Adaptive Engineering of an Embedded System, Engineered for use by Search and Rescue Canines

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ABSTRACT

In Urban Search and Rescue (US&R) operations, canine teams are deployed to find live patients, and save lives. US&R may benefit from increased levels of situational awareness, through information made available through the use of embedded systems attached to the dogs. One of these is the Canine Pose Estimation (CPE) system. There are many challenges faced with such embedded systems including the engineering of such devices for use in disaster environments. Durability and wireless connectivity in areas with materials that inhibit wireless communications, the safety of the dog wearing the devices, and form factor must be accommodated. All of these factors must be weighed without compromising the accuracy of the application and the timely delivery of its data. This paper discusses the adaptive engineering process and how each of the unique challenges of emergency response embedded systems can be defined and overcome through effective design methods.

Keywords: Embedded Systems, Adaptive Engineering, Adaptive Design Model, Requirements Engineering, Form Factor, Computational Public Safety and Canine Pose Estimation.

1. INTRODUCTION

Computational Public Safety (CPS) involves the application of computational resources, theory and practice in support of and improvement to public safety processes. The objective of this work was to develop a new capability ─ to acquire situational awareness in search operations through the determination of canine pose. The work can improve how Urban Search and Rescue (US&R) is conducted by utilizing technology to provide situational awareness to US&R canine handlers, supporting emergency first responders and search managers. A number of challenges exist in determining canine pose and communicating the relevant information back to the handler. These challenges are: 1) determining canine pose; 2) evaluating the accuracy of the canine pose estimate; 3) engineering the CPE device with the smallest form factor possible while compromising its function and 4) evaluating the network's competency to transmit the canine pose data in a timely manner to all interested parties.

US&R dogs are often used to find people trapped in rubble. Dogs are fast, agile and accurate, whereas a human handler is slow and may be left behind thus losing sight of the dog. The Canine Pose Estimation (CPE) system provides situational awareness in these situations by remotely determining a dog's body orientation (pose). The data is sent over a wireless mesh network (WMN) to a computer, where pose is determined.

2. BACKGROUND

2.1 Urban Search and Rescue

The fastest and most reliable means of finding people trapped after a building collapse is through the use of trained US&R dogs. These dogs are the state-of-the-art when conducting search operations within an urban disaster like those that occurred in Mexico [1], Kobe [2], Turkey [3] or New York [4]. Search operations necessarily occur before rescue can take place. Since there is a finite time that someone can survive entombed in rubble, it is critical that search operations occur as quickly and effectively as possible so that victims are found alive. Search operations have several challenges that increase the time it takes to find survivors (often called "patients") within the wreckage. A particular matter requiring improvement in the situational awareness [5-7] canine handlers have while conducting searches under certain conditions. Situations can arise where a handler is not aware of their dog's whereabouts or behaviour. This lack of awareness is generally due to the distance and obstacles between the handler and the dog. In the extreme, a handler may be asked to send his or her dog into the rubble of a building without the ability to actually follow, because human access may be precluded. If the handler's awareness of the dog's situation could be enhanced, search times could be reduced, improving the performance of the team, resulting in more lives saved.

A complementary area of research is the augmentation of US&R dogs [8-12] with technology that allows first responders to experience what is happening around the dog while it is searching. This area of research seeks to sense what is around the dog however, the handler still will not know what the dog is actually doing while out of sight. The orientation of the dog is very important for the handler to know as the dog's posture communicates a significant amount of information. Pose is important, because US&R dogs are trained to adopt different poses to indicate various conditions they experience. In a sense, they use pose as a language. A typical example of this is an US&R dog, which is cross-trained to search for cadavers. Under certain circumstances this dog assumes the *sitting* pose when it has found a cadaver. Another pose, *lying down*, indicates that the dog has stopped searching. In both cases the handler must know the dog has stopped and why.

Past research has been conducted on animals in terms of behavioural assessments [13]; however, not in terms of acting as instruments for providing situational awareness--needed for USAR operations. Handlers are limited in their ability to assist a searching dog in cases where their dog cannot be seen. At the moment there are no solutions that provide the canine handler with situational awareness regarding what the dog is actually doing when it cannot be seen and what orientation or "pose" it is in.

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USAR dogs are often used to find people trapped in rubble. Dogs are fast, agile and accurate, whereas a human handler is slow and may be left behind thus losing sight of the dog. The Canine Pose Estimation (CPE) system provides situational awareness in these situations by remotely determining a dog's body orientation or pose by collecting relevant data from sensors on the dog. The data is sent over a wireless mesh network (WMN) to a computer, where pose is determined.

2.2 Adaptive Engineering

The design of an embedded system requires many steps, including: deciding on a design model to follow, implementing each of the steps in the design process and working out the detailed design of the system. In the following sections each of these steps is discussed in greater detail.

Settling on a design model can affect the optimality of the final embedded system. Selecting a model can depend on weather the system is new or is being redesigned. For our purposes the CPE system prototype already exists and the proof of concept has been achieved. Our goal is to design an optimized device. The Adapting Design Model will be followed. This paper discusses the design process in section 3 and covers pertinent issues regarding form factor in section 4. Finally in section 5, conclusions are listed.

3. ADAPTIVE ENGINEERING

The adaptive design process includes the following steps: system specifications, requirement definition, functional design, detailed architectural design and finally implementation. All of the steps can be found in Figure 3.1 and are discussed in detail below.

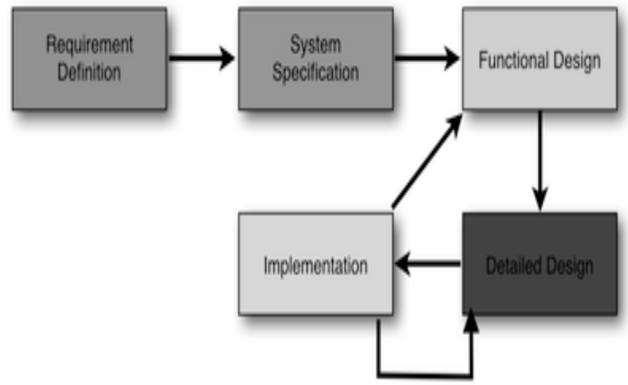

Figure 3.1 Adaptive Design Model

3.1 System Specification

The CPE device collects sensor data from the dog and then transmits that data in real time to the canine handler's human interface. The sensor data must be accurate and reliable in order for the CPE algorithm to predict the dog's pose. The current CPE device is equipped with two dual-axis accelerometers, which require that the acceleration readings to be converted into angles. This causes a significant delay in the system, as each sensor reading occurs multiple times per second.

Canine handlers are currently equipped with wireless enabled laptops, using Wi-Fi. The CPE device must also be Wi-Fi enabled in order to connect with the laptop and transmit the sensor data. It must be able to sustain its wireless connection within the arduous environment found in urban disasters. The device itself must be durable enough to withstand harsh impacts with surrounding debris, while the dog is traversing rubble. It must also be able to withstand the extremities of the environment, which includes: wind, rain, snow, and extreme temperatures—both hot and cold.

Two software applications are required, one for the CPE device to collect and transmit the sensor data and the other to reside on the laptop, performing all the necessary calculations to determine the canines pose and display this in real time.

3.2 Requirement Definition

The needs and conditions relating to the use and design of the CPE device fall under two categories, functional and non-functional requirements. The requirements are determined by assessing the different uses of the device by the different stakeholders. In section 3.2.1 the stakeholders are described and their role in the US&R system as it pertains to the use of the CPE device in operations. In section 3.2.2 the non-functional requirements are discussed, which include: durability, weatherproofing, form factor, mass, safety and cost.

3.2.1 Stakeholders: The stakeholders for this project include: US&R canines, canine handlers, rescue workers, Emergency Management Systems (EMS), and US&R managers. The canines will be equipped with the CPE device. The canine handlers will use the CPE device to determine a course of action when searching for victims, so that they may respond faster and better informed. Rescue workers will receive pertinent information from the canine handlers and take action to rescue trapped and hidden people. EMS will receive pertinent information from canine handlers regarding any casualties requiring immediate medical attention. US&R Managers receive pertinent information from canine handlers regarding the situation and any further assistance required to speed up the process.

3.2.2 Non-Functional Requirements: The non-functional requirements are extremely important as they ultimately dictate the success of the device and its deployability in real search and rescue disaster situations. The non-functional requirements include durability, weatherproofing, form factor and safety. Each of these requirements is discussed in detail in the following sections.

Durability
In an urban disaster the different types of debris vary significantly. It can include a manner of building material in various forms plus the contents of the collapsed structure. Our device needs to be ruggedized so that it will be durable enough for deployment in the harsh conditions of a such a setting. The device must be able to withstand impacts. In many cases it has been observed that the US&R dogs smash the equipment worn into any material that happens to be in their paths. This can range from a plank of wood to a concrete pillar. The positioning and securing of the device will also play a part on how durable it needs to be. All points on the dog may be impacted, as debris is not organized in a disaster area and is everywhere.

Weatherproofing
The environment includes the extremities of weather. The device will be deployed in blizzard-like conditions with high winds and extremely cold temperatures up to -40 degrees Celsius. It will also be deployed in wet weather and in extreme heat and arid conditions. The device must be weatherproof, regardless of the environment deployed in.

Form Factor
As this device will be worn by an US&R dog, the device must be small and light. A device placed on an animal should not exceed 5% of the animal's body mass [13]. Taking this into account, we analyze the mass of US&R dogs. The preferred breeds for US&R work are dominated by German Shepherds and Labradors.

Compared to the other breeds, this subset have been observed to be the ones most likely to exhibit the necessary characteristics of stamina, stability, agility, intelligence and will accept training. The adult German Shepherd and Labrador dogs weigh on average 35kg [20]. Therefore the maximum mass the US&R dogs should carry is 1.75kg. The CPE device is one of many embedded systems that comprise the Canine Augmentation Technology (CAT) system [21-25]. All of the 5 devices are to be deployed on the dog simultaneously. Taking this into consideration the maximum mass of the device should not exceed 1% of the mass a US&R dog is expected to carry. This translates to a maximum mass of 350g for the CPE device.

The available space on a dog for a device is extremely small, which is why there is a real constraint on the size of the device. The average length of an US&R dog body (excluding the head and tail) is 75cm, with an average width of 12cm [20]. In addition, the device on the dog must be small enough so as to not impede the canine's ability to search effectively. We want to minimize the size as much as possible, without compromising the components we choose to use in the device.

Safety
The device must not put the dog in harms way. Their security is a high priority for the handler. Each of these specialized and highly trained dogs undergo thousands of dollars worth of training over and extended period of time [26]. To replace a dog is not only expensive, but time consuming. It is quite an arduous process to train them, requiring many years before they are deployable in the field and useful for US&R operations.

There are a few foreseeable issues with the device that could endanger the dogs, while conducting a search. One factor to consider is the production of excessive heat. This could irritate the canine and affect its abilities to function since dogs have few ways of shedding heat except for panting. The device's mass and placement on the dog could also cause discomfort, affecting its performance. In addition, the securing harness could get caught on debris such as protruding rebar leading to the dog becoming trapped or even strangled.

3.3 Functional Design

The functional design of the CPE embedded system includes three key requirements, which dictates the success of the device. The design includes the accuracy of the data collected, the processing requirements, and the communication requirements. Each of these is discussed in further detail in the following sub sections.

3.3.1 Accuracy of Data Collection: The sensors will gather useful data from a dog that can be translated into the canine's pose. The sensors need to be positioned and secured at fixed relative points on the dog so as to ensure the accuracy of the pose prediction from the measured sensor data and with minimal injected noise.

3.3.2 Processing Requirements: The device needs enough processing power to receive the sensor data at the rate it is produced and transmit it immediately utilizing the wireless communications on the device. All other processing of the sensor data, which requires much greater processing power, can be done more effectively using the laptop's capabilities.

3.3.3 Power Supply: The options include the following types of batteries: alkaline, nickel cadmium (NiCd), nickel metal hydride (NiMH), and lithium polymer (Li-Poly). The details of the battery chemistries won't be discussed here, however it is important to note that the NiCd, NiMH, and Li-Poly batteries can be recharged.

3.3.4 Power Supply Regulation: There were two options considered to regulate the power supply for the various onboard electronics of the CPE device. The options considered were: voltage regulator (step down), and voltage divider circuit. The voltage regulator is easier to implement since it is a single integrated circuit. Both of the options dissipate extra energy as heat.

3.3.5 Power Consumption: The device will use about 270mA, with all components running at full capacity. In order to determine how long the lithium polymer battery will last we calculate this using the following formula:

Therefore the duration for the maximum continuous current consumption would be equal to 1.67 hours or 1 hour and 40 minutes using a single 9V Li-Poly battery. Search and rescue continues 24 hours a day, for weeks at a time with the canine teams taking shifts. Using two of these batteries will last through an entire shift (4 hours) without the need to change the battery. The device is guaranteed to work through the entire shift without dying, if the battery is fully charged. This is more than sufficient for devices intended use in
USAR operations.

3.3.3 Communication Requirements: The wireless communications needs to be reliable in the environment where it will be used as described in section 3.2.2, weatherproofing subsection. It must have a good transmission range and should be robust enough for this application, which requires transmission over distances greater than 500m [27]. The wireless device used must be compatible with and able to connect quickly with the devices already in use by the US&R team. The data collected from each sensor must be transmitted in one message to the canine handler's laptop. They currently use laptops, but the application on their end should be reconfigurable for future incorporation into smaller, more portable devices.

The deployability of the wireless network must be easy and fast so that the US&R teams can focus their efforts on searching for people. They will not spend an exorbitant amount of time setting up a network in order to use the CPE device.

The components required in the system are: microprocessor, sensors, communication between devices, power supply, board, soldering and connectors, form factor, and a wireless network. The sub-processes required in the system are: software for the micro controller, and software for the laptop. Each of these components and sub-processes are described in detail in the sections below.

3.4 Architecture Design

The design of the CPE system was challenging because of many constraining factors including: size and mass, sensor placement, type of sensors to use, type of wireless data transmission and the disaster environment conditions. Taking into account these factors, the resulting design consists of a specially designed harness housing two inclinometers, a microcontroller, and a wireless module as shown in Figure 3.2.

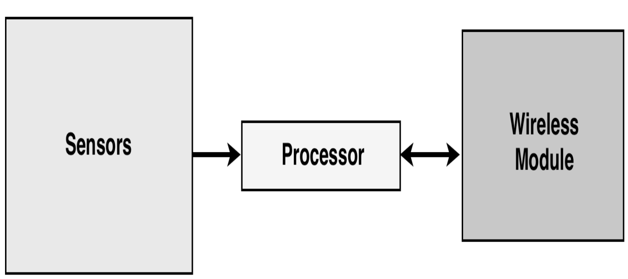

Figure 3.2 CPE Device Interaction Between Components

We have selected a low technical design, as this is cheaper. The number of units that will be created is not large enough to warrant outsourcing the development of custom boards etc. The specific details of each of the device components and the overall operation of the CPE device are discussed in the subsequent sections.

3.4.1 Processor: There are several options including Field Programmable Gate Arrays (FPGAs), single board computers, microprocessor, or a microcontroller. Below is a discussion of each of these technological options in relation to their functions, costs and use. In comparing each of these we take into consideration ease of use, cost, size, weight, and power consumption.

Field Programmable Gate Array (FPGA)
The advantages include the ability to re-program in order to fix bugs, and lower non-recurring engineering costs. The first advantage does not apply to our device. An option could be to manufacture the final version, preventing further modifications when the design is finalized. The size is very small which makes it a good option for use in this application. The FPGA has a high development cost associated with it; prices per chip range from $12 to $4,496 USD. A simple USB based development kit can be purchased for around $230 (DLP Design Inc.'s DLP- FPGA-M, available at www.digikey.ca). This development kit utilizes the Xilinx SPARTAN-3E FPGA (XC3S250E-4TQG144C), which costs around $18 per chip. The chip has 108 I/O pins, which far exceeds the amount required for the CPE device. The primary disadvantage of the FPGA technology is that it requires a lot of low-level design, which increases the amount of time required to develop a device.

Single Board Computer
A single board computer (SBC) is literally an entire computer on a circuit board, including memory, hardware ports, and processor. A single board computer design that was considered was the GumsStix (www.gumstix.com). The computer is about the size of a stick of chewing gum, giving the project its name. The GumStix has its own operating system and can run high-level programs such as those written in Java. Much of the processing power and capabilities of the GumStix would not be utilized by the CPE device. The size, weight, cost, and power consumption make it impractical as the primary processing component for the CPE device.

Microprocessor
A microprocessor is a small and light-weight processor. It incorporates a central processing core on a single integrated circuit and is used for general purpose computing applications. Microprocessors are found in everything from calculators to computers. Microprocessors are available at many different price points, and processing power levels. Typically, microprocessors are very powerful processing devices such as those sold by Intel or AMD. This type of microprocessor is not necessary for the CPE device, unless we wanted to run the Canine Pose Estimation in real time on the canine itself. However, this would use significantly more power.

The primary disadvantage of the microprocessor is that it is just a component of a computing device. In order to make it operational, we would still have to add memory, storage, and other components. It would make more sense to simple buy a single board computer such as the GumStix discussed above.

Microcontroller
A microcontroller was selected as the most efficient and economical processor for the CPE device. A microcontroller contains a CPU, ALU, RAM, ROM, and digital and analog I/O ports. Everything that is needed to read sensor data, perform operations on the data and send it out to a communications device are housed inside an integrated circuit. Microcontrollers come in many different flavours. In particular, the microprocessor considered here was an Atmel ATMEGA88PA-MUAVR. It is an 8-bit microcontroller with 23 I/O pins, eight channels of 10-bit ADC, and a number of serial interfaces for programming and for communication. Here an 8-bit microcontroller will suffice in processing power and accuracy of the data collected. The microcontroller will contain a short and simple algorithm to collect and transmit the sensor data. The remote laptop computer will contain the very complex Canine Pose Estimation algorithm. The microcontroller is the smallest and lightest of all the options listed. It is also the most cost effective and is very power efficient. The ATmega88 is available for $3.39 per chip.

3.4.2 Sensors: Three specific sensors were considered, that could be mounted on the dog to determine canine pose. In this section we look at each of these options and discuss the viability of their use for this specific application.

The three specific sensors were: gyroscope, accelerometer, and inclinometer. Since each of the sensors is a MEMS device, their power consumption, size, and weight are very similar.

Gyroscope
A gyroscope is a sensor that measures angular rate. The particular gyroscope that was considered was the Analog Devices ADXRS613. The sensor is capable of measuring angular rates of +/-150 deg/s. The output signal from the sensor can be integrated to determine an angular position that could be used to indicate canine pose. However, since the sensor only senses rotational motion, it would not pick up any of the canine's translational movement; thus it may not be as effective in determine pose.

Accelerometer
Accelerometers are designed to measure acceleration. The particular accelerometer that was considered was the Analog Devices ADXL320. This MEMS type accelerometer is capable of measuring +/-5g's of acceleration. Since the sensor is capable of measuring the static acceleration (gravity), the sensor can be used to determine tilt, making it a good choice for canine pose determination.

Inclinometer
The final sensor that was looked at was the VTI Technologies SCA61T Inclinometer. This sensor is slightly more expensive than the accelerometer or the gyroscope, however it has the distinct advantage of being able to measure inclination angle directly. The other advantage of this sensor is that it is capable of both analog and digital out.

3.4.3 Communication: There are many options available for the transmission of the sensor data. They include Bluetooth, Xbee, radio modems, WiMax, and WiFi. Here in this section we have looked at the benefits and detriments of each and discuss their viability.

Bluetooth
Bluetooth was used in the first prototype of the CPE device. It is very small and compact, which is a great advantage as it helps keep the overall size of the CPE device to a minimum. However, the transmission range is low, which makes it not feasible for use in USAR, as the canine can get many kilometers ahead of the handler. The Bluetooth module operates as a wireless serial (RS-232) cable replacement and any serial stream ranging from 9,600 bps to 115,200 bps can be seamlessly transmitted. Communications between Bluetooth devices is limited to approximately 10 m [27].

Xbee
Xbee is a specification for a suite of high-level communication protocols using small, low-power digital radios based on the IEEE 802.15.4-2003 standard for wireless personal area networks (WPANs), such as wireless headphones connecting with cell phones via short-range radio [27]. The technology defined by the XBee specification is intended to be simpler and less expensive than other WPANs, such as Bluetooth. XBee is targeted at radio-frequency (RF) applications that require a low data rate, long battery life, and secure networking.

WiMax
WiMax is based on the IEEE 802.16 standard. It provides different types of access, from portable (similar to a cordless phone) to fixed (an alternative to wired access, where the end user's wireless termination point is fixed in location.) It is only for point-to-point applications and therefore is not sufficient for the CPE device. The range is quite high, 3km [27-28]. The equipment is very large and would pose a problem in setting up in a disaster environment. It is also quite expensive, making this a poor choice.

Wireless Fidelity
Wireless Fidelity (Wi-Fi) technology has higher throughput and greater signal strength resulting in substantially greater range compared to Bluetooth. Greater signal strength is important in a disaster area where debris from collapsed structures can interfere and affect the connectivity of any device. During training deployment exercises in Toronto, the search canines often reached distances of 250 m ahead of their handlers [27]. The Wi-Fi range can be extended indefinitely by deploying more Wi-Fi nodes in the area [28].

The Wi-Fi-to-Serial module will be integrated into the CPE device is the EZL-80 from Sollae Systems Co., Ltd [28]. The module functions by translating data from serial to Wi-Fi and then sending the data to its internal buffer for transmission, which occurs in 20 ms transmission intervals. The serial to Wi-Fi module is necessary because the microcontroller communicates serially.

Wi-Fi provides easier connectivity since USAR workers are already equipped with Wi-Fi based laptops. The disadvantage is that Wi-Fi modems are larger than the Bluetooth and XBee modules and use more power.

3.4.4. CPE Device Inputs and Outputs: A schematic of the components interacting with each other is show in Figure 3.3. The inclinometer outputs a voltage, and the analog to digital converter on the microcontroller, converts the voltage to a digital number. This converted number is used with the sensor calibration curve (found in the datasheet) to convert this number into engineering units, which would represent an angle.

The microcontroller then sends this angle to the Wi-Fi module, which transmits the data through the Wi-Fi card. The laptop, which is Wi-Fi enabled then receives the wireless transmission via the 802.11 wireless standards. If the laptop were to send a message to the device (which isn't necessary, but is possible to setup), the Wi-Fi module is accompanied with a Wi-Fi to serial software that can be installed on any computer with a Windows operating system. This program then takes the Wi-Fi transmission and converts it from Wi-Fi to serial so that when it is received by the Wi-Fi module on the device the data is already converted to serial so that the microcontroller can process this data and use it accordingly.

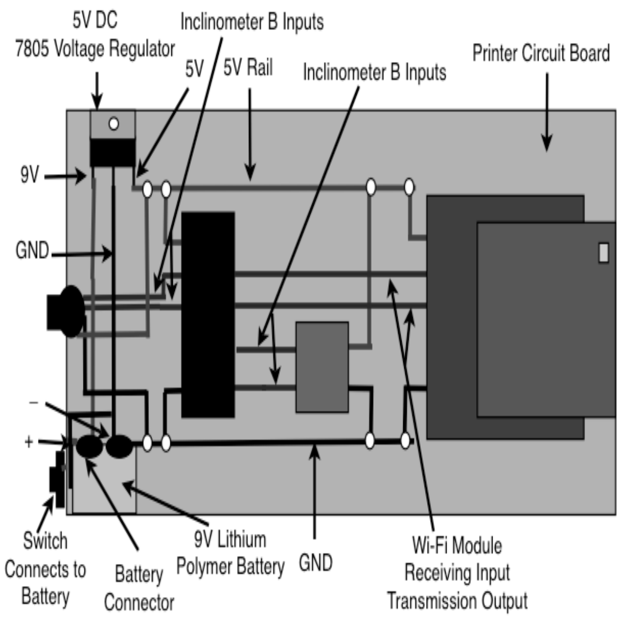

Figure 3.3 Inputs & Outputs of Printer Circuit Board Design

4. FORM FACTOR

There are a few different elements that need to be taken into consideration that affect the form factor of the device. This includes the weatherproofing of the device, safety of the dog, positioning of the device on the dog, casing's size and mass.

4.1 Waterproof

Circular waterproof DIN connector twists and locks create an impenetrable barrier. This will replace the molex connector used in our prototype. The molex connector is inexpensive and can be purchased for 50 cents, but it is not waterproof or durable. We will also use a special grommet for the smaller enclosure case for the second inclinometer, which is also waterproof. This creates a rubberized seal around the hole where the wires enter the case. Both cases should be equipped with a rubber gasket. This is a rubberized seal around the metal plate, which completely covers the screws ensuring that the case is waterproof. The battery compartment door that the handlers will remove to replace the battery will also have a rubberized seal.

4.2 Harness Design

The harness is designed for comfort allowing the dog to maintain their ability to perform searches unimpeded. Stability is important as the harness needs to secure the sensors in place. This is achieved using the handler's harness, which is made of tubular webbing with plastic buckles, which allows the ability to adjust the size of the harness for each dog. The CPE device will no emit much heat, but when put together with the other devices in the CAT system, this will no longer be case. The harness can light, heat blocking material commonly found in oven mittens, and would be used to create a barrier between the dog and the device. There is no need to wrap the material around the entire device. This could prove to be detrimental as the device will not be allowed to breath and may overheat. The harness must be easily removed from the dog if caught in debris, possibly with the use of magnetic clips. When the dog pulls to break free the force opens the clips and the harness is shed.

4.3 Affixing of the Canine Pose Estimation Device

Using a specially designed harness, the device's placement is depicted in Figure 4.1. Inclinometer A will be affixed on the dorsal vertebrae (withers), which are near the head of the canine. Inclinometer B will be affixed on the lumbar vertebrae (loin), which is near the tail of the dog. The most effective way to secure the sensors would have been to shave the canine and secure the sensors on the canine's skin. However, considering that the dogs are working in all conditions, removing protective fur is undesirable. The harness was designed with the ability to adjust its length so that the sensor's position could be moved depending on the girth and length of the dog.

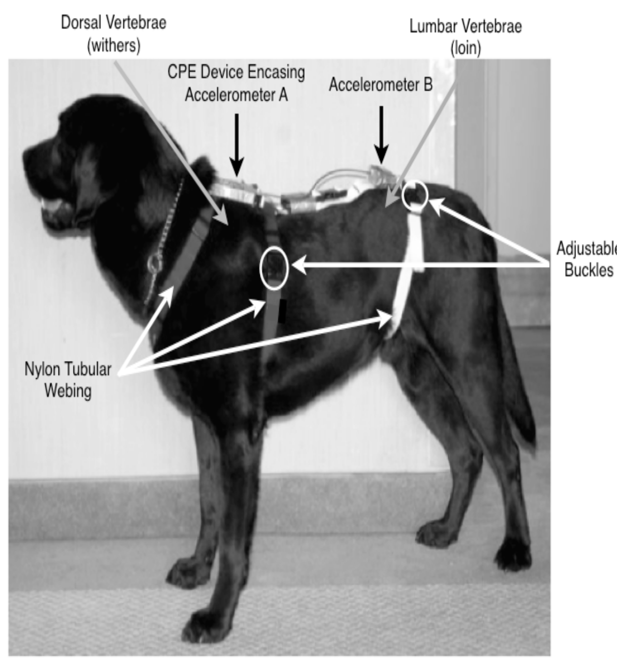

Figure 4.1 The CPE Prototype worn by US&R Canine

4.4 Size

The size of the device, when considering the design of the board and the size of each of the individual components should be 11cm long by 5cm wide by 3cm high. If we used 3D printing, we could create the case to a specified size with no wasted space. The shape will be rectangular so that it fits along the back of the dog. A wire will run along the dogs back to inclinometer B, which resides on the loin, connecting it to the device.

4.5 Mass

The objective of the design of this device will be to ensure the form factor comes in well under 350g, to ensure that the CPE device will not impede the searching capabilities of the dog below this average mass. The total mass of the device cannot exceed 350g, not including the harness as this will be shared between all the devices within the CAT system. Each of the required components and their mass are listed in Table 4.1. The total mass of the device is 143g, which is much less than half of 1% of the dog's mass. Including the harness, the total mass is 219g, which is still well below the maximum. This will ensure that when joined with the other devices the combined mass will remain below the 5% maximum of 1750g.

Table 4.1 Mass Budget

Components	**Mass (g)**
Microcontroller	3
Inclinometer (x2)	4
Wi-Fi Card	40
Waterproof Circular DIN Connector - Amphenol 4 pin	30
PCB & Imprinting	3
1ft Twisted Shielded Pair	10
Stranded Hookup Wires	5
Voltage Regulator	3
Project Enclosure + Screws + Rubber Gasket	13
Smaller Project Enclosure	5
Special Grommet	2
Waterproof Push Pin Switch	1
Fuse	1
1 9V Lithium Polymer Battery	22
Battery Connector	1
Harness	75
CPE Device Total	**143**
GRAND TOTAL	**219**

4.6 Wireless Network for Communications within system

A wireless mesh network (WMN) is a self-healing, self-configuring, self-regulating and adaptive network [28]. WMN's can function without human intervention or administration and can be easily deployed in an urban disaster with nodes placed where required to extend the network; typically, this would be done in a number of pragmatic ways including first responders dropping nodes off around the disaster zone to facilitate interconnection. This flexibility is a major asset for disaster environments, as each disaster is unique in terms of its layout, materials and dimensions. Once the mesh routers have been deployed they connect together to form a network through self-configuration. If there are any changes in the network such as the loss of connectivity (such as a battery failure) between any of the other nodes, they adapt and heal the configuration and remain connected. The WMN has dedicated configuration and routing nodes. The protocol used is Wi-Fi, which makes it compatible with the handler's laptops and the CPE device.

The CPE device's microcontroller sends the sensor data serially to the Wi-Fi module, which encodes the serial signal to Wi-Fi and then transmits the data. The ruggedized mesh routers would receive the sensor data from the CPE device and then transmit the data from one node to the next nearest node until it reaches its destination (the handler's laptop), taking the shortest path. Once the handler's laptop receives the data with its Wi-Fi card the Wi-Fi to Serial encoding software converts the data back to serial so that the CPE algorithm can use this data to determine the canine's pose. This process can be seen in Figure 4.2.

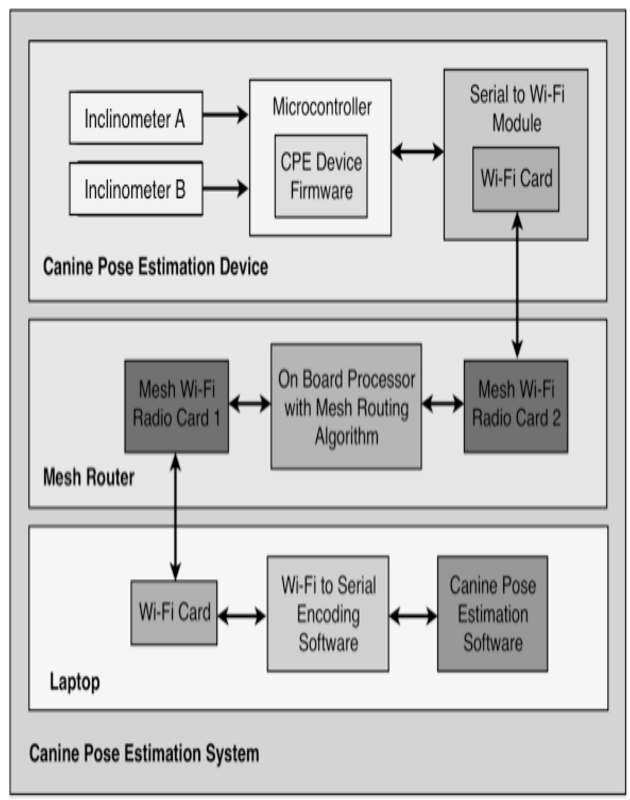

Figure 4.2 Canine Pose Estimation System Components Schematic

4.6.1. Software for micro controller: When the sensors are active, they consistently gather data. The programming needs to be asynchronous, because the inclinometer data is put into a buffer and then transmitted. This will ensure that the CPE device behaves as it should with the hardware and the form factor described above. The compilation tool is AVRDude, which is a free C program compiler, that enables microcontroller programming.

4.6.2. Software for laptop: This software will also be written in the C language and will be compiled using Quincy (or any other free compiling tool). This program receives the sensor data then uses it to determine the pose of the dog.

5. FUTURE WORK

The CPE algorithm is not very effective in determining the difference between the lying down and standing pose. This could be rectified with the use of additional sensors added to the device. A pressure, sonar or laser could be affixed onto the harness, where it wraps around the dogs torso. If the dog lies down the sensor would indicate this with either a pressure reading, or in the case of the sonar and laser sensors they would calculate of the distance between the dog and the ground to be zero.

Although, each of these sensors would work in theory, in practice there would be many instances where they would result in a false positive result, as they would be activated by surrounding debris. In the case where the dog is standing but there is a rock directly beneath his torso and which is high enough to activate the sensor, the algorithm would display the dogs pose as lying down, instead of standing. Experiments could be conducted to determine how often the false positive case occurs and whether this additional sensor increases the accuracy of the algorithms prediction.

The vibration sensor would enable us to detect when the dog is not changing poses but adjusting its footing on rubble. In these cases the inclinometers read the changes in movement even though this movement has nothing to do with a change in the pose. When the vibration sensor with a reading within a small threshold, could indicate that the changes in the inclinometer data are not to be used to determine a new pose and that the dog is still in the previously determined pose. This could minimize false negatives in the CPE algorithm.

6. CONCLUSION

The adapting design model and process clearly outlines all of the requirements and design details for the CPE device and its intended use. The system specifications describe the intended behaviour of the system in relation to how US&R operations currently take place. Requirement definitions include details about all of the stakeholders and how the CPE device will interact with their roles in US&R. It also lists all of the non-functional requirements in great detail, pertaining to the environment and other non-technical factors that affect the design decisions of the CPE device. The functional design defines all of the components the system requires. The architectural design, results in a concrete structure of all components from which the system must be made. Finally the reoccurring and non-recurring expenses were discussed.

This design model yields the most effective design with respect to each component chosen for the intended use of the device in its environment. It is also the smallest size, lightest mass and most cost-effective design solution, without compromising the accuracy of the results, the reliability of the network communication and the durability of the device in its working environment.

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8. ACKNOLEDGEMENTS

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