Advances in Remote Semi-autonomous Monitoring (Utilising Drones, UAV & Robotics to inspect substations & power lines)

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EEA Conference & Exhibition
Auckland
2014, 18 – 20 June

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(Utilising Drones, UAV & Robotics to inspect substations & power lines)

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1. Background

With the advances in computer processing and associated size reduction in sensors, it is becoming possible to utilise "Drone" or line-crawler systems to undertake routine examination of network assets. (And if you believe Amazon – deliver packages and pizza.)

Officially named "Unmanned Aerial Vehicles" (UAVs) the Federal Aviation Authority (FAA) estimates there will be 30,000 flying within U.S. airspace by 2035. As their cost to own & operate drops and the technology becomes more accessible, a new opportunity has been created for everyone, from the government to farmers, real estate agents to network owners and more. Size is no longer a restraint (See Black Knight UAV that will take off with a fully laden weight of approximately 1900 Kg!). Software systems allow a smart phone or iPad to control semi-autonomous devices with "one touch" control.

Current aerial drone prototypes have capability to detect other aerial vehicles and take collision avoidance action without operator involvement.

What is the next step?
As drone (both UAV & crawler) technology evolves, what are the drivers and
Are there technical, social and ethical implications?

Line crawlers have the potential to do detailed inspections as well as on-line repairs at full voltage.

This paper looks at some of the recent advances in semi-autonomous mobile remote monitoring and offers a glimpse into some of the competing systems that are being tested. The presentation consists of a discussion of some systems that could be useful in network applications and shows of a few videos (currently not available to the public) to illustrate the progress.

As ever, the presenter does not claim to have the answers, just a lot more questions and possibilities!

2. Drivers

The drivers include:

Revenue - Financial cost of "manned" operation & observation (i.e. helicopter, truck or by foot), including cost of the vehicle in the event of an accident.
Environmental cost & footprint including fuel.
Reliability – towards asset optimisation
Recruitment & payroll costs - Skills availability (i.e. pilot).
Routine - Ability to repetitively perform "boring" tasks without error

Improvement in speed of processing & reporting
Risk & Safety
Relational - PR & attracting young engineers
Ability to multi-task (semi autonomous)
Opportunity for Hidden/anonymous observation (i.e. vandalism)
Physical limitations & access issues - Beyond line of site

3. Alternative Approaches

Development has moved in a number of directions, but for the purpose of this discussion, we have focused on two leading directions:

A sub-sector of the UAV – Quadcopter (As opposed to fixed wing & helicopters)
A sub-sector of live on-line travelling (crawling) robots

All devices had to be able to complete out-of-sight sorties and deal in an autonomous manner with a range of expected problems – even though current Civil Aviation Authorities do not allow UAV's to operate out of line of sight.

4. Quadcopters

Quadcopters benefit from the following:

- Ease of launch (VTOL versus fixed wing, no pylon climbing required.)
- Ease of operation & hence program control.
- High rate of travel (Not as high as fixed wing)
- Robust & stable flight, even in gusty conditions
- Ability to "limp" in the event of a motor failure – making rescue simpler
- Reduced blade noise & turbulence when compared to helicopter systems allowing opportunities for broader applications

Software for semi-autonomous systems is now available, including "Free Flight" models controlled from smart screens with a radio transmitter attached.

Some of the restrictive factors include:

- Payload
- Energy demand for flight and hence duration of inspection.
- Distance of approach (due to corona issues, not due to detection of conductors, navigation or stability.)
- Civil Aviation restrictions for non-line of sight operation and avoidance capability.
- Rescue issues in the event of failure of communications (very difficult to locate an errant UAV that can fly 5 km in any direction) or loss of power.

Current UAV capability is typically

- 20 minutes flight covering approximately 7 km while carrying up to 5 kg in calm to medium wind conditions.
  - As a comparison a small gas powered helicopter will do flights of about 4.5 hours covering up to 300 km while carrying up to 15 Kg.
  - The larger Schiebel unit is able to fly for about 6 hours covering 50 to 200 km (using external tank & reduced payload) with a payload of up to 34 kg.

5. "On-line" Robots

Robots designed to travel on the conductor benefit from

- Closer physical inspection capability
- Lower power utilisation & hence longer inspection runs
- Higher payload weight capability
- Some able to do basic repairs – i.e. clamp loose strand.
- Stable in medium wind conditions
- Ability to traverse line dampers, aerial markers, insulators & droppers.
- Ability to launch via non-conductive rods and cope with corona issues (No line shutdown)
- Do not require coordination with Aviation Authorities etc.

They require specialised programming, but allow concise program control.

Some of the restrictive factors include:
- Tower launch required with live-line staff
- Rate of travel
- "Rolling axle" style robots are usually only applicable to lines that are duplex or greater.

6. Quadcopter tests

Corona issues when approaching live lines is being cautiously explored. (See parachute protection below)

Video

7. Autonomous Software

Current software development is focusing mainly on the challenge of robustly determining the position and velocity of the UAV, in three dimensional space, using on-board Simultaneous Localisation and Mapping (SLAM). This is referenced the launch point and may integrate with "Google Maps" and does not necessarily need a GPS location once calibrated.

Although capable of autonomous flight, the UAV is primarily intended for semi-autonomous operation, where the operator instructs the UAV where to go. However, if communications with the ground station are lost, it can backtrack along its path until communications are re-established. Civil Aviation restrictions on flying outside of line of site apply in NZ and are a limiting factor when considering true remote operation from a central control room.

Video

8. UAV Capability

220kV EHT Transmission Line at Shankerpally, AP, INDIA – Video from Venkat

Video – 220, 15 & 33 kV line survey + Corona camera – multiple sources.

Currently testing UAV which can fly within 5m from 350 KV lines and do this for around 300 km on a 7 litre fuel tank. The UAV uses GPS for "coarse" guidance, and then object recognition and video target finding to track the line. This video system is also used to calibrate and correct the fine guidance. Data feed is to a ground station that can be up to 1000 km away.

We consider that if the UAV approaches closer, there could be a potential surface arc on the UAV and it may be knocked out. As a precaution we've implemented a ballistic parachute and a shaped airbag to move the UAV away from the line and ensure a soft landing - it is automatically deployed the moment the UAV goes "crazy" or loses power. ("It's just not cool dropping Euro 250K's worth of hardware onto the ground from 10+ meters.")

The camera will experience the same interference as the MultiCAM hanging under the line walker.

Onavir's range of platforms can be operated as an on-site, visually remote controlled system or sent on a mission using a pre-constructed 3 Dimensional flying plan, with or without a human intervention.

The UAV Company is working on a website with new branding and look. http://onavir.com/

8.1. Next Steps

- Advances in simplification of user interface while increasing the power of the autonomous software, especially for collision avoidance.
- UAV with fully silenced sound capability with self contained mic/speakers allowing corona "crackle" to be heard & hunted.
- UAV with actuator arm to install specialized Clamps to fix a damaged portion of the Conductor.

Further information provided by Venkat.

9. Line Walker RSA

Progress has been made on two fronts:

- High-voltage testing of the prototype in laboratory (up to 100 kV, limited by the lab setup), and
- Progress on design of a pre-production version.

Developers are testing if the robot hanging from the live conductor will generate a corona glow which may reduce the sensitivity of its on-board CASs camera.

The HV testing has been quite interesting. The way that we deploy the robot (rolling from the tower to the line on an insulated rod) causes arcing when the floating body of the robot gets close enough to the live conductor. During the lab tests, the arcing interfered with the communications between the ground-station and the robot. We measured the frequency of the noise coming from the arcing and found some of it to be close to the comms frequency of 2.4 GHz. Next generation prototypes now have a sophisticated antenna system that has been found to be very effective in eliminating the interference. We're still working with EMI experts on our understanding of exactly why some counter-measures are more effective when they don't follow the theory!

Once rolling along the live conductor, the robot works normally, as the entire machine (including its electronics and on-board computer) are electrically at the same voltage as the conductor.

So far during HV testing, we've had no hardware failure, which indicates that the overall engineering is sound.

Next stage – run the prototype in ESKOM HV test facility with full-scale mock-up lines and increasing voltages from 200 to 400 kV.

Video & photographs from Trevor including lab tests at 100 kV for Corona

10. Evolution of control systems

The use of SLAM (See section 7 above) has accelerated the ability of innovators to improve semi-autonomous operation, as well as making the interface with end-users easier. Control has shifted from dedicated "radio control" style controls to "game style" interfaces on smart phones using video feedback and first person view.

Video – evolution 6 – from computer control, to dedicated remote control to smart phone.

Appendix 1

11. The ideal of a "$10,000 Corona Camera"

If Infra-Red cameras have dropped in price so rapidly, what about Corona cameras?

Until there have been advances in a number of key areas we do not see the price of corona cameras coming down in the immediate future, aside from economies of scale price reductions. As always, developers are funding research to find those "disruptive" advances that will kick over the whole "established" market and allow better and cheaper products to the market.

11.1. Technology - IR versus Corona

External Partial Discharges (Corona, Sparking & Arcing = CSAs) are not as easy as Thermal inspection - a hot spot is easily located using image processing, quantified and classified as too hot given simple rules.
CSAs on the other hand can only be classified as a problem once the observer has identified the cause based on the visual image under the discharge blob. This image is usually complicated and at this stage would require a human operator.

The current restricting factor is the resolution of the camera; work continues on higher resolution cameras, but they are nowhere near approaching multi-Mega Pixels like SLR's. This resolution limitation, unfortunately, one of the limiting factors in identifying the cause of the CSA activity from the on-board images.

11.2. Physics & debate over operation

As for the UV glow, remember that the corona light emission is at that plane in the electric field where the ion/electron causing the ionisation has slowed down enough to in-elastically interact with gas molecules.
If it was elastically, the molecule would just emit another electron and no glow would occur. For a point, the plane on which the corona light emission would occur is a hollow sphere. The diameter of the sphere is dependent on the electric field strength.

Shout, comment, write, call out if you don't agree with this one, the developers have asked various physics scientists and even they can't agree!

There is some evidence to suggest that the corona light is emitted perpendicularly to the direction from which the ion/electron impacts on the molecule. Sadly the electric fields are usually so complex or small that we cannot (at present) use this idea to determine the local field strength.

11.3. Interference & false results

Air heated to over 1000 Deg C will emit UV, so if a metal foundry/smelter has an "open barn" design you will get UV scatter out of the building. Thus Smoke Stacks at industrial facilities dumping hot air can also be a source of UV which can be erroneously detected.

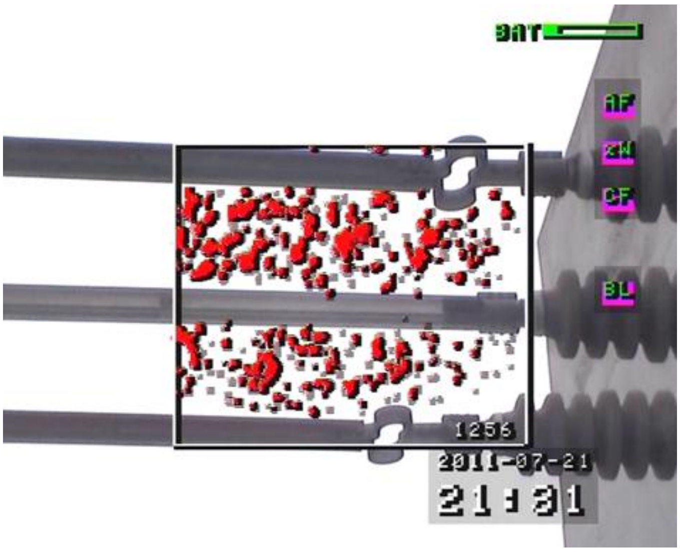
Welding, grinding, some lasers, some light sources & field fires can cause UV emissions in air which the camera can detect. Lasers are specifically becoming an issue near military facilities as a number of western militaries are switching to UVc lasers for secure short range comms.

(Monterey in California (where the US Navy has a research facility) is almost a “no-go” area for UV inspectors as secure c-laser communication systems and UVc based target and rescue markers experiments are causing lots of “noise” for UV detecting systems.)

A number of developers currently have Ph.D students building programs for optimal UAV flight path planning specifically for inspection of various design pylons and conductors. This includes RSA, Penn State etc.

11.4. Examples of False Readings

The CSAs intensity is not related to its severity and the intensity is affected by many different variables - some causing up to a 20% increase in UV intensity. The blob indicating the CSAs presence can "bleed" around the structure on which the discharge is taking place. Causing it to be seen, but the actual cause hidden.
CSAs are intermittent; time between pulses can be seconds. Again the theory on why this occurs is sketchy! As noted above, various false signals can cause the camera to generate an alarm when it's not a true corona event.



Example of UV scatter from industrial activity (welding & grinding) reflecting off a low cloud ceiling in Lima, Peru.

With present technology CSA source will cause an event trigger, then the operator needs to locate it on the hardware, and arrange a physical inspection to determine the cause.

11.5. Next steps

3D capable camera to facilitate the location – i.e. disregard false positives that occur behind the structure. Requires suitable separation of camera view points.

The ability to “silence” the UAV/Crawler opens the door to the use of audible detection of corona – the idea being it will reduce false positives and assist in accurate focussing. Venkat to provide test data.

PEOPLE

Kristian Jensen graduated with a BSc(Hons) Electrical Engineering and then completed an MBA while working in the mining & heavy industrial sectors across Southern Africa. He has been involved in a number of areas from 11 kV switchgear design to arc fault containment, specialised surge protection and transmission projects up to 220 kV. He brings a “big picture” approach to projects which are combined with a knack for finding the right multi-disciplinary teams to crack problems. He is an active LEAN proponent and has spoken at a number of productivity seminars.

Trevor Lorimer graduated as a Mechanical Engineer and went on to receive a master’s degree in Electrical Engineering, at the University of KwaZulu-Natal, RSA. He is currently a researcher at the same institute, where his focus lies in power line robotics. He works with a number of High Voltage utilities including Transpower (NZ) and Electricity Supply Authority of South Africa (ESKOM). He has one patent (South Africa), and an application for it has been filed under the PCT.

Venkat Chundi has a BCA in computer science and an MBA (IT) from Alagappa University, India and over 18 years experience in the international telecommunications sector. This includes R&D work undertaken mainly in USA & India on communication systems. He is currently a Vice President with GSR Technologies Inc USA.

Appendix 2
References, Acknowledgements and Articles of Interest

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Olivier Küng, co-founder of Switzerland software company Pix4D, 2013 TEDx talk in Lausanne, Switzerland.

APPENDIX 3

The evolution of aerial platforms:

1. **Multicopters, not planes.** UAV's started with fixed-wing aircraft, but quickly realized that most locations don't have landing strips. Even short takeoff-and-landing planes get hammered quickly in regular use without dedicated landing areas, which few locations have. Meanwhile, multicopters, which can take off and land anywhere, are gaining endurance (see figures above & in slides). Planes are only suited for the largest sites on long surveys – even then the requirements to remain within line o site is a problem - missions need to be planned very carefully to find places they can reliably land.

2. **Phones/tablets, not laptops.** People don't want to drag laptops into the fields. Any drone that is expected to be used by regular consumers should be entirely operated by a standard (Apple or Android) smartphone or tablet. Engineers will accept more complexity, but want much more power from the software in return.

3. **One-click auto missions, not "flying".** Likewise, customers & consumers don't want to have to fly things. UAVs should be fully-autonomous, from takeoff to landing. The experience should be as simple as pressing a "Start" button on a phone and the drone flies the entire mission on its own.

4. **Fly the camera, not the aircraft:** What the customer is interested in is a picture — not the acquisition of the picture. Let sophisticated planning tools figure out precisely how to gather the right images, let autonomy take care of the details of flight dynamics, and let humans do what humans do best — specify high-level details & directions.

5. **Video can be worth more than stills.** Don't discount how good customers are at spotting things with their own eyes. Sometimes a first-person-view live video feed will allow them to spot issues and direct the vehicle to more closely inspect the problem area. (Needless to say, this is only really practical with multicopters). Indeed, customers may not even know what they're looking for initially. Sometimes general situational awareness is the task, rather than delivering a specific data product (such as a mosaic).

6. **Flexible Platforms**. Numerous authors anticipate a big move towards payload systems that are swappable and removable. It always comes back to ease of use. A user will be able to collect more of what they need, when they need it, Nuilha

understanding what is happening and taking action. Often there isn't an opportunity to go back out and get the data again.