Requirements elicitation interviews and applications for an underground remote-piloted aerial system

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Being underground is dangerous, it really is. People shouldn't go there if they don't need to, especially in an age where driverless cars by Google and shopping delivery by Amazon are on the brink of implementation in unstructured public environments; but held up, not by technology, but by wrangling about legislation covering liability determination, and fears of hacking drive-by-wire systems. Underground mining is a secure (from an IT perspective), structured, and predictable environment with limited and controlled human access – an ideal place for automated or remotely piloted systems.

This paper outlines the semi-structured interview process that was executed to determine the requirements for an underground remotely piloted aerial system (U-RPAS). The potential applications are explored; including search and rescue, the business-orientated activity of regularly scanning rockpasses to predict and prevent blockages, and scanning a blocked rockpass to determine the blockage location and structure. An even more 'out-of-the-box' application, using the vehicle to deliver explosives to the underside of a blockage, was included in the brainstorming discussions. Interviews with ten mining and unmanned aerial systems experts were conducted with a questionnaire as the primary data collection tool. The questionnaires were analysed to determine the representatively of the sample set, and therefore the validity of the gathered data, based upon expertise ratings in each of the relevant areas of knowledge: mining, surveying and mapping, and remote-piloted aerial systems. The goal was to identify the key performance requirements of a U-RPAS, and determine the feasibility of such a system being developed. A specialized company providing a scanning service emerged the preferred implementation method, and the rationale for this choice is presented. As context, the sub-system prototypes used in the brainstorming section of the interviews are presented, as are the implementation scenarios discussed in the interviews. It is thus shown that this method of requirements elicitation is suitable for this type of technology implementation project.

INTRODUCTION

With humanity turning more and more to computers to control vehicles in the uncontrolled environment of the world, is it not time for the mining environment to do the same with its fleet of vehicles? Above ground, where GPS is available, the task is proceeding at full speed. However, underground, without the assistance of GPS localization, this process has stalled. The technology for managing vehicles in unstructured environments is out there – as illustrated on 6 April 2016 when 44 trucks in six fleets traversed Europe in autonomous platoons. The front truck determined the speed and route, with following trucks communicating via wi-fi to autonomously 'follow the leader'. All arrived safely and simultaneously at Rotterdam harbor, after departing from areas all over Europe (see Figure 1) (Platooning, 2016).

It was widely reported in the media that Google's autonomous car recently bumped a slow-moving bus, after over 1 million incident-free miles, as a result of unusual road conditions (sandbags over a storm drain) and some driver assumptions causing the mishap (Bowles, 2016). Other motor manufacturers are developing driverless technologies, with Ford, Audi (Figure 2), Volvo, and GM all claiming level-four autonomy capabilities, and all testing vehicles in the UK, where the laws are most conducive for autonomous vehicle testing (Murgia, 2016). Amazon, the massive online retailer, has made big news of its research into using a personalized unmanned aerial delivery system, direct from the warehouse to your door (Figure 3).

Figure 1. Autonomous trucks traverse Europe (Platooning, 2016).

Figure 2. Autonomous Audi (Murgia, 2016).

Figure 3. Amazon delivery drone (Murgia, 2016).

WHAT IS A U-RPAS?

In this paper we propose a new acronym for the Underground use of Remotely Piloted Aerial (or Aircraft) System (U-RPAS). There are many alternative names, *i.e.* the more common 'unmanned aerial vehicle' (UAV). The international Civil Aviation Organization (ICAO) uses 'unmanned aircraft systems' (UAS) (ICA Organization, 2011), but that typically applies to larger systems than the one under discussion in this paper. The term 'drone' has military connotations, as does the other UAS acronym, 'unmanned autonomous system'.

In the mining environment, the acronym Remote Piloted Aerial System (RPAS) has gained traction, although that does not give scope for an autonomous system, as RPAS implies that there is a person in the loop at all times acting as 'pilot' of the system. This acronym matches with the current law for commercial systems in USA (Blyenburgh and co., 2015) and South Africa (CAA, 2015a, 2015b; Twala and Patterson, 2015). This legislation, however, applies only the airspace under control of the Civil Aviation Authority. There is a grey area about indoor, and by implication, underground airspace, in which this mining application is based.

Unmanned Mining Vehicles

Many of the ground-based remote piloted systems currently in use for mining have control rooms with operators separated from the systems, sometimes by thousands of kilometres, as is the case with BHP Billiton's IROC (Integrated Remote Operations Centre in Perth (Crozier, 2013), Or by hundreds of vertical meters, as was the case with the Sandvik Automine system at the Finch diamond mine autonomous haulage system (automation.com, n.d.).

U-RPAS APPLICATIONS IN MINING

At a conference on Mine Emergency and Preparedness, a workshop on the requirements for a robot rescuer was conducted, where an aerial vehicle was identified as a possible search-and-rescue assistant (Green, 2013a). The main outcome of the workshop was for a ground-based reconnaissance system, but it was also noted that an aerial vehicle would be easier to deploy, and quicker to survey an area. It would be independent on the ground conditions, as water, mud, or rubble could be traversed. It would also be lighter than a ground-based system, which would be important in a rescue scenario, where the rescuers have to carry in all equipment and time is a critical factor in providing assistance to an injured miner. The following characteristics were necessary for underground operation (Green, 2013b):

- Intrinsically safe/flame-proof
- Waterproof (IP65)
- Streaming video to operator/s

• Gas sampling of environment (to protect against methane explosion).

Search and Rescue

In a search-and-rescue scenario, the following characteristics were identified as important:

- 100–200m range from deployment to region of interest
- Man-packable (approx. 25 kg)
- Speed requirement from hover to 5 km/h
- Interchangeable battery for rapid redeployment (this is significant in an intrinsically safe design)
- 360° awareness/void mapping
- Disposable cost (no specific value was given).

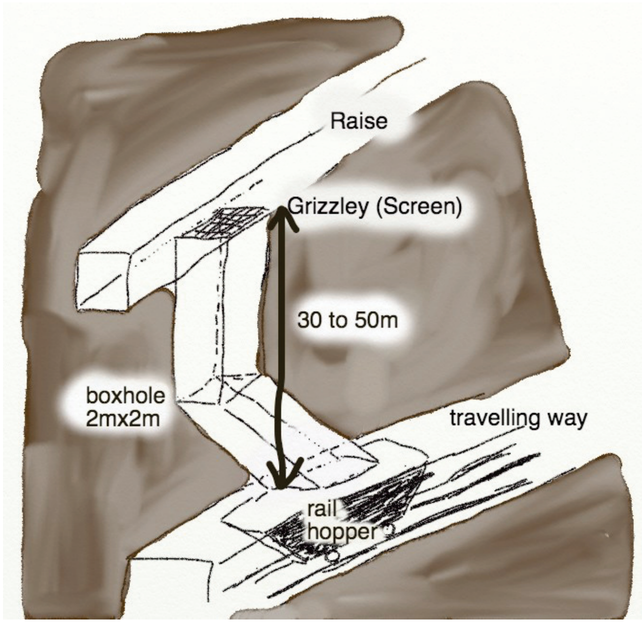

Figure 4. Diagram of a boxhole structure and dimensions.

Rockpass Survey

There are two scenarios where a rockpass survey may be applied.

Detecting Blockage Locations

There are instances where the traditional methods of detecting and unblocking a rockpass are insufficient – for example, if the blockage position cannot be identified, is too high up for saplings to be used to support the explosives, or is beyond the dogleg and out of line of sight (see Figure 4). A 'sputnik' has been proposed in the past (Plastics; n.d.), but it relies on significant infrastructure to be deployed prior to use, and seems to have enjoyed limited uptake in industry. The alternative – estimating the location, and drilling a hole from a safe location to deliver explosives – is slow and inefficient (Hadjigeorgiou *et al.*, 2005). In order to determine the best unblocking methods, a good knowledge of the blockage location and structure is required. An airborne scanner could provide that information.

Temporal Scanning for rockpass degradation monitoring

In order to prevent a rockpass from blocking, periodically scanning of the pass and monitoring for temporal variations (changes over time) could identify future problems, and determine remedial actions to prevent blockages.

Proposed Deployment Scenario for U-RPAS

An operator, upon request:

1. Goes to the area to be surveyed (a boxhole – Figure 4)
2. Deploys the survey U-RPAS from a safe location
3. It flies, under the operator's control, with semi-autonomous manoeuvers, into the unsafe area, and gathers information
4. The UAS then returns to the safe area
5. The data is downloaded and processed (off system)
6. Outputs are delivered for analysis and action decision.

REQUIREMENTS GATHERING FOR U-RPAS ROCKPASS SCANNING APPLICATION

Elicitation Techniques

The requirements engineering methodology for the development of an unmanned aerial vehicle (quad-copter) for the underground mining application of boxhole inspection was presented by Green *et al*. (2015b). The methodology (based upon a literature survey) suggested elicitation methods matched to the project characteristics of a market-driven, technology-based, research project with distributed stakeholders, limited budget, and a flexible timeline. It proposed semi-structured interviews and brainstorming on a one-to-one basis, executed cyclically, as suitable requirements elicitation techniques. The tools of prototyping, modeling, and scenarios were motivated as suitable for us in the elicitation process based upon the characteristics of this project.

Interview Questionnaire

One purpose of the questionnaire was to identify the field of knowledge and level of expertise of the person interviewed. This is used to assign a level of confidence to the interviewee's opinions in relation to other interviewees. In this way conflicting opinions can be resolved by exploring the relative level of expertise of the individuals with the conflicting opinions.

The broader goals of the questionnaire are:

1. To identify the interviewee in the mining value chain (what kind of stakeholder)
2. To develop a network of information sources that are willing and able to contribute to this investigation
3. To elicit information about the possible technology implementation requirements.

Brainstorming

This purpose of the brainstorming section was to explore the implementation requirements of a quad-rotor platform as a technology for the inspection of boxholes and orepasses in underground mining in an interactive discussion using subsystem prototypes, use case models, and scenarios.

Subsystem Prototypes

A number of subsystem prototypes were developed specifically for the interviews (Green *et al*., 2015a) in order to encourage discussion and a better understanding about the problem of blocked boxholes, the current methods for their unblocking, and how technology could be used to develop an aerial scanning system to counter the challenges.

The subsystem prototypes included the following.

Quadrotor Aerial Platform Demonstrator

As a demonstrator for the flight capabilities and responsiveness, a micro UAV (Figure 5) was used in the interviews to give an indication of the type of platform that could be used. The final version would naturally be larger and sized to carry the desired payload, as well as have some semi-autonomous capabilities (discussed below).

Figure 5. Small, simple and cheap quadrotor demonstration platform.

Platform Preservation System

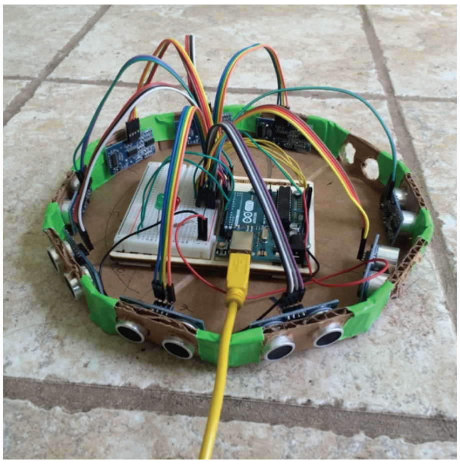

Figure 6. Ultrasonic obstacle detection array.

An array of 10 ultrasonic sensors (Figure 6) was proposed as a demonstrator platform preservation system to detect walls and other obstacles around the airborne system, preventing the platform from flying into obstacles irrespective of the instructions issued by the operator. A single board Arduino computer was used as the control system, and serial communications were used to the control computer.

Mapping Sensor
Gathering the depth information for generating a map of the area was demonstrated with an Asus Xtion Pro Live (figure 7 projected light sensor. This type of sensor has been used in the past to generate underground mining 3d scans (Price et al.; 2011; Dickens and Price; 2012)

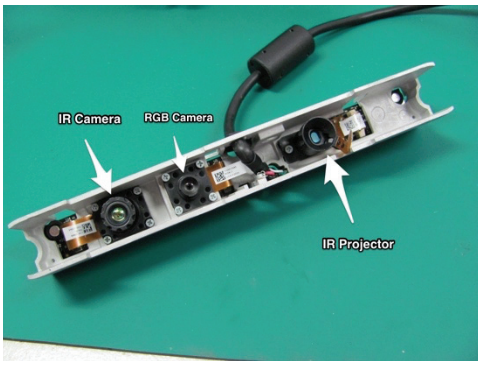

Figure 7. Asus Xtion Live sensor.

Operator Interface
A discussion about what the typical operators interface could look like was used to prompt thoughts on the typical operator, their decision-making capabilities, as well as the environment that the scan would be executed in and from. One significant discussion was the amount of autonomy that the system should have. Would a completely autonomous system be accepted in the mining environment where automation and mechanization have experienced very slow uptake? This was not resolved in the discussions.

In discussing the information that the operator would need to see on the interface, a subsystem interface to the ultrasonic array was shown and discussed.

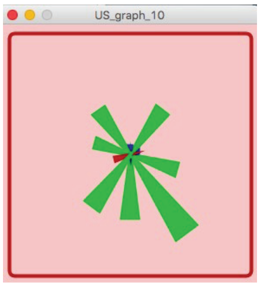

Figure 8 (a). Blocked path in red 'arm'.

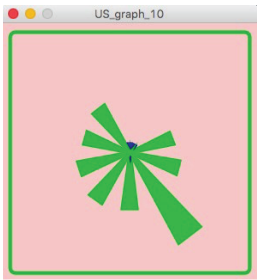

Figure 8 (b). Clear path in all green areas.

Figure 8 is a representation of ultrasonic measurement of distance to nearest object. Three colours are used to represent the different possible readings. Blue is 'no signal' or 'error' (either no object is detected within the 3 m sensor range, or the signal is reflecting away from the sensor instead of back towards the sensor, as with a flat wall at an angle greater than ±45°). Red and green both show a distance measurement to the nearest object in the readable range. Red indicates that there is an object in close proximity, and evasive action may be required. This information is not necessarily needed for the operator to fly the vehicle if the onboard vehicle preservation system uses it to prevent the operator from flying the vehicle in the direction of the identified 'near objects', but it is available for display on the GUI.

Figure 9 shows a visualization of the mapping sensor reading pointing down a horizontal travelling way. A person is visible in the centre distance.

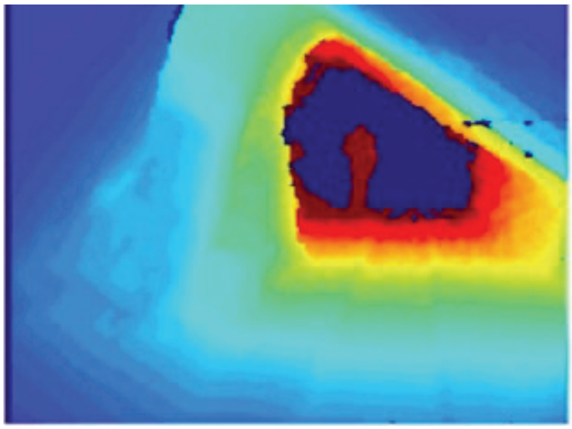

Figure 9. Tunnel depth.

BUSINESS MODEL FOR DEPLOYMENT, USE CASE DISCUSSIONS

During the brainstorming, two possible deployment scenarios were discussed, with two different possible business models. A UML model (shown in Figure 10) of the process was the basis of the discussions.

Business Models

1. The mine owns and operates the equipment.
2. A specialist company provides a service of operating the U-RPAS, and supplies the resulting data with some interpretation.

Use Cases

Two use cases were explored for each of the two business cases.

1. A boxhole or orepass is blocked, and the blockage is surveyed to determine the blockage point and cause. An unblocking strategy is then determined from that data. A stripped-down 'sacrificial' version of the scanning aerial platform can then be used to deliver a targeted, accurate explosive blast.
2. A routine boxhole or orepass survey that is triggered by a time point (*i.e.*, monthly survey).

It became apparent that the deployment model by which the technology would be available would have a significant impact on the requirements, and that decision would need to be made before proceeding with the requirements definition. The differences would not necessarily be on the functional requirements, as method of executing the scan, the timing of the need to scan, and the accuracy and resolution needed, would remain unchanged. The impact would be in the other non-functional requirements (training, certification, maintenance, data integrity and tracking, as well as in the data processing steps subsequent to execution of the scan).

The interviewees were almost unanimous in their view that the business model of an external company providing the service was better than the mining company executing the activity themselves for, *inter alia*, the following reasons:

1. The company supplying the service would most likely be the company that built the system, so they would understand it very well
2. It is a periodically required service that may not require a full-time person on the mine, forcing somebody to re-skill to be able to provide this service if it were in-house

3. Industry uptake would be higher with a service that could be purchased, compared with a person that needs to be employed/trained (lower cost to entry)
4. The training/certification requirements would be a lower barrier to entry of the technology
5. Operating the system is a highly specialized skill that becomes better with practice (or worse without practice)
6. The company would have a vested interest in maintaining the equipment
7. Ongoing development and the improvement of the level of service and capability would be feasible
8. Exposure to multiple operations data analysis would result in better analysis of the temporal scans and identifying potential problems, as well as identifying remedial action that had worked in other similar situations (leveraging the experience gained at multiple operations to improve service and performance at all the operations).

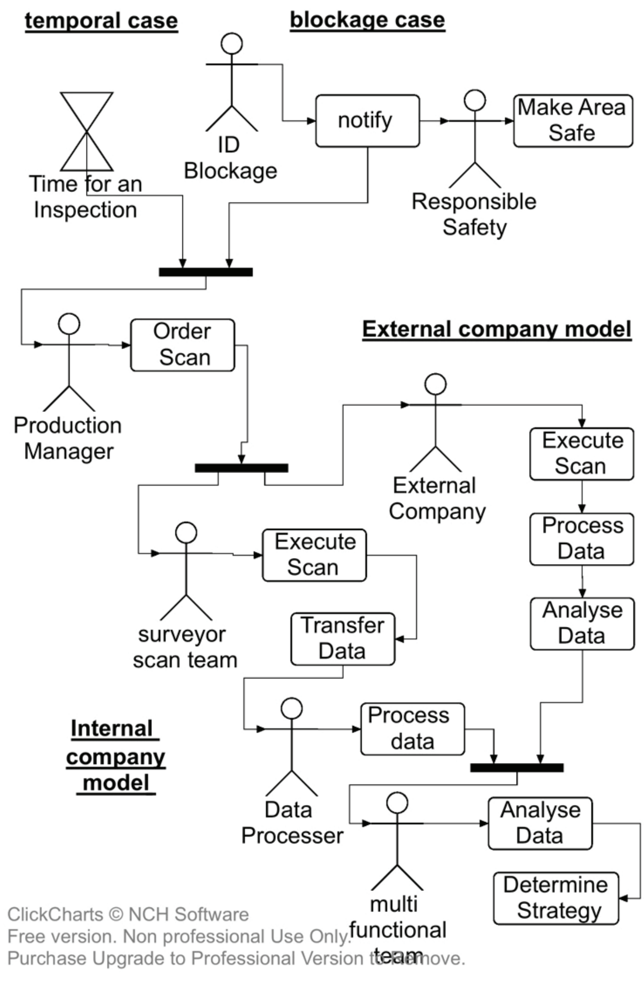

Figure 10. UML diagram for use case and business models.

PARTICIPANT ANALYSIS

In this first round of interviews, 10 people were interviewed. Each interviewee rated their own expertise in the three areas of interest:

Mining

Specifically boxholes and their blocking and unblocking.

Surveying/Mapping
This was a crossover area of expertise, and represents the field into which this technology will fit. In the mining environment it is the employees responsible for surveying the mine during construction, and ensuring that the mining occurs as planned. In the UAV arena, this area is focused on mapping, and the generation of maps based upon readings/data gathered from multiple instruments, or multiple locations. The extension of this capability is Simultaneous Localization and Mapping (SLAM), where a mobile sensor simultaneously expands a mapped area with its current set of gathered data and/or simultaneously positions itself in the map.

Unmanned Aerial Vehicles, or Remote Piloted Aerial Systems
Either in the use, development or research in the field.

It was of interest to note that not all the interviewees viewed themselves and their skills on the same scale – particularly the academics, who were familiar with a field because of some study of it, but didn’t feel that they could be rated as experts due to a limited practical exposure. Therefore the ratings (shown in Table I) have both the ratings as indicated by the interviewees and a normalized rating by the interviewee in order to compare the relative expertise of all the interviewees.

Table I. Participant knowledge ratings (1=novice, 5=expert).

	Self rating			Interviewer rating		
No.	Mining/ boxholes	Survey/ mapping	UAV	Mining/ boxholes	Survey/ mapping	UAV
1	2	2	4	4	2	3
2	1	4	4	1	4	4
3	5	4	2	5	3	2
4	1	1	2	2	2	2
5	1	1	4	1	1	3
6	3	4	3	3	4	3
7	2	2	3	2	2	3
8	5	1	1	5	3	1
9	5	5	1	5	5	2
10	1	3	1	1	3	1

It is noted that some interviewees were rated as experts in multiple categories (2 out of 10), while others did not rate as experts in any categories (3 out of 10). The analysis of the interviews is not yet complete, and thus the quality of data gathered from the ’super experts’ compared with the ’total novices’ in the groupings cannot yet be categorized. It is noted that there is an underrepresentation in the ‘expert’ category for UAVs. However half the group were rated as 3 or higher, the same as for Mining. Of interest is that there are 7 interviewees rated at 3 or higher in the mapping/surveying crossover category. These are participants knowledgeable in either both mining and surveying, or RPAS and mapping. These participants would have made the most informed contributions to the discussion. Participant number 6 was the only interviewee classified as knowledgeable in all three categories.

CONCLUSIONS

This paper has demonstrated the need for an aerial scanning system for rockpasses in underground mines, an Underground Remote Piloted Aerial System (U-RPAS). Interviews were conducted with 10 experts across three areas of expertise needed for the system in an attempt to determine the requirements for such a system:

- Underground mining, with experience in rockpasses
- Surveying, in the mining industry, or mapping in the RPAS industry

- Remote-piloted aerial systems (RPAS).

The interviews included a questionnaire to determine (*inter-alia*) the participants' level of expertise in each of the fields required. Analysis of the data showed that all disciplines were evenly represented in the sample set. A brainstorming section that included prototype subsystems in the discussion of multiple use-cases and multiple business cases showed significant agreement between the participants. Overwhelmingly, an external company providing a specialized service was chosen as the preferred implementation model.

This level of agreement indicated that the problem is well-enough understood by the interviewees, and that the requirements recorded in the interviews and the brainstorming can form the basis of a requirements document for a U-RPS for rockpass surveying. The technology embodied in the prototypes can form the foundation for a demonstration system for a second round of elicitation techniques that will include verification of any discrepancies that emerge in the requirements. The techniques employed in the elicitation process thus far have been a success.

FURTHER WORK

The initial questionnaire is to be given to another 10 interviewees via the internet. The brainstorming section cannot be executed as an interactive discussion, as it was with the initial 10 participants, and requires a significant amount of thought on how it should be structured such as to elicit information from the participants.

Subsequent to the completion of the second round of virtual interviews, the transcripts of the interviews will be text-mined for trends that were missed in the initial analysis. Participants are sought for this process, as well as another round of one-on-one interviews planned for the future that will include the requirements verification process.

Once the complete requirements set has been extracted from the interviews, any conflicting or ambiguous requirements will be resolved using the delphi method, to gain agreement from the experts in the areas that show discrepancy in the requirement characteristics required performance.

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After matriculating at Marizburg college, Jeremy enrolled in a general engineering degree at University of Natal, Pietermaritzburg campus. This enabled him to apply for bursaries to complete his studies in many of the engineering disciplines. A bursary from DeBeers for mechanical engineering allowed him to head to Stellenbosch University, where he completed his mechanical engineering undergraduate degree. DeBeers kindly differed his bursary obligations for a time, to allow him to peruse a masters degree in Mechanical Engineering, also at Stellenbosch university.

After university he moved to DebTech in Crown Mines, Johannesburg, to work at the research and development group for DeBeers diamonds. He Completed the engineers in training program, and enjoyed a one year secondment to the Diamond Trading Company research group in maidenhead England, just outside London. The recession saw a contraction of diamond sales, and a shrinking of the research team. From over 500 when he joined to only 42, 10 years later.

An opportunity at the CSIR Centre for Mining Innovation, to build an R&D team to develop a robotic mining team for ultra narrow deep tabular orebodies, drew him away from the shrinking diamond business. It turned out to be to an also shrinking gold mining business. After 5 years, and an equal number of prototypes, the Center was shut down in 2014, and the resources reassigned around the CSIR.

During this time He had moved to the USA (June 2012), and was only working part time as team leader, while also working on his PhD through the University of Johannesburg. The change in employment status relaxed restrictions on his thesis scope, and after some 'topic wondering' he settled on requirements elicitation techniques for research projects, specifically in the development of an underground unmanned aerial system.