DESIGN OF A TRANSMISSION LINE MONITORING SOLUTION FOR AN UNMANNED QUADCOPTER

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Abstract. Eskom owns thousands of kilometres of transmission lines that need to be inspected in order to plan maintenance. Current methods of inspection are costly and ineffective and could pose safety risks. Systems already developed for inspection purposes do not meet the specifications as determined by Eskom for transmission line inspection. A solution is proposed by the design and construction of a monitoring system consisting of a single board computer (SBC), USB video and infrared cameras, and a GPS unit. The system is attached to a quadcopter that flies along the transmission line to collect data. Software is developed that stream the video and GPS data to a monitoring station and provide logging capability.

Key Words. Eskom; transmission line monitoring; quadcopter.

1. INTRODUCTION

Eskom's Transmission department spends a vast amount of money per year to perform transmission line inspections. Current methods are costly and ineffective. The monitoring system design presented in this paper is aimed at providing a system that provides the same level of functionality as current methods used by Eskom at a reduced cost. High quality inspection data must be acquired in order to plan maintenance activities.

The remainder of this paper is structured as follows: First, a brief background of current inspection methods and existing technologies are presented. Then, the system analysis, functional analysis, monitoring system design, monitoring system operation, results and future work are discussed. Finally, a conclusion is drawn.

2. BACKGROUND

This section provides background on current methods of inspection and existing monitoring solutions.

2.1 Current methods of inspection

Eskom makes use of two types of inspections, namely air inspections done by helicopter and ground inspections done by patrolmen. Three types of air inspections are done: detailed air inspection, fast air inspection and fire risk air inspections. Detailed air inspections are done every three years to evaluate the condition of the line hardware, conductors, conductor spacers, insulators, earth wire and tower structures from as close as is possible using a helicopter. Fast air inspections are conducted annually. The purpose of this inspection is to establish the general condition of the transmission line and servitude [1]. It must be ensured that the transmission line and servitude complies with all the minimum legal, safety and environmental requirements. Fire risk air inspections are done in areas where veld fires are experienced on a regular basis. The purpose of this inspection is to evaluate the potential fire risk in an area before the annual fire season. Ground inspections are conducted once every twelve months. Ground inspections are done to identify obvious defects on the line. All findings for an inspection must be recorded and supported with photos and video. When crews are conducting an aerial inspection, defects with regards to the following aspects needs to be inspected and noted [1]:

- Broken or damaged insulators.
- Pollution that negatively impacts the performance of the transmission line. Types of pollution to be noted include industrial, mine/dust, marine or bird pollution.
- Birds' nests on structures and damaged or missing bird guards.
- Moved or missing vibration dampers.
- Broken or missing spacer.
- Trees, reeds, grass or other natural products impairing servitude.
- Defect regarding general hardware including anti-climb devices, tower members, tower labels, stays and other general hardware concerns.
- Damaged conductors.
- Damaged shield wire.

2.2 Existing monitoring solutions

Systems have been developed for the purpose of transmission line inspection. The LineScout is a robot developed by Hydro Québec to be used for inspecting live transmission lines [2]. The LineScout uses two wheels to run on top of a live line. The LineScout is equipped with a three-axis robotic arm. The arm is equipped with a camera and has the ability to grip a variety of tools. The robotic arm grants the ability to carry a variety of sensors to be used for inspection, such as visual-, infrared- and electrical resistance inspections [3].

The Expliner is a robot developed by HiBot to be used to perform inspection tasks on high-voltage lines [4]. The Expliner moves along the transmission line by means of four wheels mounted on two axles. The robot is equipped with four sets of laser sensors to perform detail measurements of the transmission line conductor. The robot also houses a high-definition, high-zoom camera to be used for detail visual inspection of the line.

All of the systems considered above attach to the transmission lines by means of wheels or rollers. These systems thus have difficulty in moving past obstacles such as vibration dampers or visibility markers. Further, these systems focus on the acquisition of specialized data or general repair. Eskom inspections do not require such specialised data or repair functionality. These systems are thus not suited to perform Eskom transmission line inspections.

3. SYSTEM ANALYSIS

This section contains the system analysis of the monitoring system.

3.1 Project Objective

Conceptualise and design a monitoring system that will be placed inside a quad-copter type unmanned aerial vehicle. The monitoring system should provide the same level of functionality as current methods for inspection. Data collected should be of such quality that it could effectively be used to plan maintenance activities [1], [5].

3.2 Requirements Analysis

The design of the system presented in this paper was done according to a set of specifications in order to satisfy the design problem. These specifications are:

- Live video streaming must be achieved to provide real-time monitoring capabilities.
- The system must be equipped with a mobile network connection. The system will be mounted on a quadcopter and a wireless network connection is thus needed. It must be ensured that the wireless network connection has sufficient bandwidth to enable live streaming of data from the monitoring system.
- The system must have locational awareness. Locational data must be captured in order to plan maintenance activities.
- The system must be lightweight as it must be mounted to a quadcopter. Excess weight will impact negatively on the flight characteristics of the quadcopter.
- The system will run from battery power and must thus have low power consumption. Low power consumption will mean longer flight times.
- The system must be compact as limited space is available on the quadcopter.
- The system must be reliable.
- The system must be designed with future improvement in mind.

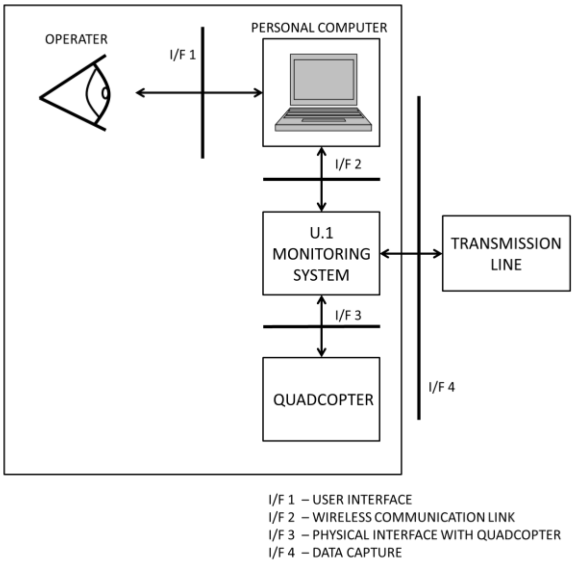

Figure 1: Operational architecture

3.3 Operational Analysis

Figure 1 shows the operational analysis of the system. The operator will interact with the system via a computer running the correct software (I/F 1). This computer will act as a remote control station. A wireless network connection will be established between the computer and the monitoring system (I/F 2). This interface will allow controlling the system and facilitate the transfer of data to and from the monitoring system. The monitoring system will be attached to a quadcopter via I/F 3. Finally, the monitoring system will acquire data from the transmission line via I/F 4.

4. MONITORING SYSTEM FUNCIONAL ANALYSIS

Figure 2 shows the functional architecture of the monitoring system. High level functional units are identified. The system will have a central processing platform to which all other components will connect (F/U 1). Software to control the system will run on this functional unit. Hardware will be added that will acquire data from the transmission line (F/U 2). A locational sensor will be added to log the position of the system (F/U 3). F/U 2 and F/U 3 will both interface with the transmission line via I/F 4. Wireless communication (F/U 4) is added to the system to enable networking functionality between the remote control station and the monitoring system via I/F 2. The system will contain a power source (F/U 5) to power the system. A housing is designed to contain the system (F/U 6).

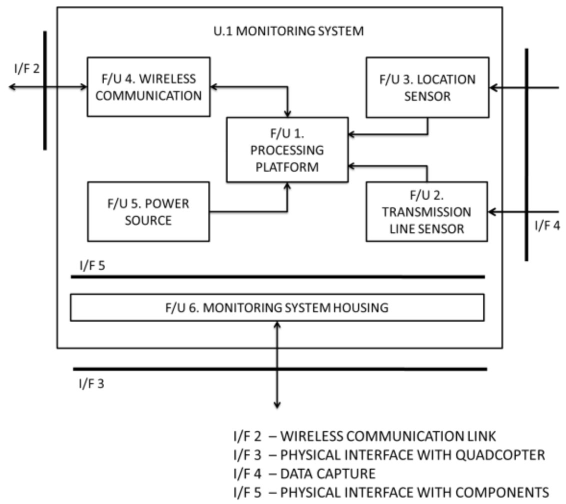

Figure 2: Monitoring system functional architecture

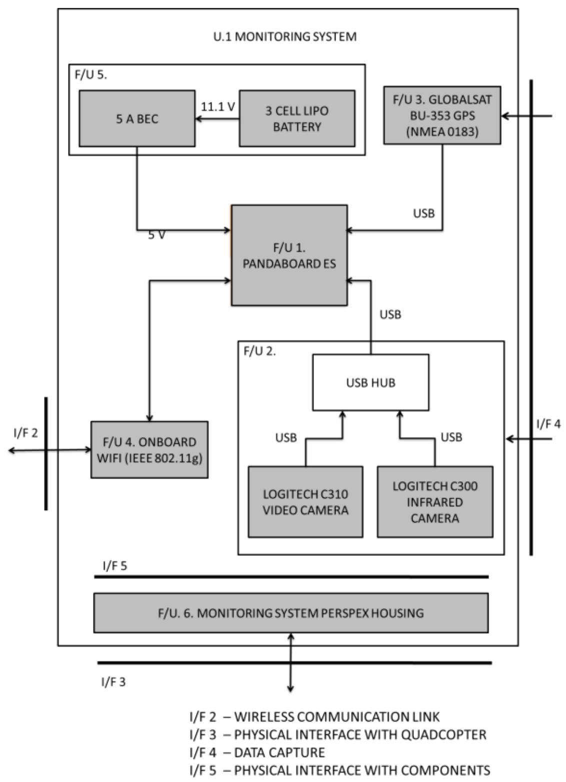

Figure 3: Monitoring system design

5. MONITORING SYSTEM DESIGN

This section contains the details of the design of the monitoring system. The design of each of the functional units present in Figure 2 is considered. The software to run on the monitoring system is also described. Figure 3 shows the detail design as discussed in this section.

5.1 Processing Platform

It was chosen to use the single board computer (SBC) architecture for the processing platform. Its compact size and low power consumption have made SBC's a popular choice for embedded systems [6]. The Pandaboard is used. The Pandaboard is the most powerful SBC available. It features a 1.2 GHz ARM A9 dual core processor, 1 GB of RAM, two USB ports and onboard Wifi. The Pandaboard is well suited to the task at hand and is the choice SBC in many video processing applications [7], [8], [9]. The features setting it apart from other SBC's are its processor and large amount of RAM. The availability of these resources made the Pandaboard an attractive option when also considering future development. The Pandaboard uses a SD card as storage. A 16 GB SD card is used for this purpose. The Pandaboard runs from a regulated 5 V source and draws a maximum of 4 A. Figure 4 shows the Pandaboard used. Important aspects of the board are marked on the figure.

5.2 Transmission Line Sensor

USB cameras were chosen to use to capture visual data of the transmission line. A USB webcam design was chosen as it is inexpensive and it will be easily integrated with the SBC platform. The camera must be able to provide a level of detail that will enable effective inspection and maintenance planning. Cameras considered were high-definition cameras. The Logitech C310 camera was chosen to use as the video camera for the system. The camera is capable of 5 MP image and 720p video capture. This will be sufficient quality to perform inspection.

Equipping the system with an infrared camera will enable the temperature of the transmission line to be monitored. It was found that all photo sensors in digital cameras are susceptible to light in the near-infrared spectrum. Manufacturers add an infrared filter to keep infrared light from reaching the photo sensor. If this sensor is to be removed the camera will be able to capture the near-infrared light. A filter can then be added to filter out the visible light so that the camera only sees infrared light. A USB camera can be used and modified for this purpose. A Logitech C300 camera was used and modified into serving as an infrared camera.

5.3 Location Sensor

GPS units were considered to provide locational data for the monitoring system. GPS modules that provide a USB interface were selected as they would integrate easily with the SBC configuration. The Globalsat BU-353 GPS module was selected to be used on the system. The GPS uses the SIRF Star 3 chipset and the manufacturers claim an accuracy of 10 meters. The GPS takes at most 42 seconds to get a fix on its location in the case of a cold start. The module is certified to be waterproof to the IPX6 standard and features a magnetic mount. The data sent from the GPS is sent in the NMEA 0183 protocol at 4800 baud.

5.4 Wireless Communication

Wifi was selected to be used for the wireless network connection between the monitoring system and the remote control station. To enable Wifi connectivity, both the monitoring system and the remote control station needs to have access to the Wifi network.

The Pandaboard features an onboard Wifi module. This is convenient as no extra hardware is needed to connect the monitoring system to the Wifi network. To connect the remote control station to the Wifi network, a Wifi access point will be used. A local Wifi network will be hosted from the remote control station to which the monitoring station will connect. A local Wifi network will have sufficient bandwidth for the purposes of the system and to demonstrate the concept.

5.5 Power source

It was chosen to use a Lithium Polymer (LiPo) battery to provide power to the monitoring system. A three cell 3300 mAh battery was used for the purpose. However, a three cell battery has a nominal voltage of 11.1 V, which is not suitable for the Pandaboard, which runs of a 5 V supply. A 5 A battery eliminator circuit (BEC) was used to regulate the voltage from the battery to 5 V. A BEC is a switch mode regulator popular for use in the radio control hobby community.

5.6 Software

Ubuntu 12.04 LTS was loaded onto the SD card used by the Pandaboard. Using Linux as an operating system abstracts the developer from the technical aspects of using the Pandaboard as the operating system takes care of the technical details. Using connected hardware components become easier as drivers for the hardware are packaged with most Linux distributions. Custom C++ software was developed to run on the Linux platform. The software controls the operation of the system and enables communication between the monitoring system and the remote control station. An open source multimedia framework, Gstreamer, was used in conjunction with the C++ software to simplify the process of video streaming and camera control.

6. MONITORING SYSTEM OPERATION

The software on the monitoring system was configures to run as soon as the Pandaboard starts up. As soon as the system is active, a signal is sent to the remote control station to indicate the system is online. Figure 5 shows the user interface from which the system is operated. The user has the ability to select one of the two cameras and switch the video feed on or off. A separate screen shows the video feed. The coordinates and time as recorded on the monitoring system is sent to the remote control station every three seconds. The software has the functionality to log issues that is identified during an inspection. Comments are typed into a textbox and saved to text file with the current time and coordinates.

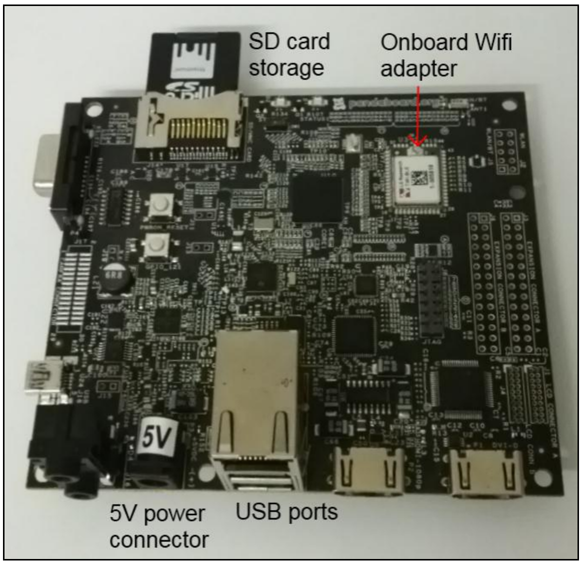

Figure 4: Pandaboard SBC

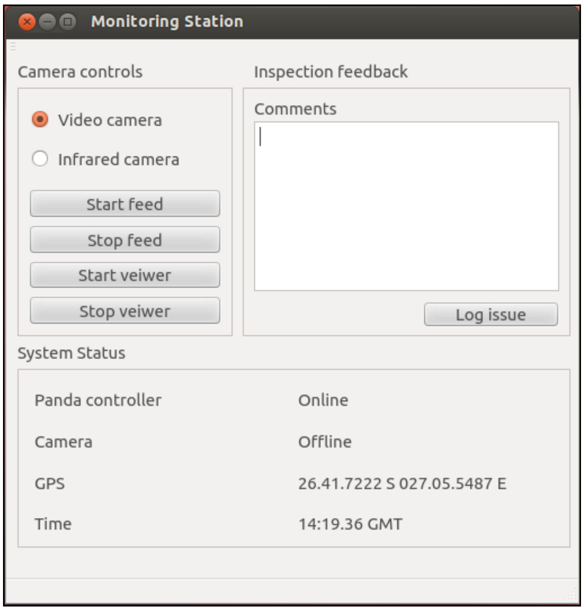

Figure 5: Remote control station user interface

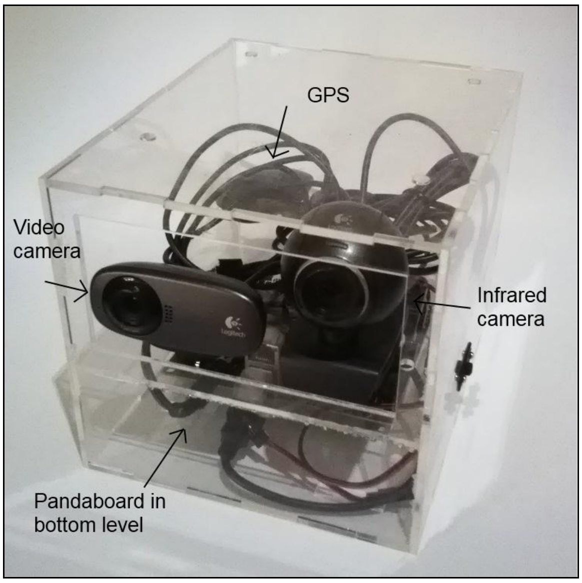

Figure 6: Monitoring system in Perspex housing

7. RESULTS

Results found while testing the system will be included in this section. Figure 6 shows the system without the power source contained in the Perspex housing before being attached to the quadcopter.

7.1 Power consumption

The power draw was measured at various times in the operation of the system. Figure 7 shows the power draw at the various stages of operation. The system draws mainly between 2 W and 4.5 W on startup. When the system is in idle, it draws an average of 4 W of power. When the cameras are enabled, the system draws up to 5.5 W. The system draws approximately 5 W of power during normal operation.

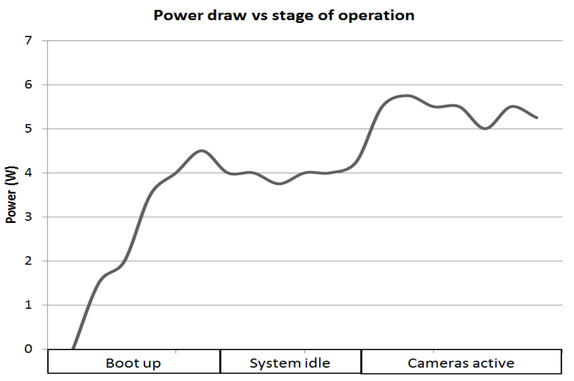

Figure 7: Power draw vs stage of operation

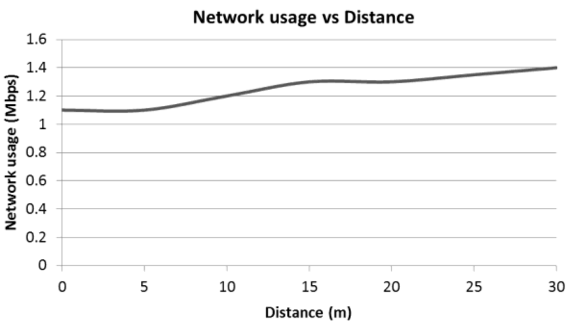

Figure 8: Network usage versus distance

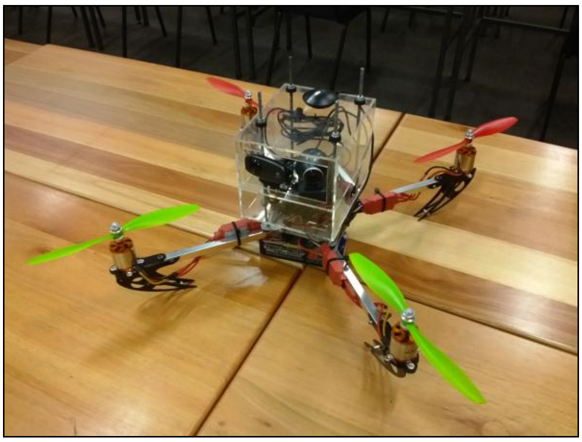

Figure 9: Integrated system

7.2 Network usage

The network usage of the system was measured. It was found that when the monitoring system is moved further away from the Wifi router, the network usage increased. Figure 8 shows the network usage at different distances away from the Wifi router. The system uses between 1.1 Mpbs when closer than 10 m and up to 1.4 Mbps at the limit of the range for the local Wifi network.

7.3 GPS accuracy testing

The accuracy of the GPS used on the monitoring system was tested. The GPS coordinates extracted from the GPS module can be seen displayed on the graphical user interface shown in Figure 5. A commercial Garmin GPS was enabled at the same location and the coordinates noted. Figure 10 shows the coordinates as recorded by the Garmin GPS.

Figure 10: Garmin GPS coordinates

The coordinates captured by the monitoring system are S 26°41.722’ E 027°05.546’. This is almost identical to the coordinates measured by the Garmin GPS.

7.4 Integrated testing

The monitoring system was integrated with the quadcopter. Figure 9 shows the monitoring system installed on the quadcopter. The monitoring system can be seen mounted on top of the quadcopter between the propeller blades. The system was tested in a realistic environment as what it would be used in. The integrated system was flown next to a substation and transmission lines. Video from both the video camera and infrared camera was recorded. Figure 11 and Figure 12 show images taken from the video and infrared cameras respectively.

Figure 11: Image taken from video camera stream

Figure 12: Image taken from infrared camera stream

It can be seen from Figure 11 that the quality of the video is such that details of the transmission line and associated hardware can clearly be seen. The quality of the video enables transmission line inspection to be performed. Although the concept of a thermal imaging camera was proved, the infrared camera was not sensitive enough to infrared light to effectively be used as an alternative to a thermal imaging camera.

8. FUTURE WORK

This section will detail work that will be done in the future. The system as designed is aimed at proving the concept of a monitoring system attached to a qaudcopter to perform transmission line inspection. Further work needs to be done to improve the quality of inspection data or add other types of sensors to the monitoring system. High quality thermal imaging will be added to the system. This will enable the system to accurately gauge the temperature of the transmission line to detect failing hardware. Lidar sensors will be added with which the system can form a 3D map of the surroundings. Servo operated camera gimbals will be added to enable smoother operation of the cameras.

Further work also needs to be done on the networking capabilities of the system. This system used a local Wifi network to prove the concept. Adjustments to the system will be made to incorporate technologies such as cellular networks for long range communication and data streaming.

9. CONCLUSION

In this paper, a monitoring system was designed for transmission line inspection. The monitoring system attaches to a quadcopter that flies along the transmission line. The monitoring system is capable of real-time video streaming to a remote control station from where the system is operated. GPS coordinates accompany the video feed. Fault logging capabilities are provided. High quality inspection results were obtained that can successfully be used as a cost effective alternative to current methods of inspection.

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