Project Ngulia: Tracking Rangers, Rhinos, and Poachers

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Abstract—Poaching and wildlife trafficking is an escalating problem. The park rangers today are not only conservationists, they are also the guardians of critically endangered animals in the field. Many of them have been killed in recent years in the line of duty. The rangers in wildlife organisations have paramilitary training, but their equipment is very basic. Often the poachers are better trained and equipped than those seeking to protect national parks from intruders. Smart security technology—from communications tools to surveillance sensor technologies used for protection of critical infrastructure—is needed. In this paper we describe how innovative, cost-efficient technology can be used to assist wildlife organisations to combat poaching and wildlife trafficking. We use an ongoing pilot initiative, project Ngulia, led by the Kenya Wildlife Service aimed at protecting wildlife and other natural resources in Kenya.

INTRODUCTION

A WILDLIFE CRISIS—WITH GLOBAL SECURITY AND DEVELOPMENT IMPLICATIONS

On a bright day inside the Ngulia Rhino Sanctuary in Tsavo West National Park in Kenya, the guardians of the rhinos—the park rangers—can see as far as Mount Kilimanjaro. It emerges beyond a layer of other peaks that surround Ngulia, which stretches out over a 90 km^2 area. The area is called rhino valley because once upon a time 10,000 rhinos roamed here. Today, rhino valley is a shadow of its meaning. In the 1970s, Kenya was home to 20,000 rhinos. Today, there are only 650 left. The region's elephants have also seen significant reduction in recent years and this depressing story is all too common around the world. Between 2010–2015, almost 5,000 rhinos were slaughtered by poachers. Equally troubling, some of the world's worst terrorist organizations and transnational criminal syndicates are benefitting from this heinous activity and other environmental crimes. Indeed, the Islamic State, the Sudanese Janjaweed, Joseph Kony's Lord's Resistance Army, Boko Haram, and Al Shabaab are all directly or indirectly involved in raping mother earth of its wildlife and natural resources. For countries that rely on the tourist-popular animals, widespread poaching and other wildlife crimes are detrimental to their economic viability. The Kenyan tourism sector, for example, represents 15 percent of the country's gross domestic product (GDP). No animals to attract tourists with, means lost jobs and lost revenues. The problem is today well described in media, and for further reading on wildlife and environmental crime, we recommend [3], [4], [7], [9], [11], [15], [20], [25].

A GLOBAL RESPONSE EMERGES

As the national security and development implications from poaching and wildlife crime is becoming clearer, countries around the world are responding. In 2013, U.S. President Barack Obama and his former Secretary of State, Hillary Clinton, initiated a process that has led to a new U.S. national strategy to combat poaching and wildlife crime. Not only environmental agencies around the world are asked to up their efforts. Even the United States Department of Defence has been given marching orders to support the mission of safeguarding wildlife and other natural resources. The United Kingdom, Germany, the United Nations, the European Union, and a slew of other public and nongovernmental organizations are also spending more political capital and resources on the problem than at any other time in history.

PROJECT NGULIA: TECHNOLOGY AND INNOVATION ON EMERGING MARKETS

Project Ngulia is part of the global response to this wildlife crisis. Led by the Kenya Wildlife Service, the government authority charged with protecting Kenya's wildlife, a public-private sector consortium has come together to create a new gold standard for wildlife and natural resources protection. The project has the backing of some of the world's leading voices in the field, as well as the best technological competencies from both the academic and the private sector. We have a pilot project up and running in the Ngulia Rhino Sanctuary and we have a test site in Kolmården Zoo. The end result will be an impactful, cost-effective, and bottom-up technological platform that secures Ngulia, but that can also be scaled and replicated elsewhere. Our model has received international recognition by, for example, the Clinton Global Initiative and key members of the United States Congress.

BUSINESS OPPORTUNITIES

We want to save animals. We also know that no project is sustainable without the private sector seeing a commercial value in participating. Project Ngulia will do good, while at the same time present unprecedented opportunities for participating companies to break into new markets in emerging regions. Think for a second about what this and future applications of the project are trying to safeguard: wildlife, forests, and oceans. These are economic engines for countries in the same way that ports, energy infrastructure, and borders are. And all of these critical infrastructures need protection and the market for protection of critical infrastructure globally is vast. Project Ngulia is an unprecedented opportunity to prepare for this expanding market, reaching new costumers and finding new value for their products and service.

RESEARCH OPPORTUNITIES

No doubt, there are many positive effects and intentions of this pilot project. However, the purpose of this contribution is to highlight the connection to sensor fusion as a subject area in research. The research aspect of the project is two-fold: demonstrator opportunity and a test site to provide real data from a real application.

First, there is an increased demand from funding agencies and industry that research should benefit society, and that demonstrators are the first step to show relevance for real applications. In contrast to this bottom-up approach, funding agencies such as the European Union also define societal challenges from which research programs are defined. Both these trends aim at overcoming the "valley of death", commonly used to illustrate the gap between research at universities and development in industry. Project Ngulia provides ample opportunities to demonstrate research results, and perform long-term tests in real environments. Ultimately, sensor systems and platforms provided by industry together with fusion algorithms developed in this partnership can come quite close to complete products.

The Poaching Problem

- 140,000 elephants and more than 3,600 rhinos have been slaughtered by poachers since 2010.
- Over 1,000 park rangers have died in the past decade while defending the animals.
- The illegal wildlife trade currently generates between \$7–23 billion a year—more than the illicit trafficking of small arms, diamonds, gold, or oil.
- A rhino horn is worth more than \$65,000 per kilogram on the black market, which is more than gold or platinum.
- Between 35,000–50,000 elephants are killed every year in poaching; three rhinos are poached every day.

Second, researchers need real data for algorithm development, and the project will feature a test site at a zoo, where networks of heterogenous sensor systems will be deployed. Ground truth can be obtained by putting Global Position System (GPS) loggers on both humans and animals. All data will be accessible in real time from a cloud database, and algorithms can be illustrated for the general public through a web application programming interface (API).

It is the purpose of the remaining paper to explain these aspects in more detail.

TECHNOLOGY FOR WILDLIFE MONITORING

Using technology for wildlife monitoring is an old research area, and an early textbook on the subject is [27]. A recent survey of sensors for wildlife monitoring is provided in [6]. They use the taxonomy in [19], where a survey of different models for animal movement is presented. They divide the models and sensors according to whether they monitor trails of individual animals (called Lagrangian approach) or the presence of an animal at a specific place (called Eulerian approach):

- Tracking sensors: GPS, RFID, inertial sensors, radio transmitters.
- Surveillance sensors: radar, sonar, camera, thermometer, PIR, thermal camera, electronic noise, microphone, geophone.

An earlier state of the art survey of tracking technology is presented in [22], where the conclusion is that GPS is the most cost-effective tracking device, but that there are other radio-based options.

This section provides an overview of state of the art in research and technology initiatives. These initiatives are usually not described in the scientific literature, but more information is easily found by searching the Internet for the keywords we provide below. A common theme is that most initiatives are centered around a technical product or a single technical concept. A few of the initiatives selected below include several technology aspects. As we describe in the following sections, our approach differs significantly as being a bottom-up approach, where small technology and training steps are taken in a long-term holistic plan.

CAMERA SURVEILLANCE

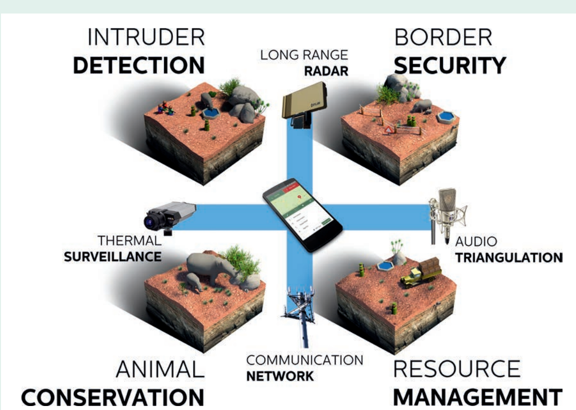
A common theme in many initiatives to detect poachers in the park at the same time as monitoring wildlife, is to put camera traps along the animal trails. The use of camera traps for wildlife monitoring is very old, and a good survey of the history is provided in the textbook [5]. With the advance of machine learning, these camera traps can be quite sophisticated. The traps can analyse the video stream in real time and save a still picture of large objects appearing in the scene. The built-in software can be more or less advanced in classifying images according to object and relevance [18]. Communication is as always a challenge, and both manual collection of memory cards (mostly for conservation purposes) and real-time transmission via cellular or satellite communication systems are used today. Among such initiatives we mention:

- The development of low-cost nano-satellites by NexGen Space LLC (US). The idea is to allow for large scale camera trap deployment, at a much lower cost compared to regular satellite communication. Surveillance sensors: radar, sonar, camera, thermometer, PIR, thermal camera, electronic noise, microphone, geophone.
- The smart camera traps Trail Guards by Wildland Security (US) include software for classifying humans. This meta information with pictures is transmitted by GSM or satellite to selected recipients.
- Instant Detect by Zoological Society of London is another camera trap initiative that has been running for some time. Its focus is wildlife monitoring, and they are using an app for crowd-sourcing manual classification of images.
- Binomial Solutions (India) is developing surveillance cameras, including thermal cameras, that include algorithms for learning animal movement pattern.

Ranger Duties and System Overview

The ranger duties include:

- Conservation: observations of individual rhinos and their condition.
- Border protection: patrolling the border by foot or by vehicle, looking for footprints or any other sign of intrusion.
- Intruder detection: poachers can rather easily pass the border, and the rangers are looking for footprints and cadavers.
- Resource management: the logistics include getting supplies out to the field and paper reports back to the headquarters, using one vehicle serving a vast area.



RADIO AND ACOUSTIC SURVEILLANCE

A survey on radio tracking methods for wildlife monitoring is provided in [14]. A particle filter based tracker is proposed in [13], where an airborne radio scanner measures received signal strength (RSS) from radio tags on the animals.

A similar approach was further tested in [21], but with a least squares approach to localisation. However, the purpose here was to find cell phones, for instance from missing people or poachers.

The field of acoustic monitoring of wildlife is surveyed in [8]. There is at least one initiative to develop microphone networks to monitor remote areas for gun shots, chain saws, motorcycles, etc. Technology Exploration Group (US) is using such a network to support unmanned aerial vehicle (UAV) missions. Further, MIT media lab has developed a ground sensor consisting of microphone and PIR motion sensor, which has been tested in Tsavo, Kenya.

AIRBORNE (DRONE) CAMERA SURVEILLANCE

The use of drones to monitor wildlife in vast areas is of course a very appealing approach, and there are many initiatives in demonstrating this approach also for antipoaching purposes. However, there are many hurdles to overcome, and large-scale sustainable deployments seem still far away. A general view of using robots to monitor wildlife in different environments is provided in [10], while below we mention a few initiatives in the field:

- The Air Shephard initiative is a collaboration between the University of Maryland, the Lindberg Foundation, and the Piece Parks. See also the Anti-Poaching Engine below.
- AidDrone uses infrared (IR) cameras to monitor the parks, and this combination has been evaluated in 52 parks in Kenya among other places.
- Wildeas has evaluated some 50 different drones for savannah monitoring. This company has also training and other sensor systems in their portfolio.

Also, manned aircraft are still used in some initiatives:

- ZAPwing is an initiative to use manned aircraft to monitor selected parks, which today covers at least 24 gaming reserves.
- Ichikowitz Family Foundation (IFF) donated a couple of helicopters to South Africa National Parks (SANparks), as a collaboration with defence industry through the Paramount group.

A machine learning algorithm is proposed in [18] for using a combination of airborne EO and IR cameras to automatically classify humans, rhinos, or other animals.

TRACKING DEVICES

The use of GPS tags is a convenient solution for tracking individual animals [17], and there are now lightweight units that can be used even on relatively small animals such as birds. For migrating birds where GPS cannot be used, light loggers is an alternative, and a tracking application based on the particle filter is presented in [26].

Energy constraints for using GPS, computations, and communication form a challenging design and optimisation problem as described in [12]. One promising solution is studied in [16]. The idea is to only use the GPS receiver for a few milliseconds every time a position is required, and let the server perform the computer-intensive and information-intensive computations. This reduces the receive time and computations several order of magnitudes, with a limited requirement on communication.

Many of the larger initiatives are also evaluating tracking devices on the animals. A spectacular trial has been performed by Piece Parks. With donations from the Dutch and Swedish post code lottery, Piece Parks has invested in a Rhino Protection Programme. In total, almost 50 million Euros have been donated to this programme, of which 15 million was during 2014. This is thus one of the largest programs in this field, and involves everything from night vision goggles to drones. The donation 2014 was used to a large extent for a sophisticated rhino horn marking project. The rhino horn is equipped with GPS trackers, color (to make the grinded horn less attractive), poison (that makes the end users sick but not dead), and radioactive isotopes (to detect rhino horn in the customs).

BACKEND DATABASE TOOLS

There are several software platforms for wildlife monitoring, such as SMART (Spatial Monitoring and Reporting Tool) [1] and Cybertracker [2]. These have been around for some time, and were originally developed by conservation practitioners.

Cybertracker is a field tool primarily aimed for reporting direct or indirect (tracks) animal observations. Today, Cybertracker is a combination of desktop and smartphone software that can be used by the rangers to report geo-tagged information about wildlife, and also human activity.

SMART was launched in 2013 as a tool to collect and analyse geo-tagged data offline, as a collaboration between multiple conservation agencies. SMART was originally developed as a desktop application for organising and visualising data from patrol reports as an off-line tool. Designing a database for wildlife reports can be challenging in itself, and [23] highlights the importance of unified data formats when handling biological data with GPS geotags. They suggest a modular software structure with a geospatial database as the core. They discuss the various requirements on the database management system that wildlife monitoring applications require.

During the 2015 Wildlife Crime Tech Challenge, there were several finalists that proposed software platforms for wildlife monitoring.

PROJECT NGULIA: TRACKING CHALLENGES

The poachers hunt the rhinos, the rangers hunt the poachers, and the rhinos are at risk. On top of this, the commanders are trying to coordinate the defence against the poachers, and the researchers are monitoring the health and conditions of the rhinos. Thus, the commanders and researchers are in great need for situational awareness, which ideally includes tracking of rhinos, rangers, and poachers. On the other hand, the poachers should under no circumstances get access to this information, or be able to use the same technology, for their heinous purposes.

Tracking these actors needs different information sources as described in this section, where also perspectives of this challenge are provided. Illustrations are in all cases results from our field tests in the local wildlife park Kolmården.

RANGERS

The ranger positions are most easily obtained with GPS. Our solution includes that each ranger has a personal smartphone that logs GPS coordinates and uploads these to a cloud database. All reports are also geo-tagged and time-stamped automatically.

RHINOS

Also the rhino positions can be obtained with GPS, and there are special collars or foot rings developed for this purpose; see Figure 1 for one example of a product from one of our partner companies. Another partner is developing a device that is put in the thick skin of the rhino's neck, which also measures body

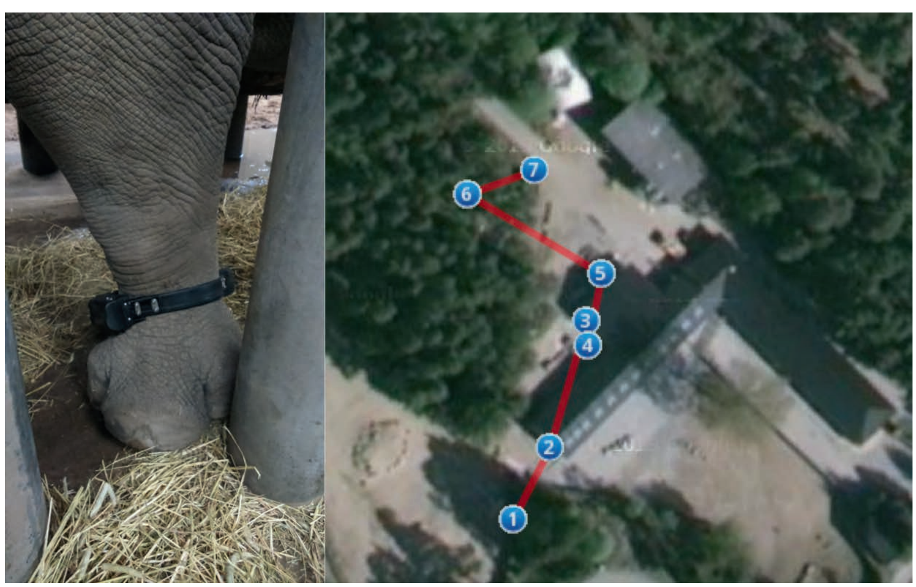


Figure 1
Example of a foot-mounted GPS tracker for rhinos. Position 6 is apparently a GPS outlier, so sensor fusion of step detections from accelerometer data to remove outliers is one research challenge. Pictures by Kolmården Zoo and FollowIT.

The Control, Command, and Communication System

A control, command, communication, and surveillance (C3S) system can include:

- A mobile platform (smartphone) for the rangers' digital reports.
- A mobile platform (tablet) for the commanders for situational awareness and command central.
- Additional infrastructure to secure robust wireless communication, perimeter protection, and wide area surveillance sensors.
- The C3S system is implemented as an app on smartphones. The first purpose of the app is to facilitate the daily work of the rangers to monitor wildlife, improve the logistics of resource management, and finally to protect the border and detect intruders. For safety reasons, among others, the ranger app is mainly an input device, where they send information to the cloud. No sensitive data are accessible from the app.

temperature and heart rate for health monitoring. It remains to be seen if any tracking devices will be on or inside the animals.

One drawback with having devices on the rhino is the powering. Batteries have a limited life-length, a couple of years for the products we are aware of. However, the rhinos cannot be tranquillised more than once during their life due to the stress it causes. Energy harvesting seems still not mature, and solar panels will suffer from dirt and wear.

Rhinos are also observed by the rangers. In fact, this is one of their main duties. This gives irregular observations over time, with rather good position accuracy. There are two kinds of reports they do.

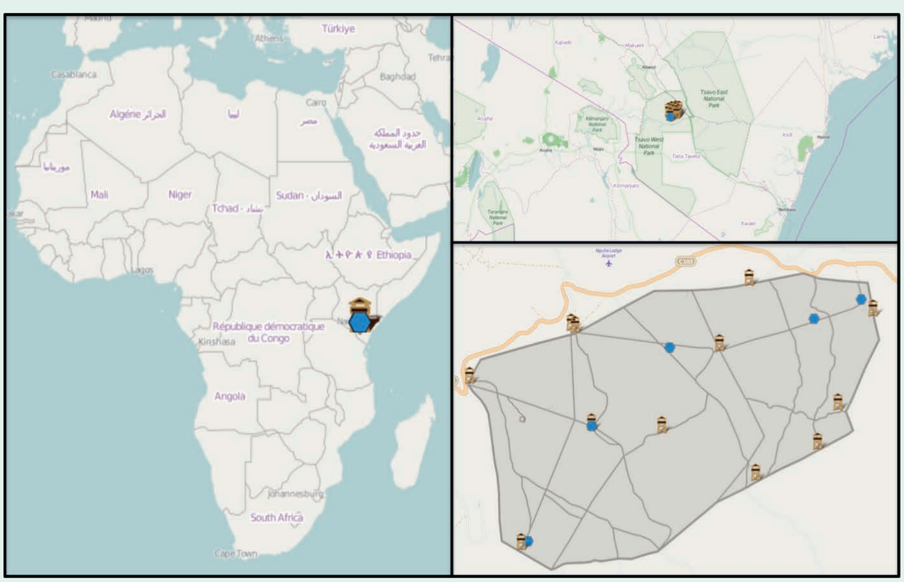
- Direct sightings in the field or more commonly at the waterholes. The identity of the rhino can be determined by ear notch markings, but this requires observations of close distance where both ears are visible. Otherwise, incomplete id data are obtained, which implies an association challenge.
- Indirect sightings, for instance droppings, browsing traces, rest places, and foot prints. These have poor time resolution. Sometimes, droppings are sent for DNA identification, for the purpose of building up a database of DNAs, but which also provides the identity of the rhino (but with a long time-delay).

Sensors can also assist in rhino tracking. Thermal cameras, for instance placed at the waterholes or the trails that they often follow, can detect and classify rhinos, but without identification of individuals. A radar can probably also give an indication of possible rhino position and speed. Ground sensors and microphone arrays and networks are future possibilities.

Fusion of sensor data with manual reports is in fact a challenging research problem in itself. Sensor data includes a precise time stamp, while indirect sightings from tracks, droppings, browsing, and resting has a large time uncertainty, but no position errors. Some initial results are presented in [24].

Ngulia

The rhino sanctuary Ngulia is situated in Tsavo West in the southeastern part of Kenya. Ngulia is about 90 km^2 large, and the border is 42 km long.



POACHERS

One way to detect poachers before they reach the border is by using camera traps along the trails. A radar with a 5–10 km range can also give indication of approaching humans.

Once the poachers reach the border, there is a range of border protection systems available. Laser and microwave barriers are one solution. Other solutions include IR detectors and surveillance cameras. All these have a limited range and require line of sight. The Ngulia border consists of long straight parts, but still up to 100 surveillance cameras would be needed to cover the 42 km border. Geophones are an option to detect footsteps, but with an even shorter range.

There are a few emerging technologies with a longer range. A wire pair can be configured to be a metal detector using the change in induction. Such a system can reportedly detect as small things as a zip. Fiber loops can also be used to sense vibrations in the ground and detect footsteps and vehicles.

The rangers provide manual and indirect observations of poachers, when they patrol the border to look for footprints. The area on both sides of the fence is regularly raked, to make it easier to detect the footsteps.

In the case that the poachers successfully enter the sanctuary, tracking becomes even more important. Again, camera traps along the trails and surveillance EO and IR cameras at hotspots (water holes) can be used.

Finally, if they use their guns, the shot can be observed and reported by the rangers, and microphone networks can detect and localise the shot.

RADIO DETECTORS

A network of radio detection and bearing units can be a powerful tool to prevent radio communication for the poachers. The point is, even with only a few units, all GSM phones inside and outside the sanctuary can be detected and located. A larger frequency band can be scanned, to also find other communication devices.

A detected cell phone can easily be associated with an intruder. First, the ranger positions are known to the system, so these cell phones can be eliminated. Second, during

Outreach Activities

Selection of outreach activities:

- Demonstration of the app platform by Martin and Fredrik for the Swedish king in April 2015.
- Fredrik in discussions with the Kenyan ambassador to Sweden and the former minister of development in Sweden, at a workshop at Kolmården Wildlife Park November 2015.
- An article published in the *Washington Post* by Johan.
- Senator Chris Coons at a meeting at Stimson Center, talking about a Wildlife crime bill currently under consideration by the U.S. Congress.
- Johan presents the project at a Clinton Global Initiative luncheon 2015 with President Bill Clinton and Secretary Hillary Clinton.

Figure 2
Experiment with localization of a cell phone by measuring the RSS from a drone. The left picture shows a snapshot image from the drone, while the right picture shows the operator view, where the measurement positions are marked with yellow, and the estimated position after each measurement is illustrated with red. The true position is also marked here for reference. Picture from [21].

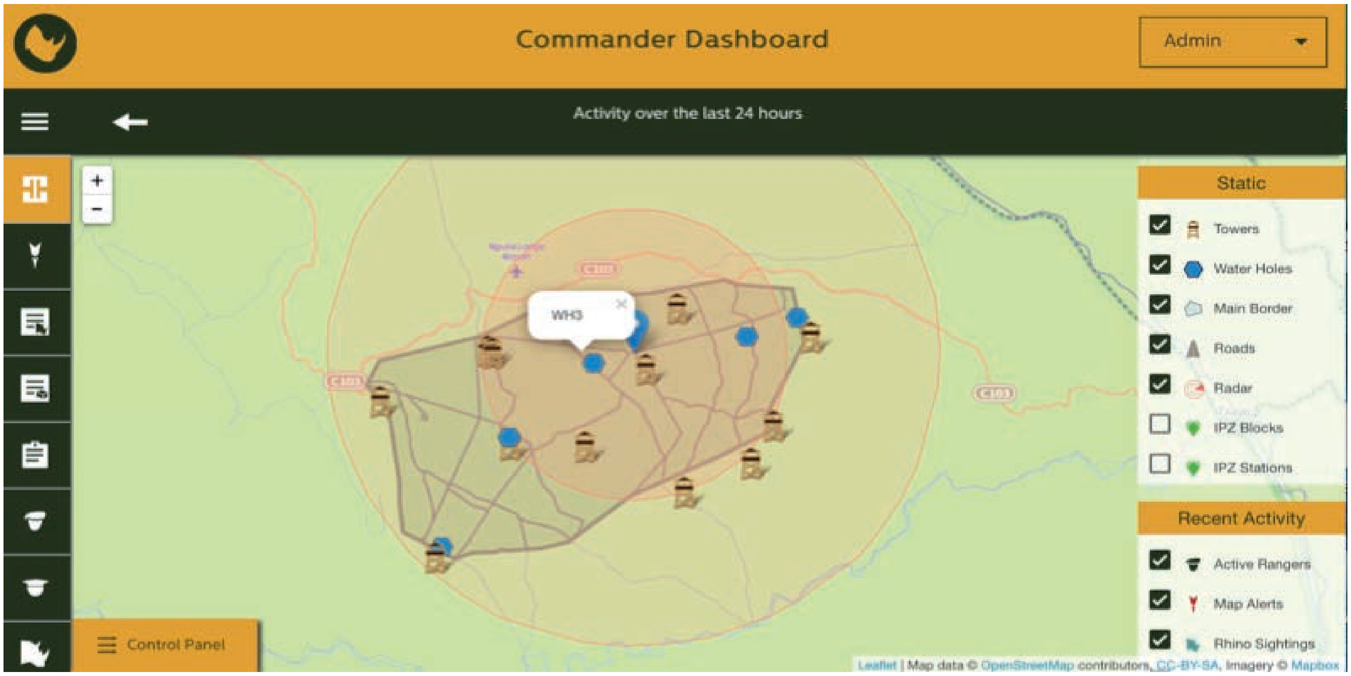


Figure 3
The commanders have an app with extended functionality, where they can access all data from the cloud. One of the map layers illustrates with circles the potential coverage for detecting humans and vehicles, respectively.

Figure 4
The top picture shows the operator view of a radar system, where the green dots mark the detections. The right view shows an image from a camera mounted on top of the radar. There is a rhino to the right and a human marked with yellow to the left. Top picture provided by Meteksan Savunma.

nighttime, the whole Tsavo park is closed for visitors. During daytime, visitors are only allowed in vehicles on the road network. Further, when visiting Ngulia 4–6 pm, they need to check in at the gate, and can after this be followed during their visit. All cell phone positions that do not correspond to any of the conditions above are thus very suspicious. Figure 2 illustrates a field test as reported in [21], where a radio receiver mounted on a drone is measuring RSS, and the location of the cell phone is iteratively improved.

High Demand

Rhino horn is valued higher per kilogram than gold and cocaine.

RADAR

A radar has the potential to be the backbone in the tracking system. A scanning ground radar has the ability to see moving objects at long distances. There are several commercial systems that claim detection of humans at 5 km distance and vehicles of ranges up to 10 km. If such a radar is placed centrally in Ngulia, it will cover a larger part of the park as illustrated with the two circles in the Dashboard view of Figure 3. For instance, all vehicles approaching the sanctuary can be detected to provide an early warning to the commanders.

Figure 4 shows a snapshot from one field test. The radar is put in scanning mode with a video camera attached to the top, and a human with GPS as ground truth is tracked, along with some savannah animals including rhinos.

Figure 5
Overlaying thresholded IR images on the EO images provide an efficient way to monitor the savannahs and assist the operator. Video, camera, and drone provided by Superfly.

Figure 6
A drone with EO and thermal cameras monitors an area where both a rhino and an intruder are trying to hide behind a tree. The thermal camera reveals the intruder, which is almost impossible to detect optically in the video stream. Video, camera, and drone provided by Superfly.

DRONES

Drones are a kind of ultimate platform for many of the sensors above, in particular EO and IR cameras, but also radio detectors as demonstrated in [21]. This obvious fact has led to many initiatives to bring drones to Africa. However, the acceptance by national authorities is not overwhelming, since still no sustainable solution based on drones has been demonstrated. In Kenya, a written agreement from the government is needed to use drones. This will likely change when the real benefits of drones as a supplement to other technologies can be demonstrated. The leap frog from no sensor surveillance to drone surveillance is simply not the right way to go.

However, the drone is a fantastic tool for wide area surveillance and border protection. An EO camera gives the commanders visual feedback, and the thermal camera can operate 24/7. Figures 5 and 6 provide illustrative examples.

With dedicated software it can automatically detect and classify humans, rhinos, and elephants. A positive side effect is that this would greatly simplify the important census challenges on the savannah.

Besides detection, tracking and classification in video streams, automatic route planning, and sensor management are research challenges for the future.

OBJECT CLASSIFICATION

The sensor information above suits a trained operator very well. However, training a large number of operators is not a sustainable solution. Support is needed for interpreting the sensor information, and calling the commanders attention only when anomalies are detected.

Figure 7 shows an example from [18] of classification from an airborne camera platform. Image learning is today a rather mature research area, and state of the art algorithms can be applied directly to training data from our field tests.

Figure 8 illustrates the micro-Doppler spectrum from a radar (the same as in Figure 4) in staring mode. In contrast to image classification, this is an emerging research area with few real data sets and experience from wildlife applications.

COMMUNICATION BACKBONE

In a country without cable infrastructure, both communication and powering are practical challenges. The sun provides energy today, both to the ranger stations and the radio towers. There are several operators with GSM network around Tsavo, but the coverage of each separate operator is poor. Inside Ngulia, connectivity was present about 30% of the time when the project started, while it is much better today after our operator has tuned the network. However, GSM offers only EDGE for data traffic, which is not what we consider to be broadband today. We have been investigating three ways to improve coverage and data capacity.

1. Radio repeaters are commonly used in distant villages, and so is our plan for the ranger stations. Figure 9 illustrates two ways the data can communicate between the devices and the cloud database. We have tested a BRCK unit, which is a locally developed kick-starter funded product. It includes a radio amplifier with external antenna, a router, a wifi hotspot, and a solar charged power station. This has the potential to improve local coverage, but not capacity.
2. Our telecom operator has partnered with a system manufacturer to boost the closest existing radio tower with a 3G base station. The introduction of H+ in Ngulia has improved data rates by several orders of magnitudes.
3. The ultimate goal of our operator is to put a radio tower inside Ngulia, to provide full coverage through the sanctuary.

Figure 7
Machine learning is used to train a classifier that is fed with EO and IR images. There are three classes: rhino (blue), humans (green), and other animals (red). Above, a zebra is found and below, a few seconds later, a rhino. Pictures from [18].

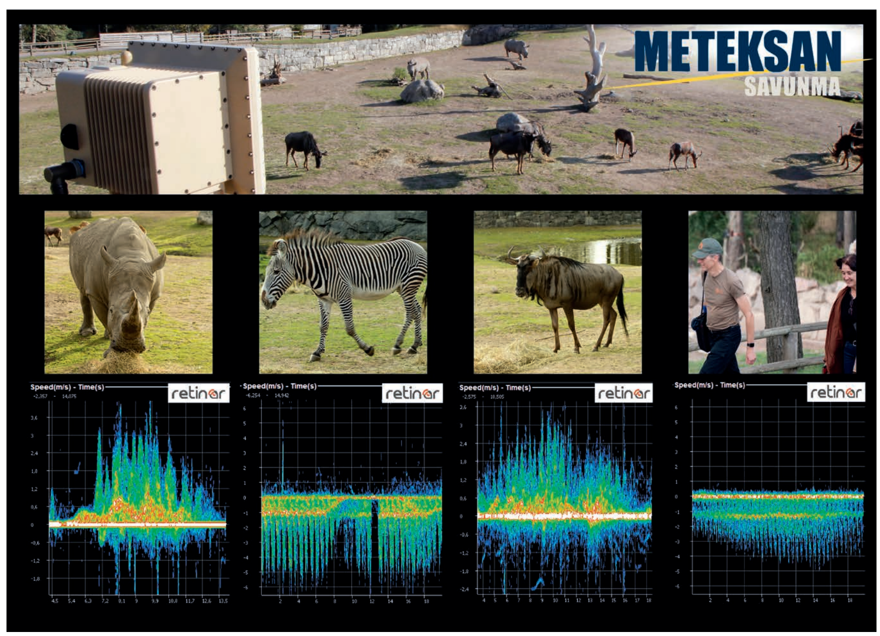


Figure 8
The micro-Doppler spectrum from a radar in staring mode reveals a particular pattern of the gait, caused by the speed variations of the limbs compared to the body. This can be used in the future for classification, also in far distances. Picture from wildlifesecurity.se.

PROJECT NGULIA: TIMELINE

This section provides a short overview of the different phases of the project, both what has already been done, and what the future plan is, as overviewed in Figure 10.

PHASE 1 (2010–2013)

The Stimson Center, in partnership with local nongovernmental organisations, conducts a comprehensive policy analysis of the current security and development environment in East Africa, particularly focusing on Kenya. Besides working with relevant Kenyan authorities, Stimson engages the broader donor community, including relevant offices in the United Nations and the governments of Australia, Finland, Sweden, and the United States. The outcome is an invitation by the Kenya Wildlife Service to conduct a pilot project focused on technology and innovation in Tsavo West National Park aiming to safeguard the remaining rhinoceros population there.

PHASE 2 (2014)

The year kicked off with a robust technical feasibility study at the Ngulia Rhino Sanctuary in Tsavo West National Park conducted in partnership by the Kenya Wildlife Service, Stimson, and the project's technology and innovation partner, Linköping

Figure 9
The C3 system exchanges information through a cloud based database, and the ranger device communicates with the cloud either directly over the cellular network, or via a wifi hotspot (BRCK) at their stations, which in turn is connected to the cellular network with external antennas and amplifiers. All data are encrypted and access relies on state of the art authentication procedures.

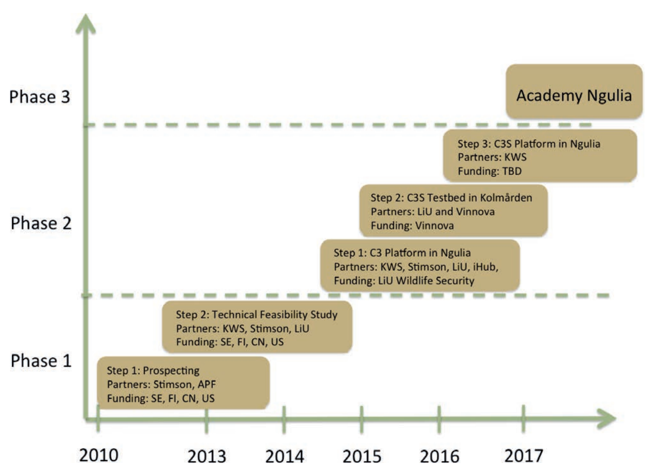


Figure 10
Overview of the development plan.

University. This exercise results in a multiyear technology and training plan. Partner organisations also negotiated and signed a Memorandum of Understanding in the fall of 2014 and began preparations to fully execute the plan in 2015.

PHASE 3 (2015–2016)

Because local ownership and investments are central tenants of our project, together with iHub, project partners design and develop a smartphone-based software for improved command, control, and communications (C3) in Ngulia. The platform is tested in the field and improved before being fully launched for use by park rangers, commanders, and research staff. The team spends a lot of time in the field for design and training; see Figure 11.

High Number of Fatalities

More than 1,000 rangers have been killed during the past ten years, and many more intruders.

A strategic partnership is developed with Kenyan telecommunications company Airtel that agrees to provide data packages and other necessities associated with the C3 system. Airtel also agrees to try to increase connectivity in the Ngulia sanctuary to ensure more advanced technology in subsequent phases of the project. Specifically, the C3 system's hardware consists of smartphones for the rangers, tablets for the commanders, and a cloud-based database hosting all information and communication. The ranger app is foremost an input device, where rangers note their observations regarding security and wildlife matters. Photo documentation is available as well as automatically geotagging. The app is also a navigation tool, where park rangers get their position overlaid on a map. The interface includes local landmarks such as waterholes, roads, trails, bunkers, borders, their patrol routes, and the like. There are also safety functions built into the app, such as the possibility to give haptic alarms in emergency situations, fall detections after accidents, as well as shot detection. The commander app includes the same functionality as the ranger app, but is foremost an administrative tool and platform for officers. The map interface shows the position and trajectories of all rangers and vehicles, security alerts, and rhino observations. The data can be accessed in real time or be analysed in retrospect. Commands are issued by broadcasting voice or text messages, and patrolling routes or ambush positions are defined for individual rangers.

PHASE 4 (2016–2017)

In this phase, sensor systems and radar for border and intruder detection, as well as area surveillance, will be added to the C3 platform. One or two radars will cover large objects moving inside and around the Ngulia border. Smart algorithms will be developed to distinguish humans from animals, and to monitor the rhino movements. The radar systems will have coverage of 5 km and 10 km radius, respectively. The radar stations are complemented with EO (standard) and thermal cameras with pan, tilt, and zoom. In this way, objects closer than a couple of kilometers detected by the radar can be zoomed in, further improving the classification of unidentified objects. Several other sensor systems will be investigated in parallel, such as microphone networks to detect shots, radio detection, and direction finding of communication equipment (cell phones) of possible intruders, border protection systems (unmanned ground sensors, fiber optics, microwave and laser barriers, surveillance cameras). At this stage, aerial surveillance could become relevant.

PHASE 5 (2018 ONWARD)

At this point, the park rangers, commanders, and research team are taking full advantage of the technological platform that makes their jobs easier, advances their mission, and cuts cost for the broader organisation. Following the successful deployment, other parks and organisations can scale and replicate the platform. This new gold standard for how technical systems can be used to tackle natural resource protection will assist governments, foundations, and the commercial sector worldwide.

The partner companies have complementary products and competences:

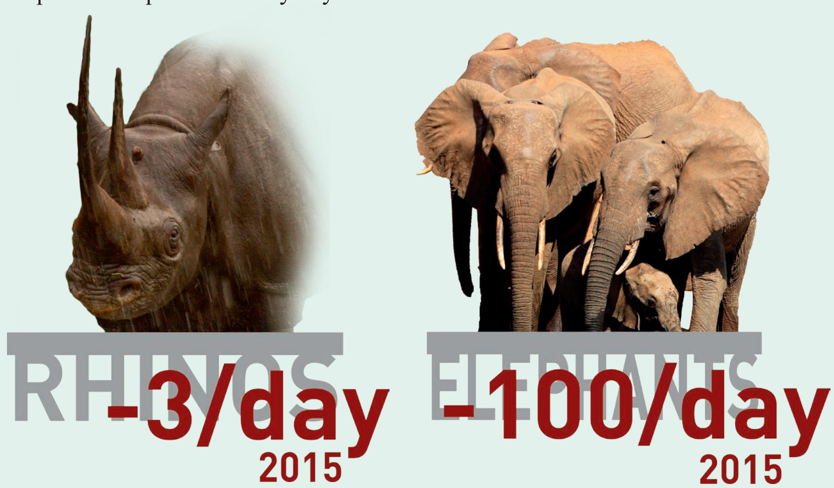
- There are sensor manufacturers (IP cameras, IR cameras, radar, tracking devices, drone manufacturers, etc).
- There are also system integrators and retailers of sensor systems.
- There are smaller highly nisched companies with deep knowledge in cyber-security and drone operation in Africa.
- There are also companies specialised in media production, such as one production company of TV films, one company for aerial video filming, and another one for aerial 3D modelling.

Finally, the Swedish wildlife park and zoo in Kolmården has a key role in the project, as a test site and providing expertise on conservation issues from the research frontier.

Figure 11
Project staff Angela, Mark, and Martin in a training session with rangers.

Poaching Statistics

Statistics from 2009–2014 show an alarming trend of increasing poaching. The trend seems to level out somewhat 2015–2016, but still 3 rhinos and over 100 elephants are poached every day.



CONCLUDING REMARKS

Wildlife security is an excellent opportunity to show what the fusion community can contribute to a societal challenge with three dimensions: conservation, economic development, and international security. The technical solutions to assist the rangers are focused around sensor and information fusion, where target tracking is the most concrete challenge: where are the rangers, rhinos, and poachers?

A further advantage of wildlife security as a demonstrator in information fusion is that it is an application on arm length's distance from military domains. The point with this is to appeal to students and the general public, to neutralize the common meaning of "drone" and "Command, Control and Communication System", and to avoid the immediate association of surveillance sensors with a threat to personal integrity.

We have a few lessons learned so far. First, the importance to think big from a research viewpoint. Many different competencies are needed, and a public/private partnership is a tool to get resources and publicity. Second, in such a large effort, researchers have to be patient, since it takes time to build up infrastructure before existing research can be demonstrated and before real data are available for new research. Finally, when working with end-users one should be careful to avoid technology leaps, and include training and continuous involvement in the development. Technology dumps must be avoided. Our approach takes many small steps, starting with a phone, ending with a drone.

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- He has a broad research project portfolio with quite a few industrial collaborations suitable for this project. The project provides a demonstrator arena for on-going research and challenging problems with field test data suitable for new research directions.
- With three successful spin-offs (www.niradynamics.se, www.softube.com, www.senionlab.com), he has experience in entrepreneurship that facilitates finding market opportunities for sensor fusion software in combination with complementing research and development.
- He is the director of Security Link (www.security-link.se), a national Swedish strategic research environment in the security area, with a focus on protection of critical infrastructure. This is beneficial for the security aspect of Project Ngulia.

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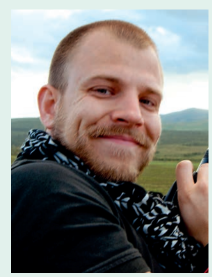
Martin Stenmarck has an M.Sc. in electrical engineering and is employed by HiQ Ace AB as a software developer and project leader. He has previously been managing director for a web and graphical design firm. He contributes in the following roles.



- He is coordinating both software and hardware activities.
- He is the supervisory project leader of a team of 10 programmers at iHub in Nairobi.
- He is responsible for homepages and all graphical material to the project. He is also a good photographer and photoshop guru.