# TRANSMISSION LINE MONITORING SYSTEM FOR A POWER LINE INSPECTION ROBOT

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**Abstract:** Eskom has thousands-of-kilometres of transmission lines running across South Africa. The current methods of overhead power line inspection (foot patrols and air inspections) have been implemented for a long time now and are expensive and infrequent. The aim was to develop a prototype monitoring system, which had to fit into a transmission line robot to collect information from the power line and will allow a person to remotely (wirelessly) inspect the power line. The hardware consists of a PandaBoard® (SBC) together with a 5 MP camera and GPS receiver to collect information. High detail (resolution) photos of the power line covered the biggest problem faced on the lines, namely: hardware fatigue. The evidence was then accessible on a website hosted by the PandaBoard® via Wi-Fi. The solution is light weight, compact and has a low power consumption. The monitoring system makes collecting evidence easy and fast. The results obtained by this prototype are satisfactory as a concept for further development and can provide a feasible and improved solution for monitoring of transmission lines for Eskom.

**Keywords:** Monitoring system, transmission line inspection, inspection robot, PandaBoard

## 1. INTRODUCTION

Eskom has thousands-of-kilometres of transmission lines running across South Africa [1]. All of these lines have to be patrolled and maintained. Eskom is currently doing a foot patrol and a fast helicopter inspection annually together with a detail/slow helicopter inspection every two years on each of these lines.

These methods of overhead power line inspection has been implemented for a long time now and it is expensive and infrequent [2]. When a key component on a tower starts failing, like a wire connector, it has the tendency to fail completely over a short period of time. Almost like the snow ball effect. Although multiple departments inspect the lines, some lines are routed in remote areas (across mountains, over rivers, etc.) which means inspection is more difficult and more time consuming [3].

Eskom mostly collects detailed photos [4] during these inspections coupled with an occasional infrared photo (usually during slow helicopter inspection). Using a helicopter to collect these photos results in high costs to Eskom. Hijacking has also become a big issue during foot patrols. The robot will also contribute to safety around live lines by not requiring a person to climb onto the live wire for close inspection, but only for maintenance [5].

This project is the first step towards an implementable inspection robot in the future, therefore this attempted monitoring system is a baseline to further expand and improve towards the complete monitoring solution intended by this project. Some key features have been identified to aim for in this first attempt as indicated in the list shown below.

- The monitoring system must incorporate sensors to collect evidence from the line.
- The sensors must collect information at a high rate to ensure that data from each part of the line are collected to prevent blind spots which may overlook key components that can cause line failure.
- The monitoring system will make use of a wireless communication device to transmit the newly collected information to a remote device.
- The wireless broadcasting range at this stage doesn't need to be very far as it is only essential to have wireless connectivity to form a base communication system. Range boosters can easily be inserted in the future to increase the range.
- The monitoring system must be integrated with the inspection robot and use its battery source without disrupting the robot's operation [6].

The aim of the project was to successfully complete an integrated hardware system which will allow the collection of detailed evidence (HD photos) together with sensors that provide location (time and GPS coordinates). The system also has to incorporate software which will utilize the hardware to a point where the intervals of data collection cover the complete line and then host the evidence, wirelessly, over a network [4, 6].

## 2. MATERIALS AND METHOD

### *2.1 Technical survey and recommendations*

After spending time at Eskom during vacation training in their central transmission division located in Simmerpan, the following problems have been identified as problems which Eskom face on their overhead transmission lines:

- Hardware problems (visible components) - This include all the physical fatigue noticeable by the human eye. Ground patrols use HD cameras to take pictures of each overhead power line tower and then take it to their office to process and look for suspicious components.
- Hardware problems (non visible occurrences) - The two invisible killers are weak connections and corona. Both are detectable by an infrared camera. Corona is also detectable with an ultraviolet camera. These two camera technologies are very expensive.
- Wire problems - Overhead power lines have to comply with clearance standards. Breaching these limits results in flashovers. To measure these distances, Eskom uses a Lidar scanner to create a 3D model which shows all the distances. But just like the infrared and ultraviolet cameras, Lidar systems are very expensive.
- High inspection costs - The estimated budget in Eskom for aerial inspections is about R 36 million per year. The helicopter is capable of a 100 km of fast inspection per hour, but costs R 14 000 an hour (excluding pilot and staff salary).

After understanding what problems Eskom face, one cannot help but wonder if the alternative solutions do not really provide the solution that Eskom needs. Eskom is currently spending a lot of money just to patrol the transmission lines. By buying a robot which specializes in temporary close inspection and small repairs (like the LineScout® and Expliner), Eskom is only shifting towards better safety for humans and not towards saving money during foot patrols whilst improving safety. Thus the LineScout® and Expliner do not meet the solution Eskom require.

The Cable crawler, just like the LineScout® and Expliner, is a very big and heavy robot. Its monitoring system isn't close to being finished, so it's too early to tell whether the developers are heading in the right direction. The High-Wire acrobat is showing potential for future use by Eskom, but the high cost and the fact that field testing will only start in 2014, eliminates the High-Wire Acrobat as a current competitor.

If a monitoring system, which only looks for visible damage (not expensive), can be placed in robots which can run autonomously on a live lines doing close inspections, then the slow helicopter inspections will decrease greatly. To complete the monitoring solution, an infrared camera and a Lidar scanner can be combined with the fast helicopter inspections to search for the invisible problems (corona and weak links). The monitoring system has to provide GPS positioning and HD photo data from very great distances to provide the live line crew with enough evidence to minimize ground patrolling. This way Eskom still has a complete monitoring system, but with fewer ground patrols and slow helicopter inspections which then results ina more cost efficient solution.

### 2.2 *Concept draft*

From the technical survey and the budget for this project, it was decided that the monitoring system should consist of the following hardware: a HD camera, a GPS receiver, voltage regulator with protection and a PandaBoard® with onboard Wi-Fi. This will provide the required hardware functionality which the software can use to form the monitoring system. The concept breakdown is shown in figure 1.

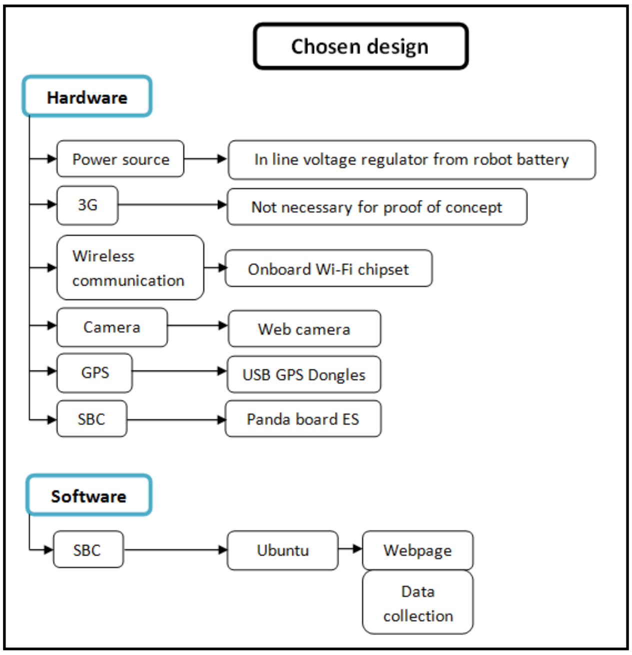


Figure 1: The hardware and software concept breakdown

For the software side there are two main requirements, namely: the data collection and the wireless hosting of the data. Below is the concept discussion of each of the requirements.

*Data collection*

The program which will record the evidence every few seconds must be able to do the following:

- take a picture
- get time stamp
- get coordinates
- combine the evidence into one file (rename the picture with the time and coordinates)
- save the file in a common location so that the web page can also access it
- wait a preset delay and start the process all over again
- allow for controllable parameters so that the user can change the parameters through the website

The program will basically be one big loop running over and over just collecting data. If all the taken data is placed in one common file location, the website just has to be written to display all the data in that file location.

*Wireless data hosting (website)*

The web page will be password protected to prevent security breaches. The following functionality must be provided:

- password protection
- display taken data
- allow user to download data
- allow user to delete already downloaded data
- allow user to control the data collection program

*2.3 Materials*

The chosen hardware for the concept is: a HD camera, a GPS receiver, a voltage regulator with protection and a PandaBoard® with onboard Wi-Fi. The PandaBoard® is a single board computer which will be programmed to use the sensors to collect information, process the info and then host the data. Figure 2 displays the assembled system.

Figure 2: The assembled monitoring system with sensors

The hardware specifications are:

- 1.2 GHz dual core processor
- 1 GB RAM and 16 GB SD card
- Onboard Wi-Fi and Ethernet port
- Ubuntu 11.10 OS
- 720p webcam
- USB GPS receiver with <10 m accuracy
- 5 V regulator with inline fuse. (2-6 cell Li-Poly)
- a total weight of 280 grams

*2.4 Software implementation*

Each one of the programs are individually discussed below regarding how they implement the requirements.

*Data collection*

The program is written in BASH since it is basic, fast and has direct access to the IO communications. The basic concept of the program is shown in figure 3.

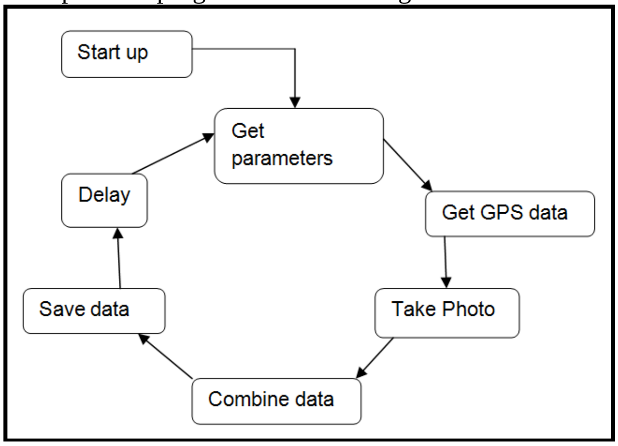


Figure 3: Overhead flow diagram for data collection

Each of the phases shown in figure 3 are discussed below:

- Start-up phase: This phase is responsible for the initialization of the program. During this time the program sleeps for one minute to give the GPS receiver time to allocate satellite reception (the datasheet states it requires 48 seconds for a cold start), sets the start up parameters, navigates the terminal to the relevant directory and sets the GPS com port with the correct settings, namely: 4800 bps, n, 8, 1 for NMEA.
- Parameter phase: The program reads the values of the parameters from a text file (which the website can change) and sets the relevant variables, namely: run, delay and colour. The run determines whether the program should sleep or collect data, the delay states the length of the intervals between data collections and the colour determines if the photos taken by the program must be colour or greyscale. Greyscale photos use less space. The program stays inside the parameter loop unless or until the run parameter changes to true.
- GPS phase: During this phase the program extracts the required location and time from the GPS receiver. The detailed flow diagram is shown in figure 4.

To retrieve the GPS data, the program runs two separate commands simultaneously. One runs in the background to stop the other program from continuing to write the GPS data to a text file. Then the program searches for the relevant data in the text file and starts string manipulation to retrieve the coordinates and time.

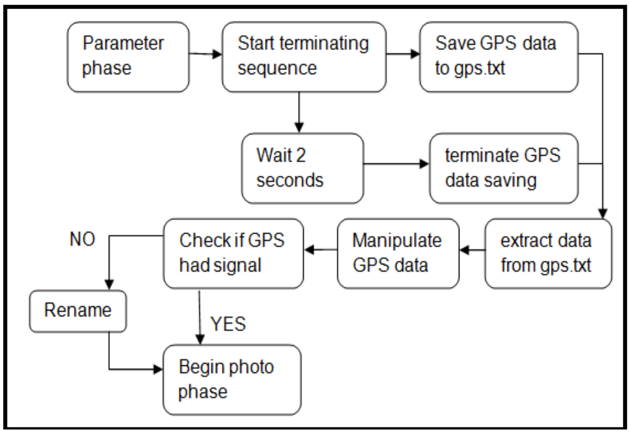


Figure 4: Flow diagram of the GPS phase

A fail-safe is included to rename the location if the GPS receiver has stopped working. How and what the string manipulation does is shown in figure 5.

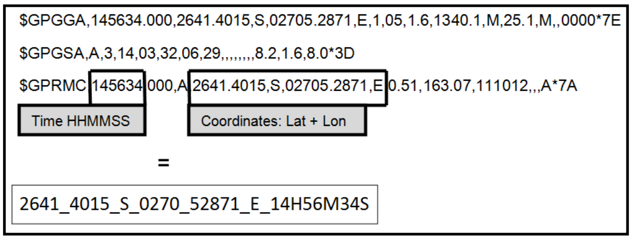


Figure 5: How the GPS data is string manipulated

- Photo phase: The program takes a colour or greyscale photo (depending on the colour parameter) with a program called Fswebcam and then saves the photo to a folder called phpimages with the name acquired from the string manipulation in the GPS phase. The program can only take 1280x720 pictures with the webcam since it does not have the ability to software optimize the picture.
- Delay phase: The last part of the program is a sleep function which lets the program sleep for the time value specified by the delay parameter. When the delay is over, the program loop starts over.

*Website*

The website was created by using LAMP® (Linux Apache MySQL PHP) as it provides all the requirements for the website. Apache provides the ability to host the website over the network of the PandaBoard® and MySQL adds a database which will be used by the PHP written website. A database was created with a table to keep track of all the user accounts and to give the website user and password protection. The table creating code is shown in figure 6.

```
| users | CREATE TABLE `users` (
  `id` int(11) unsigned NOT NULL AUTO_INCREMENT,
  `user_name` varchar(45) DEFAULT NULL,
  `user_password` varchar(45) DEFAULT NULL,
  `user_status` varchar(45) DEFAULT NULL,
  PRIMARY KEY (`id`)
) ENGINE=InnoDB AUTO_INCREMENT=4 DEFAULT CHARSET=latin1 |
```

Figure 6: Code to create the "users" table in the database

The "user_status" from figure 6 splits the users into two divisions, namely: normal - and super user. Only a super user can create more user accounts and set data collection parameters. The website is made up from multiple pages and the interlinking is shown in figure 7.

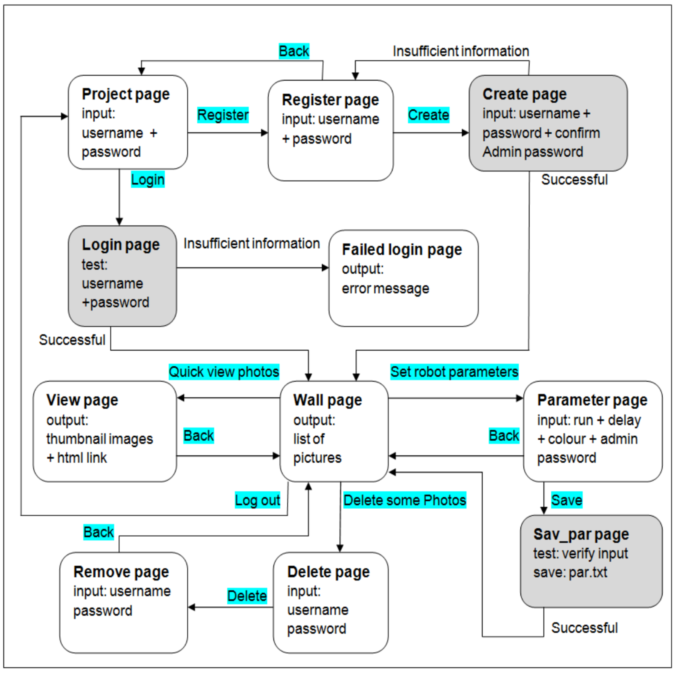


Figure 7: Flow diagram of the PHP WebPages

Some of the blocks in figure 7 are coloured in to symbolize the pages where the webpage will be making use of the MySQL database. The words that are highlighted represent buttons which the user must click in order to move to the next page. The words that are not highlighted are automated responses of the webpage. To simplify the explanation of the methods and ideas of the website, the individual pages are divided in to the following groups:

- Log in phase - Project, Register, Create, Login and Failed login. These pages allow a user to register an account with the permission of a super user and/or login in with the registered account in order to gain access to the data collected by the monitoring system.
- Wall phase - Wall. The wall page is the main page of the website which displays a table of hyperlinks of all the collected data with the created date-time and size. This keeps the page size low and allows for quick browsing.

- Parameter phase - Parameter and Sav_par. These pages allow the super users to set parameter of the data collection program by saving the values to the text file that the data collection program uses.
- Quick view phase - View. This page shows small thumbnail pictures with hyperlinks to allow the user to quickly search for specific pictures to download.
- Removal phase - Delete and remove. The remove page also displays small thumbnail pictures, but with an added delete button to allow the user to delete the unnecessary data.

## 3. RESULTS

To test the monitoring system before integration with the robot, the system first had to pass a test under full operation. At this stage of the robot prototype, live wire testing was ambitious for the little time and funds available for the project, but electromagnetic interference (EMI) is one of the biggest problems which the monitoring system will face on a power line. So to test the monitoring system in a realistic simulation, the system was strapped into a box and fitted to a quad-copter. The quad-copter then flew over a transmission line whilst the monitoring system was running. Figure 8 shows the quad-copter with the fitted monitoring system.

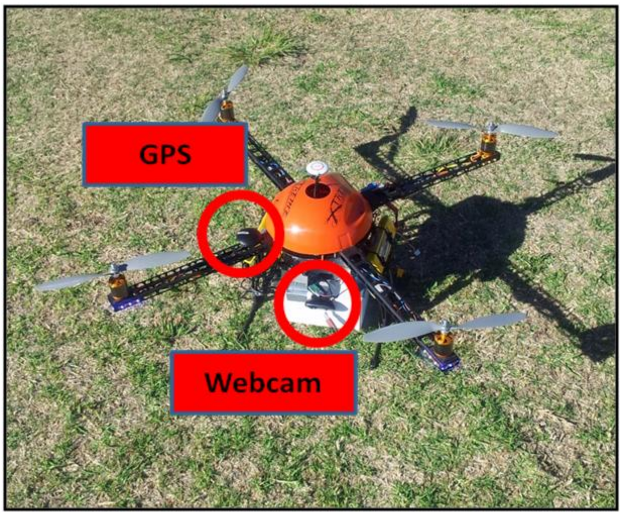


Figure 8: The system installed on a quad-copter

The quad-copter flew right above the power line, far enough to avoid risks, but close enough for the system to experience the EMI. The system was set up to take data at 9 second intervals. Figures 9 to 11 shows a sequence of three pictures that was taken with their names.

The last three digits from each photo name confirm that each picture was taken nine seconds apart. The latitude and longitude was tested by comparing the known location of the test and the results from typing the data into a GPS. The test showed that the GPS receiver remained accurate to less than 10 m whilst being exposed to the EMI. For comparison of the images, figure 12 is an image taken by Eskom during a Helicopter inspection.

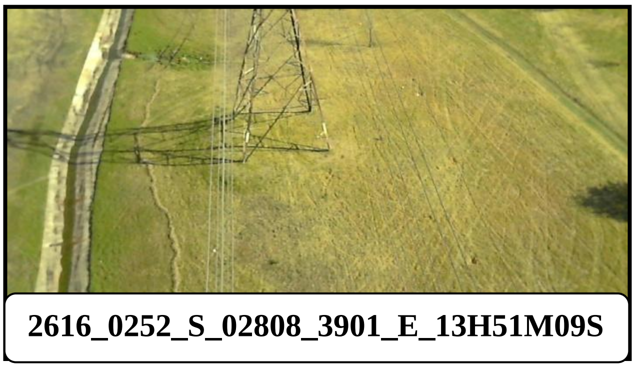


Figure 9: The first photo of a sequence


Figure 10: The second photo of a sequence

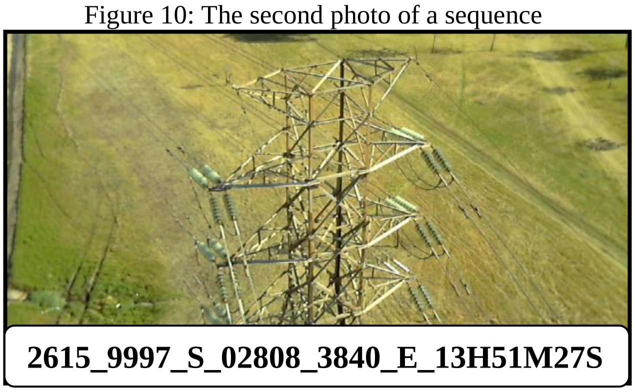


Figure 11: The third photo of a sequence

Figure 12: An aerial inspection photo taken by Eskom

The monitoring system's photos lack the quality of photos taken by Eskom, but that is due to the fact that Eskom uses higher resolution cameras. Once the monitoring system has an upgraded camera and hangs directly on the power line, the monitoring system will be more effective. The website was not the main focus during the test, but still operated without fault during testing. A detailed test was done to evaluate all the corners of the website and revealed only small issues which were fixed.

The system's current consumption was tested before integration to ensure that the robot could provide the necessary power. Figure 13 displays a graph of the load under different phases of operation. The system peaks at 1 A and uses 800 mA rms during data collection. The monitoring system was then integrated into the inspection robot for further testing [6]. Figure 14 shows the integrated systems which forms a prototype inspection robot.

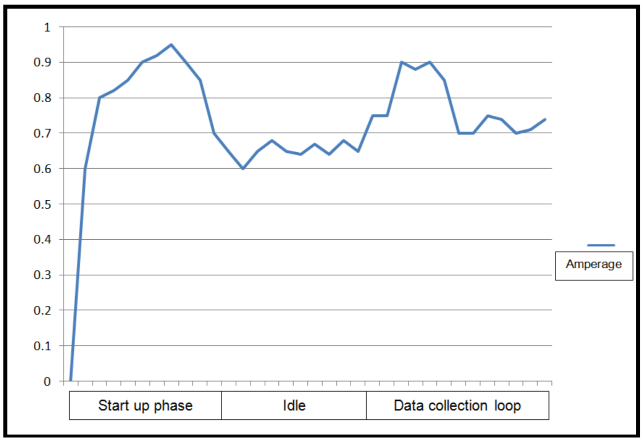


Figure 14: The amperage consumption of the system


Figure 15: The completed prototype inspection robot

## 4. CONCLUSION

The project required the development of a monitoring system which would fit into an inspection robot and through wireless communication allowed for remote inspections. As required, two sensors were used, GPS and camera, and were it not for budget constraints, more sensors to complete the monitoring system could have been added. The 3G, infrared and Lidar systems can later be added to the system and make the system effective enough to replace the foot patrols and most of the aerial inspections. For each hour the helicopter is not used, Eskom saves money.

The monitoring system provided very good results. The data collected by the system are for the most part the same as what Eskom would typically collect during one of their inspections, which makes it a direct substitute with lower running costs than the current method.

To conclude, the monitoring system which weighs 280 g can take 60 000 photos with very accurate GPS coordinates at a minimal time interval of 5 seconds and successfully hosts the data over the onboard Wi-Fi chip. This allows a person to remotely inspect the power line. The project objectives are met and some features are additionally included, like the parameter page which allows the user to control the data collection program through the website, to increase the performance and effectiveness of the system.

## 5. REFERENCES

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