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Caprivi Survey Report

Deon Joubert and Hannes Naude, 2 September 2016

The Elephant Survey System (ESS) was used to survey national parks within the Caprivi Strip of Namibia during August of 2016. This report provides an overview of the region surveyed and the system configuration used, some analysis of the data gathered and a detailed discussion and explanation of the problems experienced.

1 Overview

After improving the elephant detection [1] and the image capturing [2] subsystems of the ESS, it was felt that the complete system should be evaluated, with all the latest software and hardware developments, over a new and unseen region. As part of the preparation for the Botswana Test Campaign [3], a permit for performing flight tests in Namibia had been obtained with the help of Mr Ortwin Aschenborn. Mr Aschenborn is a wildlife researcher and pilot operating in the Caprivi Strip of Namibia. Therefore, given the permit conditions and the support available, it was decided to conduct a survey within this region.

The survey was conducted from the 12th to the 22nd of August 2016. The team consisted of:

Name	Role
Mr Mark Paxton	Pilot of the BushCat (ZU-IBK)
Mr Deon Joubert	Technical Support
Mr Hannes Naudé	Technical Support
Mr Ortwin Aschenborn	Operational and Regional Support

1.1 System Configuration

One of the aims of the survey was to evaluate the performance of the ESS using the following configuration:

- The original 28 mm lens was replaced with an 85 mm lens with a maximum aperture of f/1.2, for improved low light performance. Using the 85 mm lens necessitated modification of the camera rig.
- The longer focal length of the lens allowed the airplane altitude to be increased from 190 m to 590 m above ground level (AGL).
- The camera settings were changed to the following, so as to improve image contrast and prevent autofocus failures (as explained in [3]):
    - Manual focus, with the camera focused at infinity.
    - ISO speed set to 100.
    - An image capture rate of approximately 1 Hz, with the aim of facilitating the alignment of sequential images through a greater overlap between the images.

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- Aperture priority mode, with the aperture of the lens set to the maximum value.
- A deep network trained with all available data, including the data collected during the Botswana test campaign.

A test flight was conducted on the 8th of August at the Springs Aerodrome, with data successfully captured of the surrounding area. The recorded images were poorly focussed; but this was ascribed to a shift in the manual focus position during installation into the camera rig. As the images had been in focus during the Bela-Bela test flights [2], the rig mounting procedure was updated to prevent accidental changes in focus position. Furthermore, images had not been displayed to the pilot but this turned out to be a software bug introduced by a last minute code modification. It could easily be reproduced on the ground and was quickly fixed.

The software tested was somewhat different from that used during the Bela-Bela test in the way the faster capture rate was implemented. The CaptureApp uses the frames received from the Infrared (IR) camera as a clock pulse to signal the operation of the rest of the system. The previous version of the software had adapted the original 30 IR frame cycle so that 3 visual image capture events were triggered during the cycle. The latest version had reduced the cycle to 10 IR frames and only triggered a single capture event. This allows for better correlation with the altimeter data recorded, which is only triggered once every cycle.

Finally, as a faster capture rate is used, more data would be captured. It was calculated that a two-hour sortie would produce more data than the internal hard drive of the laptop could store and would also prolong the time needed to copy data from the rig laptop to an external hard drive between sorties. Therefore, it was decided to record data directly onto an external hard drive. Although tested in the office, there was some concern whether the vibration from the aircraft might affect the operation of the hard drive.

1.2 Caprivi Region

The Caprivi (or Zambesi) strip is located just to the north of Botswana. The permit from the Namibian Ministry of Environment and Tourism (MET) allowed flights to be conducted over all Namibian national parks within the Kavango Zambezi Trans-Frontier Conservation Area. It was decided to focus the survey on the Mudumu and Bwabwata national parks – the Mamili national park was excluded, as the elephant activity during August is low due to the park being quite dry.

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Figure 1. Map of the Caprivi Strip region. The section of the Bwabwata National Park which was surveyed is indicated in red while the Mudumu National Park is indicated in blue.

Transect sets were generated for the eastern part of the Bwabwata national park (B1-B8), crossing over the eastern border of the park to the concession areas on the other side of the river, as well as for the Mudumu national park (M1-M8). Transects were generated with a 500 m spacing between them, with a mostly north-south orientation so that the predominant easterly wind would manifest as a crosswind.

Only a small section of the large Bwabwata park was designated to be surveyed, with a focus on the Kongola river where it was believed that the most elephants would be encountered. This has the benefit of maximising the additional training data collected, but comes at the cost of confounding population estimates based on this data, since the data does not represent an unbiased sample of the park. We intended to focus the most of our efforts on Mudumu park, since it is small enough that a 40% sample survey of the entire park should have been attainable. With a 40% sample we expect to be able to produce a very precise population estimate.

2 Daily Log

The following sections describe the day by day testing and survey work carried out while in the Caprivi Strip.

2.1 Friday to Sunday, 12 – 14 August

The first three days were spent travelling to the Caprivi Strip, stopping over in Francistown and Kasane in Botswana. Messrs Joubert and Naudé followed the airplane in the ground support vehicle, picking up Mr Paxton at each airport.

On the evening of the 14^{th} Mr Aschenborn met with the rest of the crew at the Mazambala Island Lodge near Kongola to discuss the tests to be conducted for the rest of the week. Mr Aschenborn recommended that Immelmann airfield be used when surveying Bwabwata park and that Lianshulu airfield should be used while operating in Mudumu. Mr Aschenborn had also arranged for park rangers to guard the aircraft at night while it was stationed at Immelmann. It was also decided that the team would attempt to fly two transect sets each morning and another in the late afternoon, avoiding the heat of the midday when flying would be at its most difficult.

2.2 Monday, 15 August

2.2.1 Morning Session

The first flight of the week was conducted with the system configuration as described in Section 1.1. The aim was to do a short flyover of the Immelmann airfield to verify the focus and alignment of the rig. Upon landing we discovered that the application had stopped recording data early in the flight – only 10 visual images were recorded, while the infrared (IR) and altimeter data was recorded for only 2 minutes. Several hypotheses were generated of which the strongest ones were problems related to the vibration levels in the cockpit affecting the external magnetic drives and possible interference from the aircraft power supply.

Figure 2. The morning of the first flight of the Caprivi Survey.

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Examination of the IR images showed that there was a component broken within the camera, as can be seen in Figure 3. This added a third hypothesis, namely that this hardware failure in the IR camera was somehow affecting the rest of the system. As the IR camera is not used for elephant detection anymore, it was decided to disable the camera for the remainder of the survey. However, due to the design of the CaptureApp software in which the IR camera acts as the central synchronization source, this is not entirely trivial. To ensure that the CaptureApp would still function as expected, the IR camera was replaced with a software proxy that generates dummy images at the same nominal rate as the physical camera generates real images. This minimised the number and extent of the changes to the CaptureApp itself.

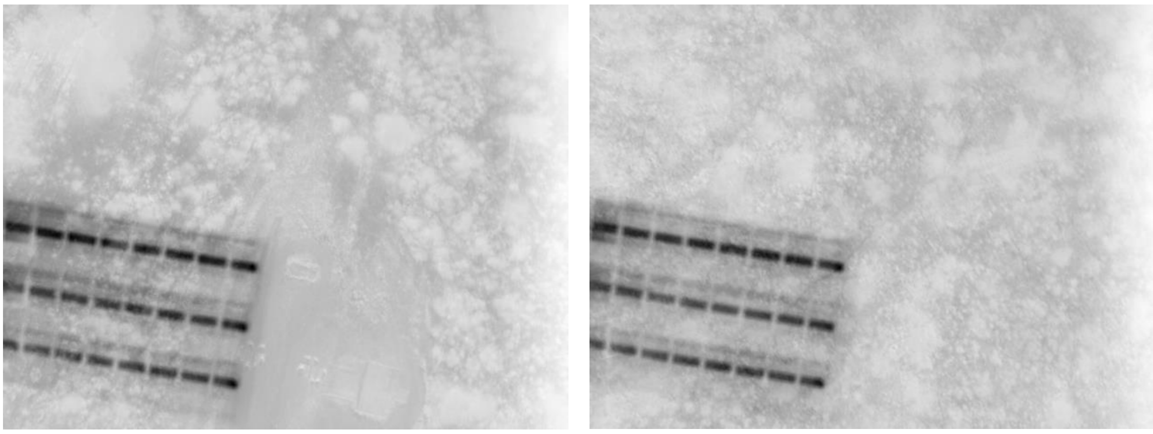

Figure 3. IR images from the first flight on the first day. Note the repeated obscuration in the lower left corner of both images, which indicates a broken component within the camera.

The second flight was conducted using the same configuration as the first flight, except for the removal of the IR camera and the fact that the external hard drive was placed within Mr Paxton's flight bag so as to dampen the vibration from the aircraft. During the flight, recording of visual images to the disk had stopped. However, both altimeter and simulated IR images were still being written to the hard drive, thereby reducing the plausibility of the hypothesis that the external hard drive was at the root of our problems.

In an attempt to eliminate all differences between our lab environment and the in-flight environment and hopefully get back to a working baseline, we then switched recording back to the internal SSD drive and unplugged both the laptop and the camera from aircraft power, leaving them to run on batteries alone. The altimeter was still powered from the aircraft supply as it has no battery backup. This flight was aborted before getting to altitude as Mr Paxton observed that the GUI reported a fault and stopped updating images. However, upon landing, we found that images were still being recorded and all the data was present as expected.

At this point we were rapidly running out of flyable hours and getting desperate to confirm camera focus and alignment and possibly still get a sortie done. So we decided to ignore the GUI issue for

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now and asked Mr Paxton to make another attempt, ignoring any errors reported on the GUI should they present themselves. Upon his return we found that image recording had once again mysteriously stopped, while altimeter data was recorded throughout proving that the CaptureApp was still active.

At this point one of the few hypotheses that had not been disproved yet, was the possibility that the problems were being caused by faulty software. We had not given much consideration to this possibility before, as the software had been tested before departing for the test, both in the lab, and in the dry-run at Springs. However, since the testing at Springs was rather cursory and the tests in the lab might have missed some subtle bugs that only manifest when the rig is fully operational, we tried rolling back the software to the version that was used without problems at Bela-Bela. Data capturing was only commenced after the aircraft engine had been started, so as to prevent a power spike from affecting the system. The start of the flight was interrupted when the camera stopped capturing images and displayed an Error 20 message on its screen. Only by removing and reinserting the battery from the camera would it return to its normal operation. The flight took off and data was successfully recorded, however by this time the laptop battery was running flat and the flight had to be stopped after only about 10 minutes.

At this point it was realised that the adapter which connected the laptop to the aircraft power supply had come loose and had been lost in flight. The whole of the runway was searched in the hope that it had dropped soon after take-off, but to no avail. Without the adapter, the laptop would only be powered by its battery of which the charge would barely last for one transect set. As it was already past 11 o'clock, it was decided to return to the lodge and devise a plan for how to continue the survey.

Figure 4. Mr Joubert installing the camera rig into the BushCat.

2.2.2 Afternoon Session

An Uninterruptable Power Supply (UPS) was brought along so as to provide clean power to the offline processing computer. As the battery in the UPS has a large capacity, it could be used in conjunction with a standard laptop charger to power the rig laptop while in flight.

It was decided to revert to recording images onto external drives, since nothing in the log files seemed to hint at file access problems. At the same time the recording frequency was dropped to about 0.66 Hz.

An initial test in the aircraft showed that the system worked as expected. The first flight took off at 16:10 with the aim of surveying the B1 transect set. After about 20 minutes of flying the CaptureApp stopped updating the displayed visual image and Mr Paxton landed so the problem could be resolved. Upon investigation it was seen that all data was still being recorded, only the display part of the application had ceased to function. The log files were downloaded from the laptop where they were still being recorded to the internal drive to allow for tracing of this issue, but in order to save time Mr Paxton was sent off again with instructions to continue flying even if the display stops updating.

While Mr Paxton was airborne, the error was traced with the help of the log files to a file access issue that occurs when the display thread of the capture app catches up with the recording thread and tries to display an image before the recording thread has released the file handle to that file. This issue has always existed in the CaptureApp code, but in previous releases the resulting exception was caught and essentially ignored inside the display loop. Therefore, while the image in question would not be displayed, the loop would continue executing and the next screen update would in all likelihood be successful. As part of the error tracing at Bela-Bela this exception handling code was temporarily commented out and it was not restored afterwards.

When Mr Paxton returned it was found that in this run the camera itself had actually stopped responding after about 15 minutes of flight and reported error 70 on its own display. The CaptureApp had continued running. The recorded images were quite dark due to the low light levels at this time of day, but seemed otherwise in order.

Back at the lodge, the camera error messages were researched. The information from Canon describing these errors is aimed at hobbyist users and rather limited. The errors that we observed during the day's flights are described as follows:

Err 20: A malfunction with the mechanical mechanism has been detected.
Err 70: A malfunction with the images has been detected.

In both cases the recommended solution is removing and reinserting the battery, which obviously solves the problem in the short term, but does not prevent it from recurring. Our only hypothesis was that perhaps this was the first sign of shutter failure (given some weight by the description "malfunction with the mechanical mechanism"), a possibility for which we had prepared by having the camera serviced and procuring a spare camera body prior to the test. We therefore swapped out the camera bodies, using the new body for the rest of the test.

We also reproduced the display failure in the lab environment (by modifying the code to occasionally attempt to open a file for which the handle was being held by an external application). We restored the erroneously removed exception handler and confirmed that the problem had been resolved.

Figure 5. Parts of the Kongola river as seen from the BushCat.

2.3 Tuesday, 16 August

2.3.1 Morning Session

The aim of the morning session was to fly the B2 transect set using the new camera body and the lowered image capture rate, with data being recorded onto an external hard drive.

The first flight was quickly aborted when the CaptureApp failed to display any images. The camera was found to have turned itself off. The camera had been switched on before the aircraft warm up procedure and it was deduced that the camera had a timer to turn itself off after a period of inactivity. Restarting the camera resolved the problem.

A second flight was attempted but was also aborted when the images stopped being updated. Visual images had stopped being recorded, while both the simulated IR images and altimeter data continued to be recorded.

At this point, we were at a loss to explain why two separate camera bodies would occasionally simply stop responding to capture commands from the software. It seemed clear that the external hard drive was not giving problems, we had already tried isolating ourselves from the aircraft supply and exhausted our rather limited fault finding options for hardware problems with the camera itself. In another bid to get back to a working baseline we reverted to the Capture software that had been used without incident during the Botswana test, thereby dropping the recording rate down to 0.33Hz which is sufficient to give 100% coverage of the surveyed area when flying at nominal speed, but not sufficient to allow for fully automated aligning of overlapping images.

A third flight was conducted with success, with take-off at 08:10 and landing at 10:30. In hindsight, the apparent success of this flight was rather unfortunate, as later investigation would show that the problems were not fundamentally caused by the higher capture rate of the newer software. Nevertheless, by the time this was discovered, there was so little flying time left that we chose to keep operating at the lower rate out of an abundance of caution.

After the flight, a presentation describing the purpose and operation of the ESS was given to the Bwabwata park management team, so as to comply to the conditions of the research permit.

Figure 6. Presentations were given at Bwabwata and Mudumu Park Headquarters to the park management teams.

Inspection of the images captured during the third flight showed that the images were overexposed and slightly out-of-focus, an example of which can be seen in Figure 7. The camera was removed from the rig and the manual focus was tested at a distance of 600 m and was shown to be correct. It was decided that the out-of-focus appearance was a subjective effect caused by the high level of exposure within the image. To address this, the aperture for the lens was changed from 1.2 to 3.2.

Figure 7. An enlarged portion of a visual image captured during the third flight in the morning session of the second day. The slight out-of-focus appearance was initially attributed to the high level of exposure.

2.3.2 Afternoon Session

The first flight had the same problem as the first flight in the morning session in that the camera had once again switched off during the aircraft warmup procedure. This came as a surprise as the timeout setting had been disabled on the camera, hinting that our earlier diagnosis had been incorrect. In hindsight it seems that these problems were also caused by the electrical interference issue that would only be identified the next day. Restarting the camera also resolved the issue.

The second flight was a successful fly-over of the airfield to evaluate the focus of the images, which was found to be acceptable. Before starting the next flight, it was realised that the laptop had not been plugged into the UPS, and upon doing so the UPS failed to power the laptop and gave a loud error warning. Later fault finding showed the UPS to have failed, possibly due to the vibration inside the cockpit or due to poor ventilation and overheating. A successful sortie was conducted using Mr Joubert's laptop from 16:51 to 18:06, with the laptop running from its battery. The altimeter was not powered for this flight. The completion of the B3 transect set had to be aborted due to low light and long shadows at 17:50.

After attempting to process the data from this flight, it was realised that no GPS coordinates were being recorded for the images. It is believed that the new camera body did not have the setting enabled by default and that the old camera body, while being serviced, had its settings reset to the factory settings. After enabling the GPS setting, coordinates were again recorded.

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While adjusting file-permissions for imported data, during the evening, a malformed command caused permissions to be changed on some critical operating system files. This problem could only be rectified by reinstalling the OS and we did not have the correct media to do so with us. As a consequence, proper processing of the data could not be done in the field and had to wait until 2 days after returning home, when the OS and all project dependencies had been successfully reinstalled.

2.4 Wednesday, 17 August

2.4.1 Morning Session

The images of the second day's last flight were found to be somewhat dark and therefore the camera was made to operate in exposure priority mode, where the exposure time of the shutter would remain fixed at 1/4000 seconds, while the aperture of the lens was allowed to change to adapt to the current light quality.

As the last flight had been deemed a success, it was decided to start the survey of Mudumu. The first flight took off from Immelmann airfield, with the pilot's GPS set to the M1 transect set and the rig laptop on battery power. While the flight was underway, the ground crew headed toward Lianshulu airstrip where Mr Paxton would land upon completion of the set. En route, another presentation on the ESS was given to the Mudumu park management team.

Having flown only 20 minutes of the transect set, the pilot landed the airplane at Lianshulu, stating that the rate at which the displayed image was updating had slowed considerably. Upon inspection of the data, it was seen that there had been a massive slowdown in the capture rate. It was also found that the altimeter had not functioned correctly during the flight. As too many obscure problems had been experienced up to this point, it was decided to halt any more attempts at flying surveys until all problems were resolved. The rig was removed and taken back to the lodge.

A quick inspection of the images recorded during the previous flight showed that they were somewhat underexposed. The exposure time was increased to 1/2500 seconds to address this issue.

After various attempts to reproduce the other observed system failures at the lodge did not succeed, with the system only working as it should, it was decided to once again take a close look at differences in the operating environment. Comparison of the data recordings made in flight with those in the office showed noticeable differences in the number of frames dropped, with performance in flight being significantly worse.

The laboratory setup was exactly the same as the operational setup, except for two key differences: the power source and the amount of vibration experienced. As the system had functioned well during the Botswana test campaign, it was unlikely that the vibration was the cause of the problems faced so far. However, the aircraft used was different, with a different power plug configuration than used previously. The aircraft power supply had now become the chief suspect.

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Due to the failure of the UPS we also had to come up with a new plan to get power to the laptop as its battery would never last for the two sorties we intended to fly in the morning. Earlier we had attempted to run a mains charger from Mr Aschenborn's inverter, but the aircraft electrical system could not supply sufficient current. We decided to cut the barrel connector from a mains charger and Mr Aschenborn set out to splice this plug to the car charger we had been using before the barrel adapter had been lost. The resultant power cable can be seen in Figure 8.

Figure 8. Ad-hoc laptop power cable, courtesy of Mr Aschenborn.

2.4.2 Afternoon Session

As Mr Aschenborn had been able to produce a replacement power cable for the rig laptop, it was decided to return to the aircraft and run a series of tests to determine the root cause of the problems experienced so far.

For the first test, the rig was coupled to the aircraft power system and the aircraft was switched on, with the engine running. The laptop and altimeter were powered directly from the aircraft power, while the camera was connected via a DC-to-DC adapter which emulates a camera battery. The CaptureApp was run for 20 minutes and no errors occurred and no frames were dropped.

During the second test the CaptureApp was run as before, except that now various subsystems of the aircraft were switched on so as to start loading the power supply. When Mr Paxton switched on the strobe lights, the CaptureApp stopped operating. The same results were obtained when the transponder was turned on.

A succession of quick tests demonstrated that when the power supply became heavily loaded, the camera picked up conducted mode electromagnetic inference (EMI), causing it to perform erratically.

By this time, it was already too dark to fly a proper sortie, but it was decided to conduct one final airborne test, where the rig was plugged into the power supply but only the GPS and radio within the aircraft were used, with the system performing as expected for 20 minutes, except for four frames dropped.

In the evening, the system was run for an hour and 40 minutes with the camera running off of a camera battery and the laptop and altimeter connected to mains. No errors were observed and the battery did not have a too large drop in charge. As a backup battery was available for the camera, it was decided to further isolate the system from any EMI by using the camera batteries for the remainder of the test campaign. The battery charging system of the laptop essentially isolates the laptop electronics from the aircraft supply, and ensured that there were would be minimal interference on the laptop. Unfortunately, the altimeter could not be isolated, although it's function, while useful, was not as vital as before as Mr Paxton was able to gauge the correct height from the aircraft barometric altimeter.

Figure 9. Elephants waiting to cross the Immelmann airfield as the BushCat comes in for a landing.

2.5 Thursday, 18 August

For the remainder of the survey, all non-essential aircraft systems, such as strobe lights, transponder and radio were switched off. Mr Paxton used a hand-held radio to communicate with local air traffic and the ground crew. The first flight of the morning was a successful survey of the M2 transect set, taking off from Immelmann at 07:56 and landing at Lianshulu at 10:07, with no data recording issues encountered. However, upon viewing the images it was realised that they were significantly out of focus. This was unexpected, since the focus had been confirmed in an earlier test, and the focus ring had been securely locked down with duct tape to prevent any subsequent shift in focus. One possibility was that what appeared to be poor focus might in fact be motion blur. This was considered unlikely, but since it would be an easy hypothesis to test and conclusively rule out it was decided to do a quick second flight to see if shortening the exposure time to 1/4000 seconds would result in an improvement – the images remained out of focus.

When the camera was removed from the rig and the focus tested using the same techniques used

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on the second day, it was found to indeed be out-of-focus, despite the fact that the focal point indicator on the lens was still on infinity. Further experimentation showed that the manual focus control was not a direct mechanism, rather the focus ring served as an electronic input into an internal mechanism. This, in turn, indicated that it would be impossible to lock the focus into an infinite position by fixing the focus ring control. Therefore, at a given focus setting the images would initially be crisp, but over time the internal mechanism would vibrate to a different position resulting in blurred images.

Therefore, it was decided to change the system so that the camera would again be set to autofocus mode. Even though it was expected that focus failures would occur sporadically, this would be preferable to having none of the image in focus. A third flight was carried out over the airfield, using the updated system. The images were seen to be crisp and in focus, as is evident in the comparison shown in Figure 10.

Figure 10. Comparison between an image from the first flight of the morning of the fourth day, with an image from the third flight, where the camera was set to autofocus mode.

2.5.1 Afternoon Session

The first flight took off from Lianshulu airfield at 15:30, with the camera set to autofocus. During the flight, Mr Paxton noticed that the laptop battery warning had come on. The power connector had vibrated from the cigarette lighter socket, which resulted in the laptop and the altimeter not receiving any power. Luckily, Mr Paxton reacted quickly and re-seated the plug ensuring that the system could continue recording data. Due to a communication error, initially a part of the B3 transect set was flown. The pilot corrected this and flew a large part of the M3 set as intended.

Evaluating the day's data showed that the altimeter had only correctly operated for the second flight

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in the morning, which indicates that there might have been further problems with the power supply from which the camera had been isolated.

2.6 Friday, 19 August

Confident after reviewing the images from the last flight the previous day, it was decided to capture as much data from the Caprivi Strip for evaluation of the system back in South Africa. As it was feared that too much time would be lost in travelling to the Lianshulu airstrip in Mudumu park, it was decided to fly only within the Bwabwata park. The following settings were used:

- The camera was set to autofocus.
- The camera was set to exposure priority mode, with a shutter exposure time of 1/2500 seconds.
- The camera was powered by its battery, while the laptop and altimeter were powered through the aircraft power supply.
- The CaptureApp was set to capture images at 0.33 Hz.
- The new camera body was used, together with the 85 mm lens and the rig laptop.

Furthermore, as the low light performance of the system was seen to be excellent, the flights for the day were scheduled to be within half an hour of sunrise and sunset.

The first flight of the morning was used to cover the B4 transect set. Take-off was at 07:13 and the pilot landed at 09:26. As the B1 transect set had not successfully been completed previously, it was decided to survey this set on the second flight, which took off at 09:49 and landed at 11:55. In the afternoon, the B2 transect set was flown from 15:35 to 17:28. Altimeter data was collected for all of the day's flights.

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Figure 11. Elephant herd travelling through Mudumu park.

3 Data Analysis

During the course of the survey, over 597 GB of data was recorded. Table 1 lists those flights which at least partially covered one transect set, the rate at which images were captured as well as stating what complimentary sensor information was recorded.

Flight Description	Transect Set	Altitude	GPS	Capture Rate (Hz)
Day 1 Afternoon 1	B1	Yes	No	0.66
Day 1 Afternoon 2	B1	Yes	No	0.66
Day 2 Morning 3	B2	Yes	No	0.33
Day 2 Afternoon 4	B3	Yes	No	0.33
Day 3 Morning 1	M1	No	No	0.33
Day 4 Morning 1	M2	No	Yes	0.33
Day 4 Afternoon 1	M3/B3	No	Yes	0.33
Day 5 Morning 1	B4	Yes	Yes	0.33
Day 5 Morning 2	B1	Yes	Yes	0.33
Day 5 Afternoon 1	B2	Yes	Yes	0.33

Table 1. List of flights with at least partial coverage of a transect set.

The images from these flights will in future be used to evaluate the ESS and to further train the system. It is hoped that those flights that covered the same transect sets can be used to compare the performance of the system for different configurations.

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As can be seen in Table 1, the flights for the fifth day were the most successful. For this reason, the flights were processed using the Midlands deep network (trained on all data gathered before this survey) and both the Verification and Herd Detection steps of ESSWeb. A total of 567 instances of elephants were found, which is quite large given that transect sets were flown. Only 49 images were found containing elephants, which gives an average of 11 elephants per image. Elephants were often found travelling in large herds, as seen in Figure 12. Table 2 summarises the results.

Figure 12. Elephants were often found travelling in large herds while processing of the flights of the fifth day.

Sortie Descriptor	Transect Set	Heatmaps	Elephants	Images with Elephants
Day 5 Morning 1	B4	2491	228	21
Day 5 Morning 2	B1	2262	234	16
Day 5 Afternoon 1	B2	2088	105	12
Totals		**6481**	**567**	**49**

Table 2. Elephant detection results from the flights of the fifth day.

From the images evaluated during the survey, a concern developed regarding the performance of

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the system close to sunrise and sunset, due to the camouflaging effect of long tree shadows. Although this concern still needs thorough investigation, images such as seen in Figure 13 indicate that the system should be able to detect elephants even in these conditions.

Figure 13. Elephants detected despite long shadows cast by trees.

A receiver operating characteristic (ROC) curve was generated for the Midlands network on the data from the fifth day and is shown in Figure 14. From the curve it can be seen that 93% of all elephants were detected at a rate of one false positive per image. Of course, the resulting curve is suspect as the network is being evaluated on elephants that the network itself has found. However, given that a number of additional elephants were found using Herd Detection and that the results are very similar to those reported in [1], the curve would indicate that the system is operating as expected.

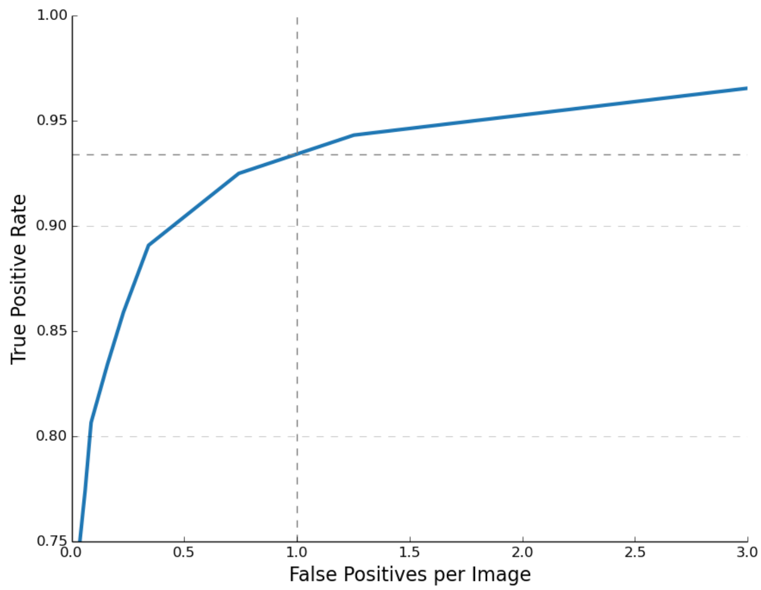

Figure 14. ROC Curve for the Midlands Network on all flights for day 5.

4 Conclusions and Future Work

Due to the problems encountered in using the ESS, not as large an area could be surveyed as had initially been planned. Very little data was obtained of Mudumu park, which had been the main aim of the survey. However, the data captured over the Bwabwata park should prove to be very useful, as the same transect sets were flown using different configurations and at different times, which should allow for interesting comparisons of system performance. Although some of the collected data has been processed, a more in depth investigation of the performance of the ESS on the whole dataset must still be carried out.

The interaction of multiple unexpected issues occurring at the same time and causing varying symptoms frustrated our fault finding efforts for a long time. In summary the issues observed were the following:

- The camera appears to be sensitive to conducted mode electromagnetic interference from the aircraft power supply. This was responsible for the majority of problems experienced during the test and manifested very non-deterministically in a variety of different ways.
- There was a software bug that caused the display to stop updating in some cases. The bug had very limited impact on the actual operation of the system, but it was significant because we prematurely rejected the EMI hypothesis, when it caused a failure during flight 3 on day 1.
- While the camera can record images at close to 1 Hz, it appears that it cannot actually sustain

this rate. After a few minutes, it starts to drop frames, even under lab conditions. This is a difficult bug to detect and it was only discovered once we had developed scripts to explicitly check the elapsed time between every pair of photos in the dataset. The impact of this issue was minimal although it also cost us significant fault finding time.

- The fact that physical locking of the focus ring does not actually lock the focus position on the 85mm lens (in contrast to the 28mm lens). This necessitated a return to autofocus operation. While we have observed a few autofocus failures (the reason for switching to manual focus in the first place), the autofocus on this lens appears to work significantly better than on previous lenses. This issue could never be found in lab tests or even in short duration airborne tests such as those conducted at Bela-Bela and Springs. Incidentally, we have always been puzzled by the rather dramatic performance degradation with the 135mm lens during the testing at Bela-Bela. This discovery provides us with a new viable hypothesis to explain that failure.

During the description of the fault-finding process, a number of hypothesized issues were mentioned. In many cases, these could not be positively excluded at the time. For the avoidance of confusion, we list those issues here, along with our current evaluation of their likelihood and severity:

- **Camera shutting down due to time-out**. We no longer believe that this diagnosis was correct. We now believe that the observed shutdowns were caused by the EMI issue. This is motivated by the occurrence of further shutdowns after the timeout function was explicitly disabled in the camera menu system as well as the fact that to the best of our knowledge this had never occurred before, in any other test.
- **Failing shutter.** We suspected this due to the occurrence of error 20 and error 70 on the Canon camera. While we cannot positively exclude this possibility, we now think it more likely that one or both of these were caused by EMI and we intend to switch back to the old body for future testing.
- **Vibration affecting the external magnetic HDDs.** Once the camera was isolated from aircraft power, this did not recur over many hours of recording. Thus we now believe that the external magnetic drives functioned just fine despite platform vibration. We nevertheless advocate switching to solid state removable media in future, for the sake of robustness.

In light of the above issues and non-issues, the following corrective actions are recommended:

- The system should run from its own battery, completely isolated from the aircraft power. This will eliminate any conducted mode EMI and allow for more representative lab testing.
- While this will eliminate any conducted mode EMI, we still need to be cautious of radiated mode EMI as well as vibration. For this reason, we recommend that a more extensive dry run be performed prior to any future tests.
- Cigarette lighter plugs should be replaced with more reliable connectors.
- The system search rate is still too low to compete with manual surveys. This has been mentioned in the past, and rig redesigns have been discussed, but in order to transition to a

camera rig equipped with a gimbal, we first needed to prove successful operation with longer focal length lenses. Now that this has been proven we can recommend a redesign of the rig to incorporate a gimbal and increase the search rate significantly.
- The external HDDs did not appear to give any problems due to vibration, but this could easily differ between different carriage platforms or different HDD models. To eliminate possible issues from vibration, we should switch to external SSDs or SD cards for recording.
- While we have made modifications to it, the CaptureApp remains the last software component of the system that has not been rewritten from the ground up by Innoventix. Given the significant changes in system architecture brought about by the removal of the IR camera, we recommend rewriting it at this time to replace it with a simpler, and hopefully more robust, alternative.
- Unlike the analysis software, the CaptureApp was not previously checked in to our version control system. This will be rectified.
- Last minute changes are the root of all evil. The changes made prior to the Springs test unexpectedly introduced a bug. While this bug itself was easily resolved, it had a ripple effect that resulted in the display error experienced during the test campaign. We intend to prevent this from recurring by introducing in depth code reviews of all changes made to capture software since the previous test prior to each test.
- The CaptureApp logs should be created on a per-sortie basis and stored alongside the recorded data, not in a single log file in the executable location as is currently the case.
- Further investigation is required to understand the mechanism behind dropped frames and find the fastest rate that the camera can sustain. Extensive lab tests of this aspect were avoided before, in order to not wear out the shutter needlessly. Given that we now know that a problem exists and that we have a spare camera body in case of failure, this seems more than justified.
- Changes to camera settings due to services or physical switching of bodies is a risk factor that needs to be managed. Possibly many of these settings can be enforced (or at the least checked) by the CaptureApp itself, but this will be dependent on what is supported by the camera API. Settings which are important, but cannot be checked by software need to be added to a pre-campaign checklist.
- Flying at the new nominal altitude does not appear to be unsafe, even during hot conditions. It is however very draining on the pilot to perform extended duration surveys, especially during hot conditions. If large areas are to be surveyed during a short period, it would be wise to alternate pilots between sorties to reduce fatigue.
- Given the amount of time it is desirable to spend in the air and the small window of opportunity, it would for future flights be better to stay as close to the airfield as possible, and rather relocate between accommodations to maximise the available time for survey work, as opposed to travelling between locations.

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5 References

[1] J. J. Naudé and D. Joubert, “Reducing the False Positive Rate of the ESS,” Innoventix Consulting, 2016.

[2] J. J. Naudé, D. Joubert and M. J. Potgieter, “Elephant Survey System, Bela Bela test campaign operations report,” Innoventix Consulting, 2016.

[3] H. Naudé and C. Potgieter, “Elephant Survey System, Botswana Test Campaign Operations Report,” Innoventix Consulting, 2015.