinel is a complex system, at this stage only the general architecture of the system is interested, and so the classification of the subsystems are kept general. For example, telemetry data is processed and analysed by several different facilities within Australia using various methods (Siqueira 2014). It is not known what procedures and techniques are involved in obtaining hotspot information from telemetry data, and therefore not included in the subsystem tree of Sentinel system. It is shown that the system can be decomposed into five subsystems, including Telemetry System, Database System, Data Processing System, Interface

System and Power system. As Interface System and Power System responsible for information exchange, and power supply and regulation respectively, these two subsystems will have limited correlation with the design concepts. The utilisation of a subsystem interface diagram that shows the interactions between selected subsystems will further develop the design configuration.

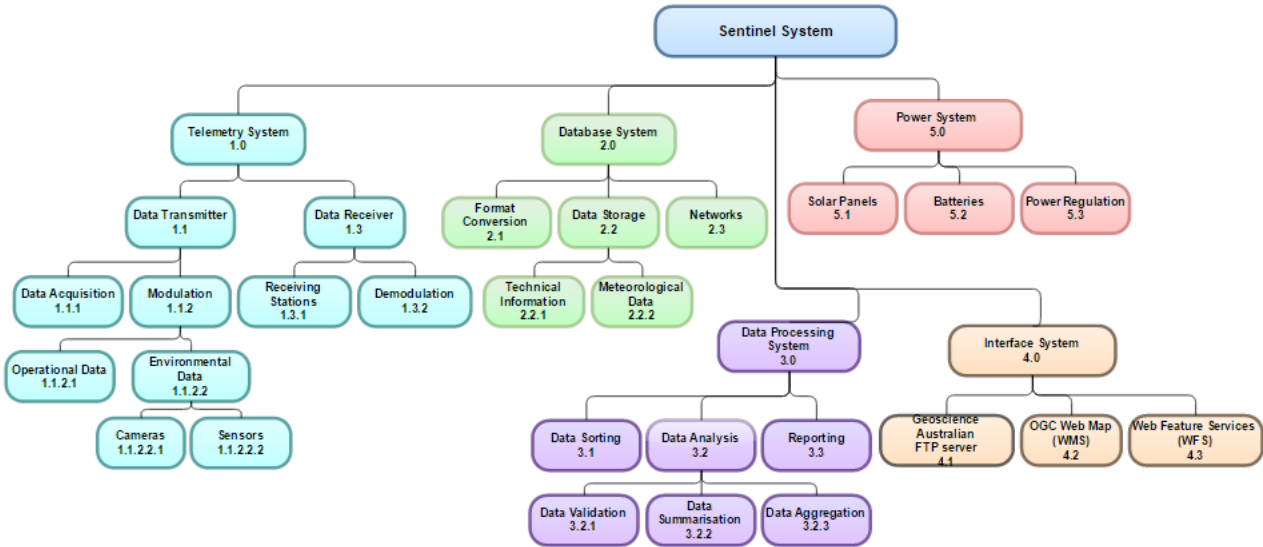


Figure 1: Subsystem tree of Sentinel System.

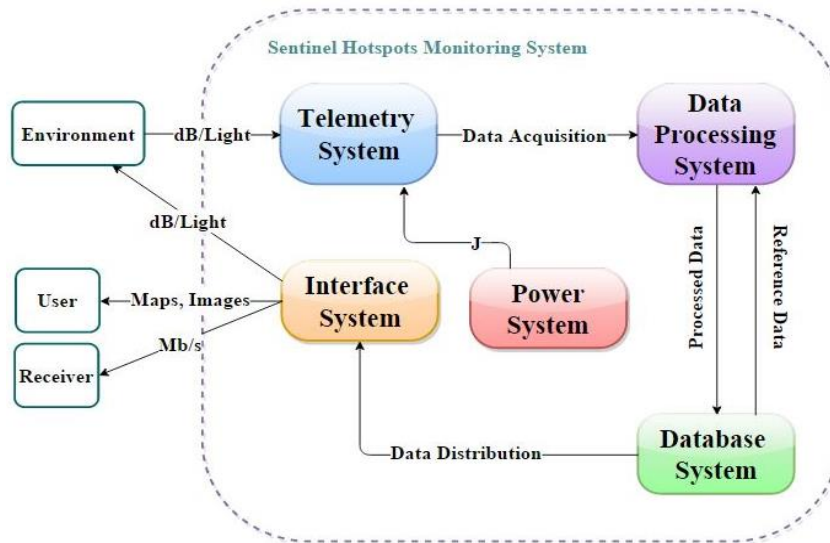


Figure 2: System interface diagram for the proposed Sentinel system.

3.2 Subsystem Interface

The subsystem interface diagram shown in Fig. 2 highlights some important structural aspects of the system. Note that subsystems within the system boundary were carefully chosen such that they each contain elements that are necessary for the system to perform its function. It is shown that the Data Processing System requires data from the Telemetry System and the Database System for data analysis and hotspots visualisation. There is a loop of information flow between the

Database System and the Data Processing System, and therefore it is essential for the Telemetry system to conduct accurate and reliable data capturing at the beginning of information flow in the system. Satellites collect image data with relatively low resolution and often influenced by thick cloud and smoke. Therefore, a more comprehensive and focused approach is needed in data capturing as it forms the basis for data analysis and data visualisation in the system. Since Sentinel is a well-established system, a new system will be introduced as part of its Telemetry subsystem. This could limit potential changes to the current system operation while provide more layered and refined datasets for NSW RFS to be more proactive in fire responses. Also, if the design fails or need upgrading, it can be replaced or maintained while the satellites continuing to satisfy requirements with relative ease.

4 Project Scope and Requirements

4.1 Problem Scope

An important stage of the design process is the problem definition. Its primary purpose is to refine customer objectives and requirements, and translate them to functional and performance requirements and design constraints (Leonard 2001). A coherent description of requirements will be used to provide the basis for research and decision throughout the process, and guide the design activity that follows. The requirements established will also be used to verify the effectiveness of the final conceptual design generated. Therefore it is essential to investigate the requirements in detail and categorise them appropriately. As the design has an objective of improving data acquisition of the Sentinel system by providing a more detailed and focused approach in data capturing, the system would be considered successful if it satisfies the following requirements:

1. The design should operate automatically (i.e. minimal manpower).
2. Integrates with the Sentinel hotspots monitoring system without hindering its operation.
3. The system needs to generate maps/images with resolution of less than 30 metres (Sentinel provides images at 30-250 m resolution).
4. Hotspots information updates more than 4 times each day (Sentinel information updates maximum 4 times/day).
5. The cost of the design should be a maximum of \$250,000, which is the funding jointly provided by the NSW and Commonwealth Government through the State Emergency Management Projects (SEMP) (NSW Government 2015b).
6. Datasets should consist of geographic positions and size of hotspots/fire.
7. The system is durable and can be used in various weather conditions.
8. The system can be used to analyse fire front and predict how a bushfire would spread.

Scope and boundaries of the system are defined through the use of a system boundary chart (Table 2). The 'system' now refers to the new system that provides layered and detailed datasets. The endogenous variables contain primarily the internal components of the system necessary to perform its function. These internal components of the system can be controlled and designed to meet the customer requirements. The exogenous elements in the system are external inputs into the system that directly affect the functionality of the system. For instance, environmental factors such as visibility, ambient temperature and weather conditions can potentially influence the functionality of the system, making it difficult to gather complete datasets. The excluded variables are considered to be beyond the scope of the system and are not considered in the design process.

Table 2: System Boundary Chart

Endogenous	Exogenous	Excluded
<ul style="list-style-type: none"> • Data acquisition • Power requirement and usage • Operating system • Weather/temperature resistance • Communication method 	<ul style="list-style-type: none"> • Visibility • Ambient temperature • Weather • Compatibility with other devices • User • Receiver • Pre-installed database 	<ul style="list-style-type: none"> • Unforeseen/unpredictable events that may affect the usability of the system

There are several trade-offs between the endogenous variables that need to be addressed in order to meet the customer requirements. Internal variables including data acquisition, operating system and power requirement contain design constraints that may potentially compromise the system performance. Detailed datasets are needed for the generation of high-resolution maps and images, which determined the accuracy of hotspots detection. Acquisition of comprehensive data often require use of sophisticated sensors. This could potentially raising the production costs and decrease the economic feasibility of the system, it must therefore be considered what is an acceptable price corresponding to what level of functionality. There is a potential trade-off between operating system and power consumption. For the operating system to process hugely complex datasets in a timely manner could drastically increase power consumption and potentially reduce reliability of the system. Failure to address these concerns could lessen the likelihood of achieving a satisfactory final design.

4.2 Requirement Analysis

The design requirements can be further decomposed into quantifiable attributes known as the technical performance measures (TPMs), which are used to measure relevant performance of the system. For each TPM, the direction of improvement of the metric value is indicated to be either increase, decrease or optimised symbolised by “+”, “-” and “●” respectively. As presented in Table 3, the customer requirements are translated into meaningful design requirements and measurable TPMs.

Table 3: Customer requirements to design requirements and TPMs.

Customer Requirements	ID	Design Requirements	Technical Performance Measures	Metric
Functional	DR01-01	High-resolution images and maps	+ Resolution	m
	DR01-02	Accurate geographic position of hotspots	- Errors in detection	%
Cost	DR02-01	Low initial upfront cost	- Manufacturing cost	\$AUD
	DR02-02	Low ongoing cost	- Maintenance cost	\$AUD/month
Durable	DR03-01	Weather resistance	● Life span	Years
Reliable	DR04-01	Battery Characteristics	+ Battery life	Hours
			+ Battery lifespan	Years
	DR04-02	More frequent updates	+ Update frequency	Times/day

Customer requirements are ranked through the use of a pairwise comparison chart (PCC), as shown in Table 4. Functionality, reliability, durability, low ongoing cost and low initial upfront cost are ranked by importance. Functionality ranked the highest because the primary purpose of the system is to acquire high-resolution image data and accurate information about hotspots. It is impossible for the system to meet the design objectives if it fails to fulfil the functional requirements. Reliability ranked second, suggesting a reliable system is needed to detect and report early outbreak of a fire for fire brigades to carry out effective and efficient responses. Reliability also refers to the quality of datasets collected, because it determines the preciseness of images and maps generation and hotspots extraction. The system will be exposed in outdoor environment for a long period of time, it needs to be capable of operating in various types of weather conditions, and therefore needs to be durable. NSW and Commonwealth Government provides a funding of \$250,000 through the State Emergency Management Project. At this stage of the design process, it is difficult to determine if the funding will be sufficient in manufacturing and implementing of the system. If it is not, then more efforts will needed to reduce costs associated with the system. Since the stages of designing a product using a systems engineering approach are constant and dynamic; ranking of customer requirements may change at a later stage, according to the actual conditions of the design process.

Table 4: Pairwise comparison chart

	Functionality	Low initial cost	Low ongoing cost	Durability	Reliability	Sum	Ranking
Functionality		1	1	1	1	4	1
Low initial cost	0		0	0	0	0	5
Low ongoing cost	0	1		0	0	1	4
Durability	0	1	1		0	2	3
Reliability	0	1	1	1		3	2

Table 5: House of Quality

9: Strong relationship
 3: Medium relationship
 1: Weak relationship
 +/-: positive/negative correlation
 : increase/decrease
 ●: optimise

Design Requirements		Client Requirements							
Ranking		High-resolution images	Accurate hotspots location	Low manufacturing cost	Low maintenance cost	Life span	Battery life	Battery lifespan	Update frequency
Functionality	1	9	9	3	3				9
Reliability	2	9	9	3	3		9	9	9
Durability	3			9		9	9		
Low ongoing cost	4				9	3			3
Low initial cost	5	9	1	9		1			
Direction of improvement		+	-	-	-	●	+	+	+
TPMs		m	%	\$AUD	\$AUD/month	Years	Hours	Years	Times/day

The strengths of relationships between customer requirements and design requirements are defined in the use of a House of Quality. Weak, moderate and strong correlations denoted by values of ‘1’, ‘3’ and ‘9’, respectively (Tapke et al. 1997). Through the use of a house of quality, influential requirements are identified and prioritised. These design requirements will also form the basis of decision making in the following process. As shown in Table 5, image resolution, accuracy of hotspots detection, update frequency and battery life are the most influential design requirements. Since these design requirements have strong relationships with important client requirements such as functionality, reliability and durability, they will be prioritised in the design process to ensure maximum number of client requirements are fulfilled. The ‘roof’ of the house shows the correlations and potential trade-offs between design requirements. There is a potential trade-off between update frequency and accuracy of hotspot detection. The system is likely to pick up more information about hotspots if it updates more frequently, and therefore increase the accuracy in hotspot location. However, this would increase power consumption and potentially reduce reliability of the system, which is ranked as the second most important client requirement in the pairwise comparison chart.

5 Logic and Function

5.1 Concept Generation

Three independent approaches are discovered through the use of a concept generation tree, shown in Fig. 3. There is a range of potential solutions to extend the advantages of the Sentinel system while reducing the gap in the flow of information and error in hotspot detection. From the Evaluation Matrix for current bushfire detection systems (Section 2 Table 1), minimal manpower and low maintenance cost are the two main advantages of the Sentinel system. In contrast with approach 2, approach 1 impaired these advantages. The quality of information collected by human is highly depended on skills and experience of the observer. In bushfire season, large number of human observers are needed to scan the horizon which is inefficient and costly. Therefore, approach 2 is the only suitable approach.

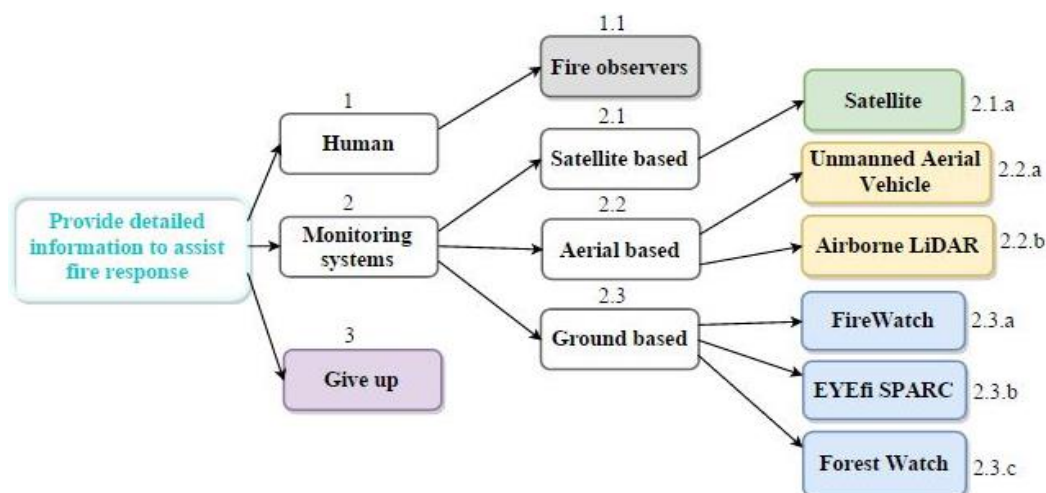


Figure 3: Concept generation tree

Following the branch of approach 2, the UAV remote sensing, Airborne LiDAR technology and EYefi SPARC are the most suitable solutions. As highlighted in the house of quality (Section 4.2 Table 5), imagery resolution is one of the prioritised design requirements. In system interface (Section 3.2), satellite-based systems are identified to have the

advantages of region-scale coverage, but often restricted by factors of cloud and image resolution. Imagery resolution provided by a satellite can be refined using sophisticated sensing technologies, which are expensive and difficult to install. Utilisation of other satellites is considered to be beyond the scope of NSW RFS's operation, and therefore not considered as an option in the design concepts. Ground based systems of FireWatch (2.3.a) and Forest Watch (2.3.c) are lack of flexibility as they require specified types of detection sensors to be mounted on a tower to scan the landscape (Matthews et al. 2010). Location of existing fire tower restricted where these detection sensors will be installed. Also, both FireWarch and Forest Watch require communication over telephone line or 3G networks. Networks and facilities in rural areas may not support such communication methods and therefore these two ground based systems are cost-prohibited and not feasible. EYEfi SPARC (2.3.b) allows detection sensors to be installed on mobile vehicles (i.e. aerial vehicles, emergency vehicles), which will increase mobility of the system. EYEfi's spatial video technology provides real time intelligence gathering and situation awareness which allow hotspots monitoring to be conducted automatically (EYEfi 2014). Small unmanned aerial vehicles (UAV) or drones have the advantages of collecting reliable data in severe weather conditions and are less restricted to controlled airspace. UAVs is a promising approach to provide remote sensing for bushfire detection and investigation. Crucial bushfire information can be collected by UAVs, which fire brigade can rely on to make response decisions. Airborne Light Detection and Ranging (LiDAR) is commonly used in mapping. It uses ultraviolet, visible or near infrared light to image objects, and therefore allows very detailed mapping of hotspots and fuel (i.e. grass, logs, forest litter on the ground) at a very high resolution (Albert et al. 2014).

5.2 Logical Flow and Functional Analysis

Higher-level functions that are necessary to achieve the system's objectives are identified and logically grouped through the use of a logical flow diagram. This diagram gives insight into what constrains will limit design flexibility. All feasible concepts generated are taken into consideration when arranging functions in a logical sequence. As seen in Fig. 4, functionality of the system considers the communication method of the detection devices with the fire control centre. Detection devices can either communicate wirelessly and directly with the control centre at real-time, or store in a memory drive first then transfer when external networks are available.

The top-level functions identified in logical flow diagram can be further decompose into simpler sub-functions through the use of a functional flow block diagram (FFBD). FFBD of the UVA concept is represented in Fig. 5. The diagram has highlighted three concerns: datasets (4.2), battery (2.1) and the problem of EYEfi SPARC not being able to provide hotspots GPS coordinates (4.1). A thermal sensor is needed for the system to collect information about hotspots. The current Sentinel system collects imagery measures in the visible and infrared bands of the electromagnetic spectrum. Near-infrared (NIR) sensors are sufficient in fire detection and fire progress projection (i.e. size and intensity of a fire), which will provide adequate information for brigades to predict fire behaviour. Sensor such as multiSPEC 4C by senseFly could be used. This sensor provides image data across four highly precise bands, including green, red, red-edge and NIR, with no spectral overlap. Green and NIR light reflects strongly off of vegetation, and have the ability to pinpoint position of forest fire. Also, multiSPEC 4C can automatically compensates for sunlight variations. This allows the UAVs to provide information about hotspots during both day and night without need to change filters or sensors. Therefore, the sensor can be mounted on an UAV with relative ease for bushfire detection (senseFly 2015).

Collection of complex and detailed datasets requires a longer time period and greater power consumption, which affect reliability (ranked 2nd in the pairwise analysis in Table 4) of the system. A common small UAV has an average flight time of 30 mins, due to its battery capacity. For the system to reduce the gap in flow of information and error in fire location, it needs to provide updates more than 4 times each day. A durable and robust UAV model, such as the MD4-1000 UAV model by Microdrones could be used. This model has an outstanding characteristic of long flying time. It can fly for up to 88 minutes, which is almost 3 times of the average flying time (Microdrones 2015). The UAV model is compatible with any types of sensor, and therefore the system can be customised to align the objectives of early bushfire detection. Since the time duration of each fly can be easily calculated after factors of altitude, route, speed and coverage are determined, detection intervals can be scheduled strategically such that the device can be charged between each fly.

EYefi SPARC provides images and video of potential fire, but requires external GPS receiver when it is attached to a moving vehicle. GPS (geographic) coordinates of fire location are needed to facilitate maps generation. To increase mobility of the system, sensors are often attached to moving vehicles such as aircrafts and cars. As highlighted in Section 5, EYefi SPARC is chosen as one of the suitable solutions because of its mobility. EYefi’s sensor does not have built in GPS equipment. Unless the sensor is fixed at a certain location, GPS receiver will need to purchase separately.

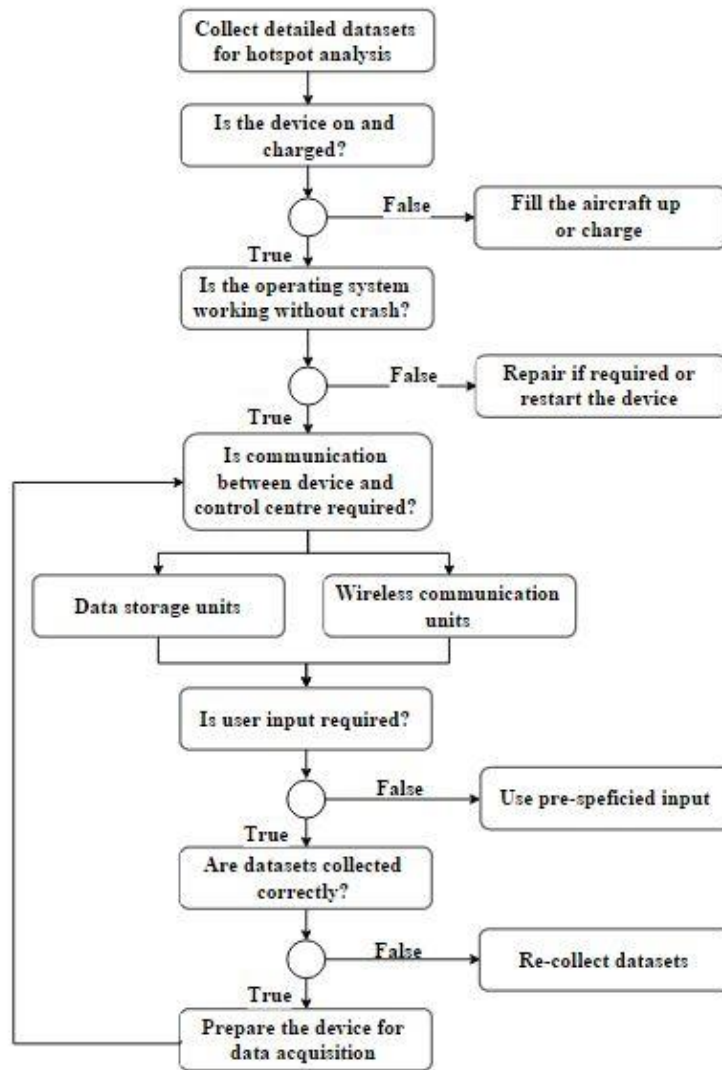


Figure 4: Logical flow diagram

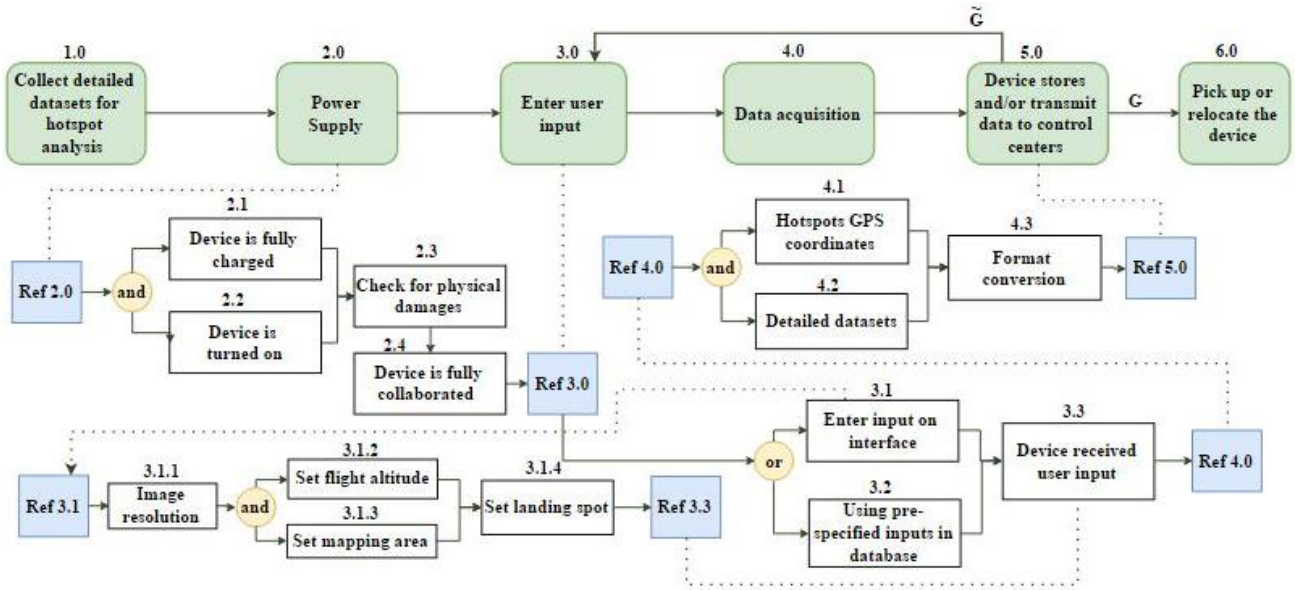


Figure 5: Functional flow block diagram (FFBD) for the UAV concept.

6 Testing and Life Cycle

6.1 Testing and Verification

Since a physical prototype of the system is not available, analytical models are used to provide theoretical analysis and prediction of system operation based on data derived from component testing of the system (Leonard 2001). The feasible solutions generated in concept generation tree (Section 5 Fig. 3) are (i) UAV; (ii) Airborne LiDAR and (iii) EYEfi SPARC. These concepts are tested against the benchmarks and their corresponding weighting as shown in Table 6. The benchmarks and weightings were originated from Section 4.1 and Section 4.2 where customer requirements, design requirements and current Sentinel performance were defined and analysed.

Table 6: Data and benchmarks of the feasible systems

Data	Benchmarks	Weighting	UAV	Airborne	EYEfi
Imagery resolution	< 30 m	5	< 5 m	0.15 – 0.2 m	100 m
Errors in hotspots location	< 10 %	5	0 %	0 %	11 %
Manufacturing cost	< \$AUD 250,000	1	\$1,000	\$41,608	\$75,218
Maintenance cost	< \$AUD 500	2	\$200/month	\$1,000/month	\$500/month
Life span	> 1 yr.	3	5 yr.	5 yr.	5 yr.
Battery life	≥ 30 mins	4	88 mins	> 30 mins	> 30 mins
Battery Lifespan	> 1 yr.	4	2 yr.	2 yr.	5 yr.
Update frequency	> 4 times/day	4	> 8 times/day	3 times/day	Continuous

Since the network installation cost is highly determined by geographical factors (i.e. current accessibility of networks) and potential technical difficulties (i.e. maturity technologies), all costs in Table 5 are in the unit of an individual sensor. These three systems are also assumed to be fully collaborated when testing. Imagery resolution needs to be less than 30m for fire location to be accurate to less than 1.5km. Since the devices are highly mobile, the benchmark of battery life is set to be greater than 30 minutes, which is an average operation duration of a detection aircraft. A lifespan of at least 1 year reduces maintenance costs and enhances reliability of the system. The manufacturing cost is set by the funding provided by the

government. Update frequency needs to be greater than 4 times a day to reduce gap in flow of information in the system. Since tests were not personally conducted, data in Table 5 could potentially be unreliable. However, the data is assumed to be relatively accurate of reflecting the general system characteristics.

6.1.1 Evaluation

Airborne LiDAR and EYEfi SPARC are eliminated through the use of a system elimination. As shown in Table 7, Airborne LiDAR provides extremely accurate and refined datasets. Due to the fact that all airborne systems are fix-wing mounted, the cost of fuel and aircraft pilot have highly increased the on-going (maintenance and operating) cost of the system. Since fixed-wing aircrafts are often restricted by controlled airspace and severe weather conditions, it is difficult and costly for it to operate more than 3 times each day. Therefore, update frequency of fire information by Airborne LiDAR is constrained. EYEfi SPARC is eliminated because the system is unreliable. The trial of EYEfi conducted in NSW by Bushfire Co-operative Research Centre and the CSIRO in 2010 has errors in fire location up to 18km and error in hotspot detection up to 11%. This system is severely limited and has little reliability in data acquisition. Since the UAV system is highly modular, it can be customised to meet all client requirements with relative low manufacturing cost. The md4-1000 UAV model has the ability to operate in severe weather conditions, therefore the operation of an UAV system can be carried out when needed and ensure more than 8 times fire information updates a day.

Table 7: System Elimination

Data	Benchmarks	Weighting	UAV	Airborne	EYEfi
Imagery resolution	< 30 m	5	< 5 m	0.15 – 0.2 m	100 m
Errors in hotspots location	< 10 %	5	0 %	0 %	11 %
Manufacturing cost	< \$AUD 250,000	1	\$1,000	\$41,608***	\$75,218**
Maintenance cost	< \$AUD 500	2	\$200/month	\$1,000/month	\$500/month
Life span	> 1 yr.	3	5 yr.	5 yr.	5 yr.
Battery life	≥ 30 mins	4	88 mins	> 30 mins	> 30 mins
Battery Lifespan	> 1 yr.	4	2 yr.	2 yr.	5 yr.
Update frequency	> 4 times/day	4	> 8 times/day	3 times/day	Continuous

Table 8: Weighted evaluation against alternatives. Compliance scale from 0 (low) to 5 (high).

Data	Benchmarks	Weighting	UAV		Airborne		EYEfi	
Imagery resolution	< 30 m	5	5	25	5	25	0	0
Errors in hotspots location	< 10 %	5	5	25	5	25	1	5
Manufacturing cost	< \$AUD 250,000	1	5	5	2	2	1	5
Maintenance cost	< \$AUD 500	2	4	8	0	0	0	0
Life span	> 1 yr.	3	5	15	5	15	5	15
Battery life	≥ 30 mins	4	5	20	5	20	5	20
Battery Lifespan	> 1 yr.	4	3	12	3	12	3	12
Update frequency	> 4 times/day	4	4	16	1	4	5	20
Total			126		103		77	

Table 9: Weighted evaluation with final design and Sentinel system. Compliance scale from 0 (low) to 5 (high).

Data	Benchmarks	Weighting	UAV		Sentinel	
Imagery resolution	< 30 m	5	5	25	0	0
Errors in hotspots location	< 10 %	5	5	25	2	10
Manufacturing cost	< \$AUD 250,000	1	5	5	2	2
Maintenance cost	< \$AUD 500	2	4	8	5	10
Life span	> 1 yr.	3	5	15	5	15
Battery life	≥ 30 mins	4	5	20	5	20
Battery Lifespan	> 1 yr.	4	3	12	5	20
Update frequency	> 4 times/day	4	4	16	3	12
Total			126		89	

By evaluating one concept against alternatives, instead of benchmarks, the UAV scored the highest mark, with the Airborne closely followed. A weighted evaluation, as shown in Table 8, is conducted to identify which solution leverages the best practices in the existing Sentinel system. Airborne LiDAR technology provides images and maps with resolution as high as 15cm. It is good to have precise maps and images, however the LiDAR technology provided far more features than needed. This could severely decrease the economic feasibility and efficiency of the system. Because UAVs are highly modular, datasets collected can easily generate images with resolution of 5m. That is, the imagery (and map) resolution in Sentinel system can be improved from 1.5km to 5m at 1/40 the cost of an Airborne LiDAR system. Once the UAV system performance is verified and validated, its network will expand to a larger scale and cover the whole NSW region. Multiple sensors will be needed and therefore it is important to select a system that can offer an appealing level of functionality at an affordable price.

A weighted evaluation is also conducted between the UAV system and the Sentinel hotspots monitoring system. The UAV system scored a higher mark than the Sentinel system because it provides better imagery resolution and more accurate fire location. Since the UAV system operates under the cloud, it can analyse and detect fires at a closer distance, which decreases the error in fire location. However, the UAV system have a shorter battery life and higher maintenance cost than the Sentinel system, which are the main trade-offs in the system.

It is important to take note that safety is not directly considered in the list of customer requirements, it will be factored into the design implementation. Although small UAV does not need a certificate of airworthiness (CofA), its operations, design specification, maintenance and training of human resources must satisfy the regulations of unmanned aircraft. Since the UAV system is only responsible for data acquisition, software at the station needs to facilitate mission planning and flying. Mission planning includes user interface and flight planning. The flight route and area covered can be planned and customised, and therefore potential conflicts of authority could be limited by ensuring the UAV system is operated within NSW regions. According to Civil Aviation Safety Authority Australia CASR Part 101, the system requires ability to conduct automated system checks, automated take-off and landing, fully automatic flight as well as manual flight. To ensure compatibility between the md4-1000 UAV model and the multiSPEC 4C sensor, senseFly’s software will be used. The senseFly software will provides base of ground control, allowing video and telemetric data to be received wirelessly. Therefore, the UAV system will has the ability to update hotspot information more frequently.

6.2 Life Cycle

The UAV remote sensing system life cycle is modelled by a waterfall diagram, as seen in Fig. 6. This model was chosen as its linearity of separate and distinct sequential stages is able to reflect the system life cycle specification and development of (1) implementation and testing, (2) use and maintenance and (3) end-of-life retirement (Munassar & Govardhan 2010). As the system phases that lead up to the UAV design are outlined comprehensively in the proceeding sections, chosen analysis covers life cycle after acquisition of the system. 1a to 3b refer to areas of discussion regarding life cycle impact or areas of improvement that are applicable to the proposed design.

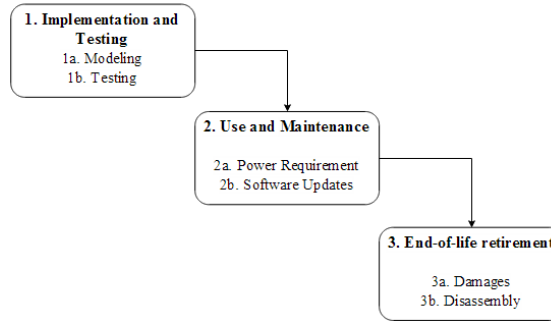


Figure 6: Waterfall model for UAV remote sensing system life cycle.

Implementation and Testing: life cycle impacts associated with implementation and testing are modelling and testing (1a and 1b). Implementation of the proposed design allows realisation of concept and examination of whether the specification captures the client requirements. Resource use for hardware can be reduced by introducing design modularity. In this case, the UAV system is highly modular and can be modified easily to align with design objectives. Its modularity characteristic reduces initial resource consumption as resources wasted in manufacturing unique components are saved. Since its component can be purchased, replaced and resold to standard market, the utility of the solution would also increase. The biggest challenge to expanding the use of UAVs is the concern of safety and liability. Although UAVs are getting safer thanks to parachutes, collision avoidance systems and fail-safe mechanism, many people are not familiar with the concept and concern about the reliability of the system (OCHA 2014). In case of mechanical failure, ultra-lightweight UAVs such as md4-1000 model which consist of a carbon fibre body will reduce the likelihood of causing injury or property damage. The proposed design needs to be fully verified and validated before put into practice. A trial period of 2 to 3 years could ensure the system operates safely and reliably, during which tests will be carried out.

Use and Maintenance: this phase comprises power requirements and software updates (2a and 2b). The chosen UAV model has a maximum flying time of 88 mins. For the solution to be more reliable and efficient (ranked 2nd and 3rd in the pairwise analysis in Table 4), charging stations need to be strategically placed to minimise vehicle stops during long distance travel. This would also allow first sign of fire to be reported quickly and maximal amount of land to be covered. Alternatively, wireless charging technology would a promising way to automatically prolong the battery life of sensor network applications by recharging the UAV’s battery. Rather than flying back to its starting position for battery charging, it can fly from one station to the next, where it can be recharged while transferring datasets collected to the closest control centre using networks provided. The charging stations can be designed using a system engineering approach. Software updates affect functionality of the system which ranked highest in the client requirements. Since software facilitates mission planning and flying, updates cannot be applied then the system is operating. However, software updates can be conducted during non-bushfire danger season, when the system is in lower demand.

End-of-life Retirement: End-of-life retirement phase considers damages and disassembly (3a and 3b). These decisions aim to minimise landfill waste and ecological footprint by creating a cradle to cradle process. As mentioned in modelling (1a), a modular design increases ease of replacing, reusing and disassembly of parts in case of damages or retirement. Solar energy is a promising resource to be used to power the charging stations, mentioned in power requirement (2a). Electricity generated using solar radiant light and heat is ecologically sustainable and environmentally friendly. To promote a cradle to cradle approach, the system should use devices from companies that employ recycling schemes. This would allow material to be recycled and reused in the technical cycle.

Ultimately, the UAV system will be customised so it fulfils desired requirements efficiently. The final design consists of a small unmanned aerial vehicle with a multiSPEC 4C sensor to collect detail image data with 5m resolution, automatically. One to two people is sufficient to operate the ground station consist of software system provided by senseFly. Image data collected can be used to generate high-resolution images in a timely manner, providing a basis for fire brigades to make fire response decisions. These image data can then deliver to Geoscience Australia data acquisition facility for further analysis along with telemetry data from the satellites. Sophisticated facility in Geoscience Australia produces maps showing the actual areas burnt, which can then be used by emergency managers. The UAV system not only improve the image data quality of the Sentinel system from 1.5km to 5m, frequent hotspot information update also improved the flow of information in the Sentinel system. The UAV system can also operate automatically. The md4-1000 UAV model is durable and can be used in various weather conditions. The fire control centre can analyse fire front and predict how a bushfire would spread by manually operating the UAV at a closer distance to the fire. The flight time of a fully charged UAV model is 88 minutes. If charging stations are placed strategically, vehicle stops during long distance travel can be minimised. This would also prolong the operation hours of the system, providing more updates of information about hotspots. Therefore, the outbreak of a fire can be detected earlier, which is critical to the success of subsequent actions to suppress them.

7 Summary

The final design consists of a small unmanned aerial vehicle with a multiSPEC 4C sensor and custom operating software. The small unmanned aerial vehicle that will be used for the design is the md4-1000 model by Microdrones. The software system will be provided by senseFly as the system is already well-established and compatible with the sensor and the unmanned aerial vehicle. Each small unmanned aerial vehicle will be customised to carry a multiSPEC 4C sensor which provides precise data and undistorted images for hotspots detection. This choice satisfied all customer requirements as seen in the design process documented in the preceding sections. As requested by the client, the proposed solution has the ability to integrate with the current Sentinel bushfire detection system, detect and report fire location, use in fire front investigation and provide fire progress projection. These would allow NSW RFS to be more proactive and efficient in fire responses.

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