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Laura Tarkkanen & Mari Aro

The Cross-Border Photonics Initiative demonstration research report

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The Cross-Border Photonics Initiative demonstration research report

CBPI

Light through borders

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Lappeenranta
University of Technology

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ENPI

Kuvat: CBPI research team

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1. INTRODUCTION

New technology is developed constantly at an accelerated pace. Not only are there several new types of technological devices, the devices invented hundreds of years ago are further developed. Photonics are amongst both of the groups, and its development has enabled people to exploit it in different contexts. For example, the smallest but extremely accurate photonics devices are used by paper industry as part of their quality control system. The more complex ones may use thermal or slow motion technology in leisure activities, scientific projects, movies and so on.

Since the latest economic depression started - and even before it - the public sector has undergone several cutbacks in funding, forcing them to let people go. With the reduced resources, efficiency improvements have been mandatory, and improved technology has offered some alternative approaches. For example automated border check gates are deployed all around the world in international airports. Technology not only eases the lack of resources, but also helps bring savings.

This report describes how, by combining drones with photonics, new technology can be applied in border surveillance. Border surveillance means "the surveillance of borders between border crossing points and the surveillance of border crossing points outside the fixed opening hours, in order to prevent persons from circumventing border checks. Currently in the Finnish-Russian border, the Finnish border guards patrolling the border line have a dog as their aid. The border is also supervised with different types of sensors, which alert the Border Guard. If the reason for the alert cannot be detected with the sensors, a patrol is sent to check the border line. However, in case the alert is given because there is a person crossing the border illegally, there is only a small chance for the border guards to catch the person, or to find him, due to a delay before the border guards get on sight. However, the alert may also be given by an animal moving about the forest. To save resources and effort, an unmanned aerial vehicle (UAV) could be flown at the site of the alarm. With an attached camera, the camera feed would be seen by the UAV operator, and it would not be necessary to send anyone at the scene on foot. Alternatively, if there was an actual illegal crossing, the UAV could follow the person, and the border guards could be guided to the right direction. This is one of the scopes of Cross-Border Photonics Initiative (CBPI) -project.

CBPI project is funded by the South-East Finland-Russia ENPI CBC funding programme 2007-2013, with an economic development theme. The main objectives are knowledge and technology transfer, institutional cooperation and cooperation networks and scientific cooperation. The project aims to foster photonics technologies for economic growth and to increase cross-border collaboration between universities and photonics companies. The project has four specific objectives to cover its activities, out of which this report concerns with development of regional world-class innovation & research networks, and development of regional infrastructure for supporting prerequisites of future photonics

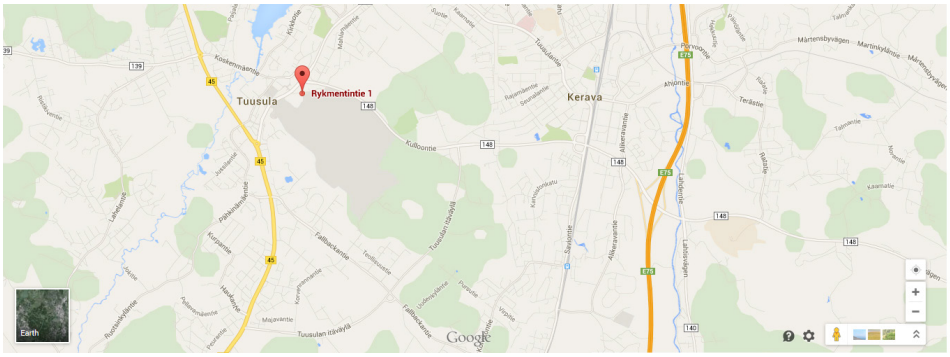
technology and platforms. The main objectives of Laurea University of Applied Sciences (UAS) are to develop and test systems of UAV platforms and sensors for automated border surveillance, and implement innovative border surveillance systems.

This report describes Laurea UASs main contribution to the project. The next chapter describes the planning of the demonstration flights, including choosing the area and equipment, explaining the permit process and creating scenarios. The third chapter explains how the demonstrations were executed, how they went, what was learned, and how the situations were altered with the newly gained information in the scenario. Chapter five analyses the results, and highlights the most important research findings. Further research proposals are then drawn together in chapter six after which chapter seven concludes the report.

2. PREPARATIONS

In order to execute the demonstrations, we needed to find as authentic a place as possible to simulate a border region. Our first choice was to cooperate with the Finnish Border and Coast Guard Academy (Raja- ja merivartiokoulu), and Laurea UAS applied for a research permit to be able to use their premises and expertise at a town in Eastern Finland called Immola. The initial contact was made in May 2014, and the permission was granted in August, with the demonstration dates set to November 2014. As our initial plan was to lease the drones from Airbus Defense and Space Finland, the permit was applied with that information. However, due to major organizational changes within Airbus Finland, we had to find an alternative leaser fast, and ended up buying a service package from VideoDrone Ltd, which included the equipment and the operator. However, due to the changes with the demonstration execution, Laurea was not able to execute the demosntrations at the Finnish Border and Coast Guard's facilities in November 2014. Thus, we needed to find an alternative area to simulate the border urgently.

One of Laurea's team members remembered a diverse and varied terrain in Hyrylä, some 30 km away from Helsinki. The area used to be in possession of the Finnish Defense Forces, but was released in public use in 2006-2007. As Helsinki's main international airport is only some 20 km away from Hyrylä, we contacted Finavia, the Finnish airport operator, and Trafi, the Finnish transport safety agency, in order to ensure flight safety during our demonstrations. The air traffic control confirmed that as long as we stay within the given limitations (maximum height 150m, maximum weight of the drone: 20kg, maximum distance of the drone from its operator: 500m, with a clear line of sight) using the requested area was ok. We also contacted the Construction Establishment of Defense Administration (Puolustushallinnon rakennuslaitos) in order to verify that they did not have any operations or limitations on flying and filming at the specified area. The co-operation with all the above mentioned agencies went well, and we started to plan our demonstrations further.



Caption 1: Map of Hyrylä

2.1 Scenarios

Laurea UASs objective in the CBPI project is to implement photonics technology in border surveillance. Laurea has prepared some scenarios which will be tested in the field demonstrations. The scenarios are in a sufficiently general level, so they can be altered from an easier to a more difficult simulation on sight. The scenarios can also be changed during the demonstrations if needed. The idea was to implement scenarios through different terrains and with different cameras to provide the most comprehensive understanding of the implementation opportunities of photonics in border surveillance. Below are listed the basic scenarios which will be executed in the demonstrations.

1. Border surveillance, both land and water line

Following CBPI-project's goals, this scenario will be the core in our simulations. This scenario is evolved throughout the demonstrations, always adding something to it. Starting with basic monitoring duties at a given area, our goal is to create an actual border surveillance situation. This is hindered by the fact that no border guards were possible to be interviewed, meaning that without their expertise our scenarios can remain at a theoretical level. By adding a person to the scenario we are able to simulate a possible illegal immigrant trying to cross the border without permission. This will be tested with video, thermal and still cameras. Even though the aim is to elude the drone, the target person will be under the command center's guidance. This scenario has significant value whether in success or failure, as it will reveal if this sort of equipment is suitable for border surveillance purposes. The scenario will also be implemented at shore line to study if different terrains bring any obstacles with the equipment, and because the external Schengen borders include both water and land borders.

2. Search and rescue

Search and rescue are amongst the many things included into authorities' duties. Especially in Finland all authorities work with interagency cooperation, especially in rural areas. These include the border region as well. Due to the aforementioned facts we wanted to include search and rescue scenarios into our demonstration. Also, there is no difference in whether a person has gone missing accidentally or intentionally, the aim is to find the target person. The scenarios will be recorded with the video and thermal cameras. After the initial testing and review onto the first flights data, we decided not to include the SRL and ortho-cameras as they did not bring any technical value. The main research interest here is whether the used technology is sufficient enough to search and rescue operations? For example, is the available technology sufficient enough to operate in different seasons of the year and weather conditions, and how reliable is the technology.

3. Chase

The research group agreed to add this scenario into the demonstrations as it may be a realistic scenario in border surveillance situations. The idea is that the target person or "illegal immigrant" has been able to cross the border line and the border guards have received an alert. The alert may be issued from a command center, a video drone operator or visually, resulting into a chase. The objective is to study how useful the drone can be in a chase situation. This scenario will also be evolved, combining features from the previously described scenarios. The thermal camera will be used and tested in this scenario.

4. Guiding someone to another person's location

This theme is a modification of the search and rescue scenario. In this scenario, a person is not trying to hide or disappear; more likely wants to be found. Therefore, the scenario has to simulate whether it is possible to guide a person towards another using the drone. We will test and simulate this scenario by guiding a person towards an unidentified item. Preliminary this will be tested with video and thermal camera. It should be noted that we base this scenario on a real-life situation, where a person was lost in the woods and was found with the drone, which guided the person back home.

5. Following a suspicious person

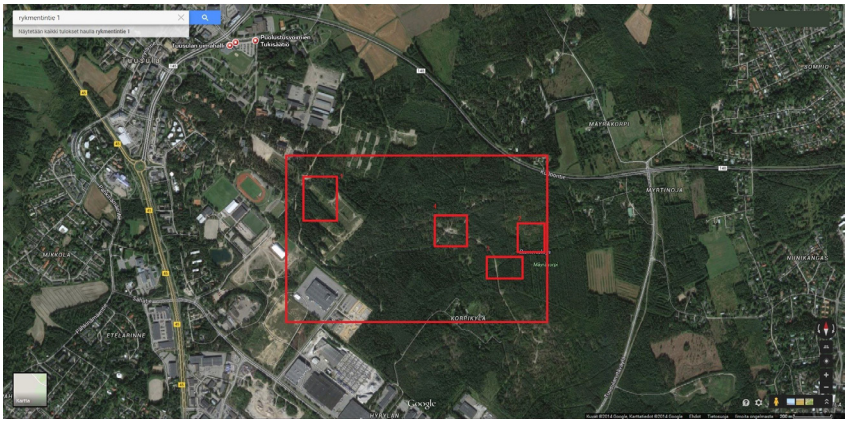
This scenario simulates how authorities may follow a suspicious person without endangering themselves. The drone will follow the target person either with a thermal or video camera when she is running around the different terrains. This scenario could be applied to police operations, where someone is displays suspicious or threatening behavior, or is detected to carry a firearm. However, as the Finnish legislation denies drone and UAV flights above crowds of people and in public city areas, this scenario can only be allied to other surroundings in theory. Another benefit of this scenario is to test the equipment.

Caption 2: Some scenery from the field trip

2.2 Choosing the scenario locations

After the decision was made and permissions granted we conducted a terrain intelligence field trip on Friday November 7th to the area, specifying and choosing potential demonstrations areas. It was difficult to choose the demonstration areas as we had never seen the drones, and had no previous experience on the requirements by the operator. The chosen areas differed from one another on purpose in order to demonstrate the varying terrain at the border. We also wanted to challenge the drone operator Mr. Juhani Mikkola and his equipment, as he brought four drones with different types of cameras attached to them. During the preliminary intelligence at the area, a Canon pocket camera was used to memorize the places.

The demonstration areas were chosen with different criteria: varying terrain, visibility, accessibility, and so on. Due to the sudden change of location, we also needed to find an area where the border line could be simulated. At the intelligence field trip we chose five different locations for the demonstrations, and the areas are marked on the Google Map caption (Caption 3) below. The areas will be called 1) The border line, 2) Uphill terrain, 3) Dark forest, 4) Cliff-top and Shore line.



Caption 3: The scenario location on a map in Hyrylä

Table 1: Terrain descriptions and classifications

Terrain	Tree density	Scenario	Visibility
Border line	Low trees, relatively dense undergrowth	Border surveillance, and Chase	Good
Uphill terrain	Trees 1,5 - 3 m, relatively scarce undergrowth	Search and rescue, and Following a suspicious person	Good
Dark forest	Tall and dense forest, no undergrowth	Following a suspicious person	Bad
Cliff-top	Tall, and scarce forest, no undergrowth	Search and rescue, and Chase	Mediocre
Shore line	Drone on top of water, target person in varying terrain	Border surveillance, and Following a suspicious person	Good

Table 1 above describes the differences between the chosen scenario locations. As is visible, the tree density affects the visibility, not only because of the density but also because of the height of the trees. Another notable issue is the location of the drone operator, as the operator has to maintain eye contact to the drone at all times.

As table 1 shows, the scenarios are tested in different terrain. As stated before, the crew conducting the field intelligence had no previous experience on the drone. We decided that before we started to execute the demonstrations we would walk the forest with the drone operator, so he would also be able to influence on the locations. Mr. Mikkola agreed with the locations, and none had to be changed. Below are described the chosen locations with captions of the places.

Caption 4: The border line

Border line

As a major goal of this project is to study how photonics can be applied in border surveillance using drones or UAVs, we wanted to simulate a border region. The Border line we chose was approximately 50 m wide with an embankment on either side (see caption 4 above) to simulate a border line between two countries. There were some short trees growing on the line, and relatively thick undergrowth. Basically, a person crossing the border line illegally could hide in the woods, but also a border guard would be able to notice something was going on. The terrain was also very good for training purposes for the drone operator, as there are not many options where the significance of the video is highlighted. Also, the drone was seen at all times, and it could be flown at close range with low altitude.

Caption 5: Picture from the drone, target person running through the border line area

Uphill terrain

The Uphill terrain area was chosen as one scenario location, as the drone operator could see the drone easily, and the forest was not too dense for the target person to hide into. It was also used for training purposes, as the thermal camera was to be tested in as many terrains as possible to verify its usefulness. Also, as the trees were relatively short (1-3 m); the operator could train the differences between lowering the drone and zooming with the camera. The filming was done at the bottom of a hill, making it more difficult compared with a similar terrain, the Cliff-top.

Caption 6: Uphill terrain with the target person

Caption 7: The dark forest

The dark forest

The dark forest was the most difficult terrain we chose. The target person could easily move around in the forest, but the drone operator had difficulties in following the target person. The trees were tall and growing densely.

Because of the branches, both the thermal camera and the video camera had trouble locating the target person. This terrain was mainly used to demonstrate following a suspicious person -scenario.

Caption 8: The dark forest from above, target person visible in a yellow jacket

Caption 9: The Cliff-top

Cliff-top

Cliff-top location was used to demonstrate the chase scenarios, as well as sending a person to verify a thermal trace found from the terrain. The terrain and forest itself were similar to the uphill terrain, with the clear difference of being "uphill" from the filmed area. The trees were tall but scarce, with relatively minimal undergrowth. The ortho-picture was filmed from this location, and the crew is visible in caption 22.

Caption 10: A map showing the shore line locations, lower being Tuusula and upper being Järvenpää

All shore line material was filmed in two locations in order to film in varying terrain. The scenario was the same in both locations, following a suspicious person at a border or shore line. The idea was to study how easily something suspicious can be identified from a relatively clear area. The terrain varied from a dense bed of reeds with heavy undergrowth to only a few trees with no undergrowth.

The demonstrations were carried out with an escalating principle, where we started with an easy scenario and repeated it for a few times, so that also the drone operator was able to get to know the terrain. We had prepared to redo most of the scenarios, as we verified most of the material twice a day: at a working lunch and at home every evening. This way we knew which scenarios had to be redone.

Caption 11: Shore line in Tuusula

Caption 12: Shore line in Järvenpää

2.3 Technical equipment

The technical equipment includes mainly Mr. Mikkola's drones and cameras. He had prepared four (4) drones which all had a different camera attached to it. While video and still cameras are the most known and used, an ortho-camera as well as a thermal camera is more unfamiliar. The table below (table 2) lists the specific details of each camera.

Table 2: Technical details on the used cameras

Use	Brand	Model	Resolution photo	Resolution video	Frames per second	Codec	ISO	Shutter speed	Mega pixels
Ortho	Sony	a6000	6000 x 4000	1920 x 1080	60/50/ 25/24	H264 AVC	100-25600	1/4000-30/1	24,3
Still	Sony	A7R	7360 x 4144	1920 x 1080	24p	AVCHD 2.04	50-25600	1/8000-31/1	36,4
Video	Sony	CX-730	-	1920 x 1080	24p	AVCHD	-	-	6,65
Thermal	Optris	PI400	-	382x288	12ms	-	-	-	-
Ground video	GoPro	Hero3	2592 x 1944	1920 x 1080	30/25p	H.624	-	-	5

The thermal camera had many different color pallets that could be altered. As the camera was new and Laurea's demonstrations were the first place to test it, the benefits of different color pallets were studied. Unlike in movies, the color pallet that was found to be the most useful in the given weather conditions was black and white, or different shades of grey. The video streamed onto the control's screen included a finder, or a cross, which automatically seeked on top of the warmest point shown on the screen. The finder could not be locked onto a chosen target. This is visible on caption 13 .

Caption 13: The grey scale of the thermal camera, the red cross points the warmest trace on screen

Caption 14: The ortho-camera's set route on the command center's laptop

Caption 15: Target person running with a selfie-stick, GoPro attached to the bottom

The ortho-camera's idea is to create a unified image of a preset area from single still pictures. The drone and the camera are synched on the operator's computer, where coordinates are set (caption 14 above), and the area from where the picture is wanted to be composed of is chosen. After the settings the drone is manually lifted into the air, after which it automatically flies the preset route taking pictures at regular intervals. After the drone has completed the set task, it hovers at the starting point of the preset route and the drone operator lands it manually. The progress can be followed at the computer during the flight. Landing and lifting are operated manual-ly in order to ensure safety.

As we also wanted to get video footage on the target person's point of view, as well as on the drone on action, we leased a GoPro camera. GoPro cameras film good quality video, are small and light and can be attached to various kinds of brackets. The camera was planned to be attached to a head and chest mount, which worked out well, even with slight tremble with the picture. We also filmed running video with the camera on a selfie stick (caption 15 above). Due to the small size of the camera, its battery did not last very long. Also the cold weather affected the energy consumption. We had two batteries which were charged every evening.

Caption 16: An eigth bladed drone, one of four

Caption 17: Three drones and the control device

Caption 18: The command center and the monitor on a stick

Even though drones are one side of our area of study, the main focus is on photonics. The technical facts of the drones are briefly described here. All the drones that were used in the demonstrations are designed and made in Finland, by VideoDrone Ltd. The cameras are attached to a stabilized camera bracket located under to engine. The drones have either four (4) or eight (8) bladed rotors.

With its carbon fiber composition and an effective payload up to 2,5kg and light cameras, the maximum flight time is 27 minutes. The drones are less than 80cm in diameter and some 40cm from the ground. They are equipped with a GPS transmitter as well as bright led lights.

In caption 17 above, the remote control device can be seen on right. It also includes a harness in order for the operator to be able to concentrate on stabilizing the flight. On left in the caption, Mr. Mikkola's specially equipped car contains inbuilt electric sockets. The device with the wires is the charger.

As the drone operator has to keep an eye on the drone, aid is needed in order to be able to constantly follow the target person on the screen. In caption 18 above, the command center (Ms. Laura Tarkkanen) shows Mr. Mikkola where the target person was last seen on the screen.

Caption 19: The drone and the monitor

Caption 20: Review of a scenario at the border line before moving on to the next simulation

Caption 21: The target person in a camouflage suit crossing the simulated border

2.4 Other equipment and accessories

As stated before and as is visible on the pictures, the demonstrations were executed in a relatively rural area, with no access to bathrooms or indoors. Because the weather in Finland gets cold during November, the research group prepared for the demonstration with taking along a primus stove with Marinol-fuel and water. We kept warm by making coffee, tea and hot chocolate, and prolonged the need to interrupt the demonstrations by taking some small snacks with us. We also had sanitary products to clean our hands. These created some extra costs for the project.

The research group wanted to make the scenarios more difficult, so a camouflage outfit (visible in caption 21 above) was borrowed so that the target person would not be as obvious and visible on the screen. In contrast, a bright yellow jacket was also taken along to be able to train the drone operator, and ease the first of more difficult scenarios. A tent mattress was also brought along so that the target person could be kept dry, and to isolate the coldness emanating from the ground in cases the target person had to lie somewhere for a longer period of time.

What comes to risk management, some first aid equipment was carried along. An addition to safety was a pair of walkie talkies (in use in caption 22 beside), one of which was carried by the com-mand center and the other one by the target person. They were used in diverse ways: giving out instructions, for asking help and to agree on new rounds of the demonstrations. They also ensured the demonstrations could be carried on without interruptions.

It should be noted that even if we have included the specific technical features of all the cameras that were used during the demonstrations, we are not engineers or experts in their use. Thus, the point of view we want to emphasize is an end-user one.

Caption 22: The operator Mr. Mikkola and the target in a camouflage suit, comminicating with the walkie talkie

3. DEMONSTRATIONS

The demonstration were held on 13th – 15th November. The weather stayed the same and the temperature remained relatively constant throughout the three days spent in Hyrylä and Järvenpää at around -1 - +3 degrees Celsius. The weather was relatively dry, some slush rained only on Saturday evening, at which point we were done with the demonstrations. We aimed to exploit the limited daylight time to its fullest potential, meaning that the demonstrations began after sunrise and lasted until after sunset.

Caption 23: The Crew, from the left: Mr. Janne Siltainsuu, Ms. Mari Aro, Mr. Juhani Mikkola, Ms. Laura Tarkkanen and Mr. Riku Leppänen

Caption 24: The crew preparing for the first ortho-flight at cliff-top area: Ms. Mari Aro on the left, Mr. Juhani Mikkola in the middle and Ms. Laura Tarkkanen on the right.

The composition of our research group had slight changes every day, but the core group with the main tasks stayed the same. Ms. Laura Tarkkanen, Laurea's project manager for CBPI-project, made notes and took pictures throughout the demonstrations. She was also responsible for helping the drone operator with observing the flight screen. She coordinated the scenarios and timetables, and acted as the command center. The drone operator was Mr. Juhani Mikkola from VideoDrone Ltd. He provided the instructions on what we could or could not do, which demonstrations should be redo from a technical and data collection point of view, and was responsible for the drones and cameras. Ms. Mari Aro performed in most demonstrations as the target person. Her tasks also in-volved the after care of some of the equipment, and data backups. Three other people were also involved with the demonstrations, all on separate days: Mr. Janne Siltainsuu acted at times as the target person on Thursday. He also was responsible for the still cameras and GoPro. Mr. Jaakko Tyni was of great help on Friday, as he played the target person as well. We also studied the thermal camera's features and capabilities with recognizing different sized people with Mr. Tyni. On Saturday, Mr. Riku Leppänen came to help out with the catch and search and rescue scenarios, and acted as a target person many times.

In order to be able to execute any of the scenarios, an "operative center" had to be put up. It was managed by Mr. Mikkola because of they were his equipment. The operative center was composed of a control device that had an integrated screen on it, a separate screen on a pole, different drones all of which had different cameras attached to them, and a computer to verify connections and settings etc. Naturally, the equipment was moved around the terrain with a car, which was also used for charging the drones' batteries. Mr. Mikkola requested for assistance in the operational phase, as following the screen he had both on his control device and on the pole along with keeping the drone with clear line of sight was hard alone. Hence, most of the planned demonstrations would have been impossible to execute alone.

Before the first flight the research group went on a tour around the terrain in order for the research group to familiarize themselves with the area. The drone operator also commented on the selected areas, and did initial plans on where to put up his operative center in each location. The demonstrations started with mapping the demonstration area using an ortho-camera. The aim of this flight was to monitor and get a clear picture from the top of the planned area to get all relevant information of it before the execution of the demonstrations. The drone's flight altitude was 150 meters above the ground, and the wind speed at that altitude

was around 7 meters per second. The photographed area was 20 hectares. The ortho-picture – however – was not composed, as the flight was mainly used to familiarize the crew with the area.

Before the flight the operator saved the coordinates onto his computer of the drone and during the flight, the drone followed the pre-established coordinates. To avoid risks, rise and landing of the drone was carried out manually. Due to the weather conditions, the research group did not get good quality footage with the ortho-camera. It was not able to get accurate enough pictures, as the amount of light was not sufficient enough. During the demonstration, the ISO value was too high and the pilot tried to increase the exposure time manually as the pictures were not approved in the terms of quality. We repeated the entire demonstration and the result was similar. Therefore, it leads to the conclusion that the demonstration cannot be implemented in high-quality in similar weather conditions. The second conclusion during the flight was that the signal kept dropping when there were trees between the pilot and a drone. During the report phase of the demonstrations, Mr. Mikkola noticed that a manual focus was left onto the ortho-camera, which also might explain why the pictures were of poor quality.

The scenarios were then executed many times in different locations throughout the three days. The demonstration reports are divided by location, and the results are explained with observations on many flight. A total of 28 flights were performed, out of which 23 are described here. No all flights are included, as some of them were only performed to train the operator at the location, or to get good quality, auxiliary data to be added to the video.

Caption 25: Mr. Mikkola (on left) and Mr. Jaakko Tyni planning for the uphill terrain demonstrations at the operative center

Caption 26: A sample of a still picture from the ortho-camera, crew visible beside the car

3.1 Border line

As the main scope of this project was to see how well a drone with integrated photonics would benefit border guards, we will start with the demonstration descriptions with the Border line location. In total of six (6) flights were executed in this area. As described before, this region was used to simulate an illegal immigrant moving along the line, usually wearing the camouflage suit. The scenario was repeated several times on all of the days, using a still-, video-, or thermal camera. We used either one or two target people at the area, and one scenario involved a border guard.

During the demonstration, the operator flew twice over the area in order to get information from two different angles with a video camera and evaluate which one would be more helpful. In the first flight, the area was monitored from further away. It was clear that the operator had excessive difficulties in locating the target person from his screen, if the drone was high and far away. The best angle to monitor the area was longitudinally and diagonally.

Naturally, one target person was easier to follow with the drone than two, even though both were located regardless their good effort in camouflaging themselves to the bushes. The target persons (one or two) were visible as they moved, but if they were still, they could not be seen. The operator was able to identify the targets as humans and their gender as well. Theoretically, a clear facial image could have been possible and was tried and succeeded with a still (SRL) camera.

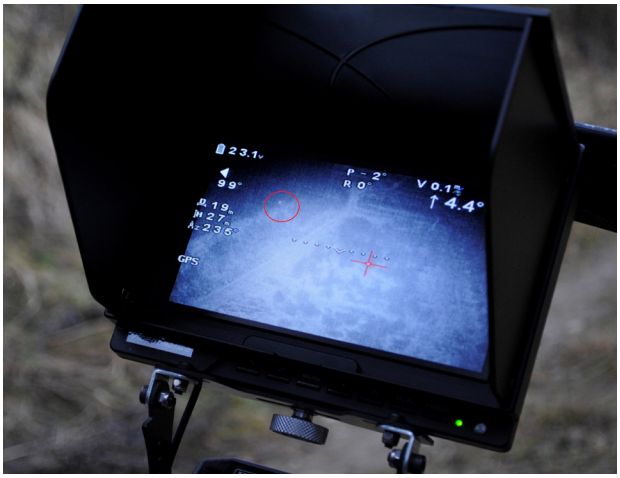
Caption 27: The drone in operation at the border line

Caption 28: Enlarged SRL camera picture at the border line

Even though the thermal image lagged behind with the image shown on the operator's screen, the diagonal angle was determined better also with a thermal camera, and it revealed the target per-son instantly. The bushes, however, covered the thermal trace well, and again, movement revealed the location. If the terrain was different, it could be possible the target person could not be detected. However, as another scenario was attempted with a border guard at the border line, and the command center instructing the border guard on the target person's location, the angle was slightly shifted.

The observations from the target person and the border guard differed from each other. However, the border guard only saw the target when he was crossing the border right in front of her. The command center guided her towards the target person before she could see him, or vice versa. In this demonstration, the communication delay caused by the camera stream lag between the command center and the border guard gave the few seconds lead to the target.

Caption 29: Target person detected by the thermal camera at the border line



Caption 30: Target person marked with a red circle (added afterwards) on the screen, border guard marked with the cross

Caption 30 below illustrates how both people, the target person and the border guard, are visible on the thermal camera. Even when the target and the border guard did not see each other at the border line, their thermal traces were clearly visible on the monitor. According to the command center, they were easily able to follow both figures. They were able to observe all of the "small things" shown by the drone. For example, they were able to evaluate the possible route of the target person on the basis of the thermal trace. The target got a few seconds leads and had time to disappear into the forest on the other side of the embankment. Unfortunately, the drone was unable to monitor his movement because of the thick forest.

As a conclusion from both demonstrations, the drone is a useful tool when patrolling the border line. The drone operator is able to detect and follow the target in almost real-time. If the technology is sufficient, the drone is able to collect data from the target. Therefore, the main issue is to development the technology.

The target person's observations were that it felt impossible to hide from the camera. Also, as the attempt to "cross the border" in the woods was progressing, the fear of being exposed because of the racket made when crawling was evident. However, the drone's characteristic noise apparently covered all noises created by crawling.

Caption 31: Drone from the target person's viewpoint

3.2 Uphill terrain

Uphill terrain was chosen as a scenario location to test the cameras' features and capabilities in varying terrain. Four (4) flights were flown in this region. We used video and thermal cameras, and one to two target people at one time. The thermal camera was tested for several color pallets, but the easiest one to work with was the different shades of grey.

Due to the terrain, the video camera was able to detect the target person's movements. When the targets were hidden, for example under a dense spruce, the video camera was not able to detect the targets. Camouflaging in the terrain was not easy and the drone was able to easily follow the target due to the distinct thermal trace. Hence, the thermal camera was better with detecting the target person from under trees and bushes, even if it was not 100% accurate at all times.

The target peoples' observations were that the terrain created an impression that it would be impossible to hide there. As the trees were very low and the vegetation was hard to camouflage into, the drone felt to be right above the target person. However, as the screen from where the drone operator followed the flight was relatively small, only movement uncovered the whereabouts of the target person with the video camera.

As a conclusion, the thermal camera found the target person more easily. However, as the thermal camera mainly shows the thermal traces as cubes on the screen (pixels), identification is hard in higher altitudes. Identification is easier with a video camera.

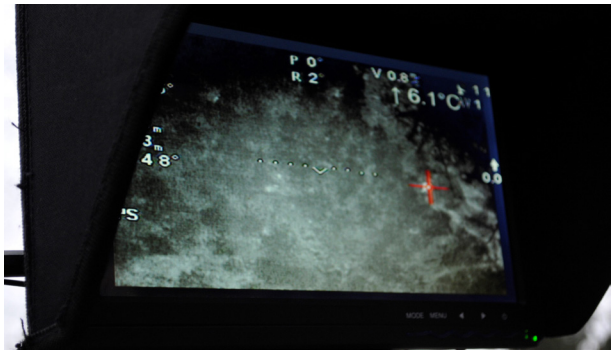
Caption 33: The target person heading to the dark forest

3.3 Dark forest

Due to the unique nature of this terrain, all of the recordings were made from straight above. This terrain was very easy for the target person, but she was hard to be followed with the drone. Both a video and a thermal camera were used, with clear differences in the success rates; the thermal camera lost the target person easily, and could not relocate her. The video camera, especially with the canary yellow jacket, was more successful.

The drone operator with his extra set of eyes from the command center was able to predict the target person's movements, as the layout or the planting of the trees was very logical. The video camera is not the best option to monitor this type of forest.

Mainly, the dark forest was too thick and the target person disappeared into the woods. The video camera could follow the target person easily when the forest was wide, trees were low and without leaves. One of the main observations was that the target herself felt very exposed. The drone flew quite close to the target person most of the time, but could not follow her. She, however, could not know she was invisible to the camera.



Caption 32: The grey scale of the thermal camera's color pallette

Caption 33: The command center following the target person by the dark forest

Caption 34: The drone operator ready for monitoring at the cliff-top

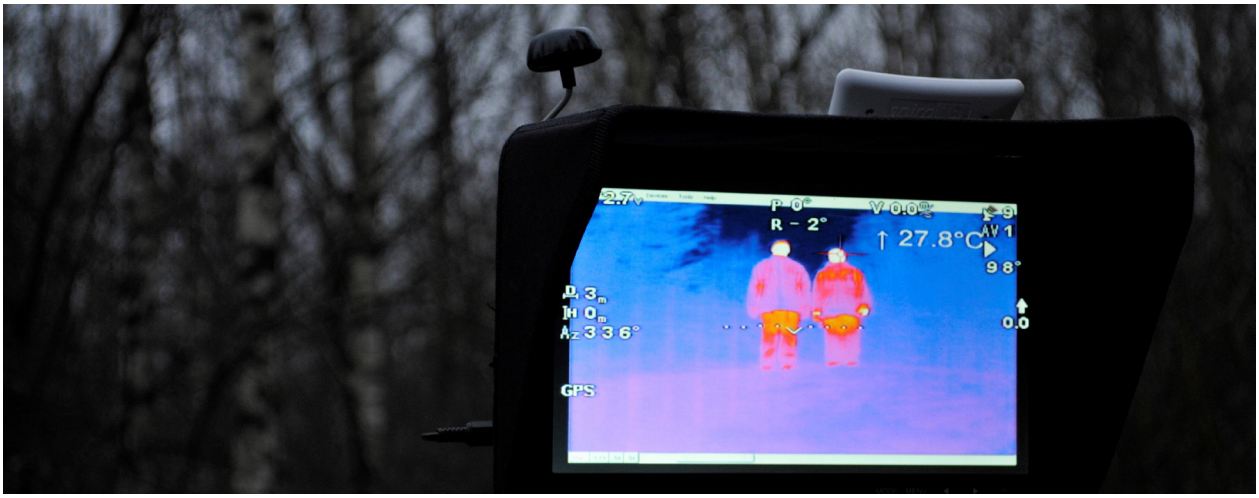
Caption 35: No thermal trace despite the low flight altitude

3.4 Cliff-top

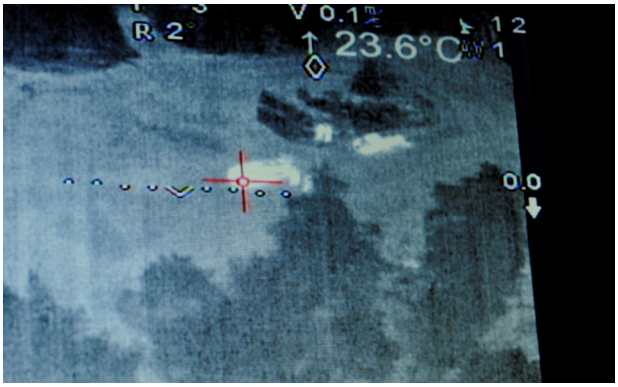
The terrain at the cliff-top area has various trails along the forest. The trees were big and tall but spread around the area, leaving visible ground from the drone's point of view. Video and thermal cameras were used here. The target person was relatively easily found by the operator in most cases, but she could easily hide under the trees and bushes intentionally. This was mainly because the thermal video was recorded from straight above, which was the best angle to find the thermal trace according to the drone operator. It also enabled the target person to hide intentionally.

Even though the scenarios worked mostly as described above, one particular time the camera could not locate the target person (see caption 35 above). Even though he moved to a more open area, the camera took too much interference from the surroundings, and the thermal camera did not locate the person. According to Mr. Mikkola, the flight altitude may have been so high and the target so small with significant background noise, that the pixels were not sufficient enough. In other words, the team failed to execute the scenario due to the technology and its inadequate accuracy.

The research group also studied the different thermal traces in the terrain with the target person in the woods. Ponds and concrete structures were clearly visible, and the thermal camera's finder locked itself onto the warmest subject on the operator's screen. The flight altitude affects the locating function and recognition, which is further complicated by the Finnish nature. Also, as the current legislation requires the operator to have a clear line of sight, the drone cannot be flown at low altitudes, as the trees would have blocked the visibility. At lower altitudes, even the size of the thermal trace (tall or short human) could we identified.



Caption 36: The command center following the target person by the dark forest



Caption 37: Studying the different thermal traces in the terrain, target persons by a pond

Another search and rescue scenario was to simulate an injured person's search from the woods. The target person went to the woods and found a place where a lost person would normally wait for rescuing. This place could be a rock to sit on, or leaning against a tree. The target person was not totally hidden in the woods but she was not in a clearly visible place either. After the operator had located the target's thermal trace and the drone was "patrolling" over the target, the re-search group was able to send the rescuer into the woods. The rescuer followed the drone as long as she was visible on the screen, after which she got instructions from the command center to her walkie-talkie.

On the other side of the cliff-top the terrain was hillside and inclined a bit downhill. Therefore, the drone operator was able drop the flight altitude compared to the previous scenario. In this demonstration, the drone operator could follow the target person easily, as the thermal trace was more accurate due to lower altitudes. The target person herself felt "exposed" even though the thermal trace was lost at time, when she was hidden in the woods intentionally. This scenario could easily occur in real situations.

To list some of the observations made during the scenarios, the nature gave its own thermal traces during the demonstration. This research was done during the late autumn and still the thermal camera spotted plenty of thermal traces, including water ponds and concrete structures. Delay between the camera feed and the monitor occurred during the demonstrations, which could be critical in a search and rescue situation. Before properly trained to the use of the thermal camera, especially as there is no locking option on the screen finder, locating the target person was difficult. Also, due to the tall trees which resulted into a forced high flying altitude, the technology was not always sufficient in finding the target person. As a result, the drone operator suggested a two-lens option, which will be further elaborated in the research results and further research proposals.

3.5 Shore line

The research group tested different cameras and their functions with the simulated border area. Because there is no homogenic border area, we wanted to include shore line as well, and see whether it brought any obstacles to the scenario. Therefore, on Friday 14th of November, the research group continued the demonstrations with the video camera, and the demonstration scene was changed to Järvenpää, Finland, another 10-20 km north. The aim was to monitor the shore line on a lake, and we chose Lake Tuusulanjärvi. Only three flights were made here, with different scopes: finding a person from the terrain and following a suspicious person.

In this scenario, the illegal immigrant moved and hide along the shore line. Firstly, the research group started at a shore line where the forest cover was not thick. As a result, the drone could follow the target person easily and she was not able to hide. Therefore, the research group continued the demonstrations in a thicker forest. The target was instructed to hide somewhere along the shore line and the operator tried to find her with the drone using a video camera. It took a while to locate the target in this terrain, as she was able to hide in the shore line and the operator had to fly the drone a few times above the water before the target was located. When the target person moved, the drone was able to locate her almost instantly.

Caption 38: The drone patrolling the shorline, target person visible at the back

Caption 39: Planning and altering the shore line scenario

Caption 40: The operator monitoring the shore line at Tuusula lake

The video camera was useful during daylight and in the easier shore line where the movement was easily visible. The advantages of video camera were that the operator was able to get accurate pictures of the target person due to the different angle on the water. In a real-time situation, the different angle of monitoring gives a more precise an accurate picture / image of the target person. Also notable, the camera is able to capture video in the different shore line and climate.

Caption 41: The target person visible on the screen at the shore line

4. RESEARCH RESULTS

In this section the research results are gathered from the demonstrations. Altogether 28 flights were made. The total amount of recorded data was 165 minutes with video and thermal cameras. Also, still pictures were taken and an ortho-image could have been formed. The research group will include the command centers and the drone operator's point of views, and where appropriate, the target person's observations will be included. The results are explained by camera type and terrain, mainly focusing on the video and thermal cameras. The last section will analyze the energy consumption by camera and flight time.

In order to ensure the videos are at all partners' disposal, the Laurea team chose YouTube as the distribution platform. The videos are only available via the links below, which are free to be shared with the relevant parties. All together four videos were composed: an overview of all demonstrations (videolink 1), and three specified videos on shoreline (videolink 2), dark forest (videolink 3) and the borderline (videolink 4). The videolinks are listed below.

1) Overview of the demonstrations: https://www.youtube.com/watch?v=VzNHez4cNCk&feature=youtu.be
2) Shoreline : https://www.youtube.com/watch?v=m8506iv-vL_E&feature=youtu.be
3) Dark forest: https://www.youtube.com/watch?v=bmHtK-gpaL2Q&feature=youtu.be
4) Borderline: https://www.youtube.com/watch?v=p7KZu-vzlQBY&feature=youtu.be

4.1 Video camera

The research group thought the drone with the video camera would be the most used equipment, but after reviewing the data, thermal camera was used the most. The crew recorded 75 minutes of material with the video camera during eight (8) flights. The video recording withholds data on the illegal immigrant scenario both at the Border line (2 flights) and Shore line terrains (1 flight), and following a suspicious person scenario was recorded at Shore line (2 flights), dark forest (1 flight) and uphill (2 flights) terrains.

4.1.1 Dark forest

The main observation when monitoring with the video camera was that the operator is not able to execute the demonstration by himself. The operator was not able to follow the target person continuously due to the terrain. Also the current legislation regulates that the operator is required to maintain eye contact with the drone at all times. As the operator raised his eyes from the screen to look at the drone, the target person could easily disappear into the background. Even though the target was not visible at all times with the operator looking at the screen, he was able to see the target person's hiding place, and anticipated the most logical direction of propagation.

Given that the aiding person would be needed when the target person needs to be detained, operations might need three people. If the target would be instructed to lead the drone astray, it would be easy. Hence, the demonstration were continued with another "pair of eyes" to follow the target person

Caption 42: Dark forest from above, following the target person was hard

Caption 43: The target person is communication with the command center in the dark forest, trying to get visible on the video camera

on the monitor, which was more than helpful for the operator. The research group concluded that the video camera is not the best option to monitor a terrain like the dark forest. Mainly, the forest was too thick and the target disappeared into the woods. The video camera could follow the target person more easily when the forest was wide, trees were low and without leaves.

Even though the operator had problems following the target person in the dark forest, the target herself felt very exposed. According to the target, the drone flew quite close most of the time. She, however, could not know she was mainly invisible to the camera. As a research result, the psychological aspect has to keep in mind. From the border surveillance perspective, the used video camera is not good enough; still, the target thought that she was revealed. On the other hand, the technology functioned properly.

As a conclusion, the video camera cannot be successfully implemented to practical border surveillance in similar circumstances. Relying on that aim, the video camera did not meet its objectives. In an ideal situation the operator would be able to monitor the area by himself. The pressures in the resources for the border guard personnel, the main target is to implement the technology which would be used as a "man and a backpack". As a conclusion, the current technology is not sufficient enough from the border guard's perspective.

4.1.2 Uphill terrain

To compare the differences in observations monitored by the video camera, the research group executed flights in the uphill terrain. The main result was that the video camera detects the target person's movement very well. Due to the terrain, the movement was able to be detected easily. The operator was able to monitor the area from a lower flight altitude which helped in detecting the target as well.

To complicate the demonstration, two target persons were used simultaneously at times. After having the above mentioned results, the aim was to complicate the demonstrations and the targets were hidden. When the targets were hidden, for example under a dense spruce the video camera was not able to detect the targets. This might create the difficulties when using the video camera in border surveillance. As a research result, the current technology is not sufficient enough for border surveillance due to the uncertainties in monitoring. As concluded during the demonstration, the drone is not able to locate the target if s/he is hidden well enough.

According to the target person, the terrain created an impression that it would be impossible to hide there. As the trees were very low and the vegetation was hard to camouflage into, the drone felt to be right above the target person at all times. However, as the screen from where the drone operator followed the flight was relatively small, only movement uncovered the whereabouts of the target person.

Caption 44: The target person is very visible in the uphill terrain

4.1.3 Border line

The video camera was used twice in the border surveillance demonstrations in order to find the best angle to monitor the area. In the first flight, the area was monitored from further away in order to monitor the entire area at the same time. Basically the drone hovered still. During the flight the perspective was found useless as the drone and the camera were too far away. The angle monitored the border area incorrectly. In this demonstration, the target got away over the border line unseen. Noteworthy, the target person did not show up at all in the monitor.

The target's observations were that it felt impossible to hide from the camera. Also, as the attempt to "cross the border" in the woods was progressing, the fear of being exposed because of the racket made when crawling was evident. However, the drone's characteristic noise apparently covered all noises created by crawling.

The results of this demonstration were that the illegal immigrants camouflaged well in the brush-wood of the peripheral areas of the border line as well as in the spruce wood in the middle. When the target people remained in place, they were out of the camera's sight. However, while targets were moving over the border line, the operator monitored both and was able to keep track of targets' movement. As a research result, the operator was able to identify the targets as humans and their gender as well. As a conclusion, the video camera is useful in certain border surveillance scenarios. For example, the video camera is able to identify the target person at a certain level. Naturally, it gives value to the border surveillance. On the other hand, the video camera is not able to locate the target with absolute certainty. As previously stated, the immobility of the target person poses challenges and the choosing of the angle to monitor the area has a great importance for localization. For example, the video camera could be an alternative camera option for more detailed monitoring after the target has been localized?

Caption 45: The drone from the targer persons point of view at the border line

Caption 46: The target person crossing the border line

4.1.4 Shore line

The shore line as a demonstration area gave similar observations than previous video camera demonstrations. Mainly, when the target person moved, the drone was able to locate her almost instantly. However, when the target person went into hiding, it took a while to locate her in this terrain. During the demonstrations, the aim was to complicate demonstrations. Therefore, the target went into hiding beforehand after which the operator started to fly the drone and tried to locate her. This demonstration gave similar observations as previous ones. For example, it took a while to locate the target person. The operator had to fly a few times above the water before the target was located. There might be a small chance if the target was camouflaged under the obstacles; the operator would not been able to locate her.

As a technical research result, the video camera was useful during daylight and in the easier shore line where the movement was easily visible. The advantages of video camera were that the operator was able to get accurate pictures of the target person due to the different angle on the top of the water area. In a real-time situation, the different angle of monitoring gives a more precise an accurate picture / image of the target. Also notable, the camera is able to capture video in the different shore line and climate. For border surveillance, the video camera could be a proper tool for easier terrain (e.g. lakeside, wide terrain) in order to obtain more detailed data from the target, also from different angles. The quality of the data is high and it may be assumed that it could be used in person or face recognition.

Caption 47: The drone operator has located the target, and zooms in for identification

4.2 Thermal camera

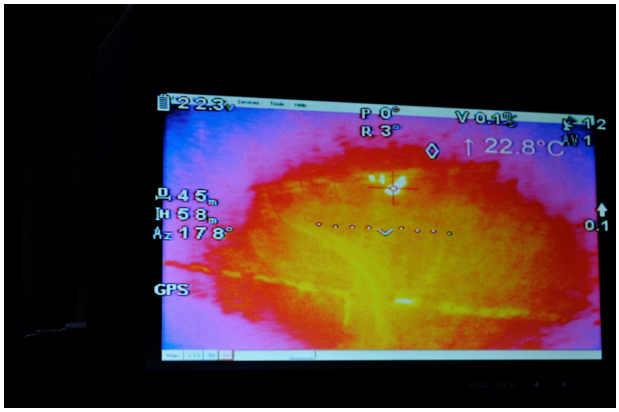
The crew used the thermal camera most out of all equipment. The thermal camera was new technology for both Mr. Mikkola, the drone operator, and Laurea team. Because of this, many of the scenarios were first piloted, and then executed, which explains the difference in the total flight time (90 min) and number of flights (14). Mainly the thermal camera was used in the search and rescue, following a suspicious person, border line scenarios where the target has to be located. The thermal camera was used in at least 9 scenarios in four different terrains.

4.2.1 Uphill terrain

The main idea behind this scenario was based on free-movement of the target person in a given area. During the demonstration, the target person tried to lead the drone astray. Camouflaging in the terrain was not easy and the drone easily followed the target due to the distinct thermal trace. However, the operator once had to request more accurate instructions on the target's location because of a vanishing thermal trace. In that case, the target person was hiding under several spruces. According to the target person, only a tracker dog would have been able to find her from the hiding place. The research group got similar results than from the video camera - the drone is able to follow when the target is not hiding. Still, it was not able to follow in the dense forest cover.

As another research result, the majority of the shades of the color palette did not work properly in that area. Mainly, the thermal trace from the forest disappeared completely. In addition, few shades of the color palette worked properly in the forest due to the more distinct thermal trace, for example the only proper thermal trace came into existence from the motocross drivers who passed under the drone. However, as a conclusion, still the distinct thermal trace was occasionally vain and the thermal camera preferred an open area. After all, the research group decided to continue the thermal camera demonstrations with the grey shade of the color palette.

Caption 48: Blue color palette on the thermal camera, the visible line is a road



Caption 49: Thermal traces of some passing motor cyclists at the bottom of the screen, at the top are two crew members and the car

4.2.2 Cliff-top

The cliff-top area was used for the several tests in order to figure out how much the accuracy of the thermal trace varied depending on the situation. For example, when the target people were hiding on purpose, the thermal trace disappeared. On the other hand, when the targets did X and Y figures on the ground, the figures were easily visible on the monitor. Also, when one target person took the top most jacket off, her thermal trace was even more visible and relatively accurate. As a research result, it is possible to influence the thermal trace in a positive or negative way, depending on the layers of clothing. Naturally, the nature has its own impact on the thermal trace.

In a search and rescue scenario, the photonics technology has to ensure and guarantee the functions in real-time border surveillance. Therefore, the first objective was to locate thermal traces what were shown on the monitor. Basically, the drone flew over the cliff-top area and spotted different kind of thermal traces which were not familiar to the operator. The purpose was to train the research group to identify the different thermal traces. After spotting, the rescuer followed the drone to investigate what gave out the thermal trace. As a research result, the flight altitude is the key issue in obtaining the good quality and detailed data. If the drone is capable to monitor on the top of the target and as close as possible, the differences in shapes and size will be better identified. However, it should be noted that exact monitoring on the top of the target is difficult or even impossible to execute in the Finnish nature and with the current legislation.

In a chase scenario, the target person's thermal trace was seen in the drone operator's monitor during the demonstration. The searcher found the target easily when she followed the drone. It was intended when the target person saw the searcher approaching towards her, she tried run away. The searcher lost the target person for a few seconds, and then he reached her.

According to the operator, the best angle is from the top of the target person - the thermal trace is more accurate. During the flight, the altitude was 50 meters. As an observation, the figures of the target and the searcher stood out very clearly in the monitor at this flight altitude. As a result of these three demonstrations - the angle is the best option for the search and rescue scenarios.

As a research result, the streaming delay between the command center and the border guard created challenges because the most important issue is to react fast.

The motion exposed the target person before his thermal trace was found, as the viewfinder kept locking onto a certain location on the screen. According to the command center, it was easy to observe the happenings from the monitor. They were able to observe all of the "small things" monitored by the drone.

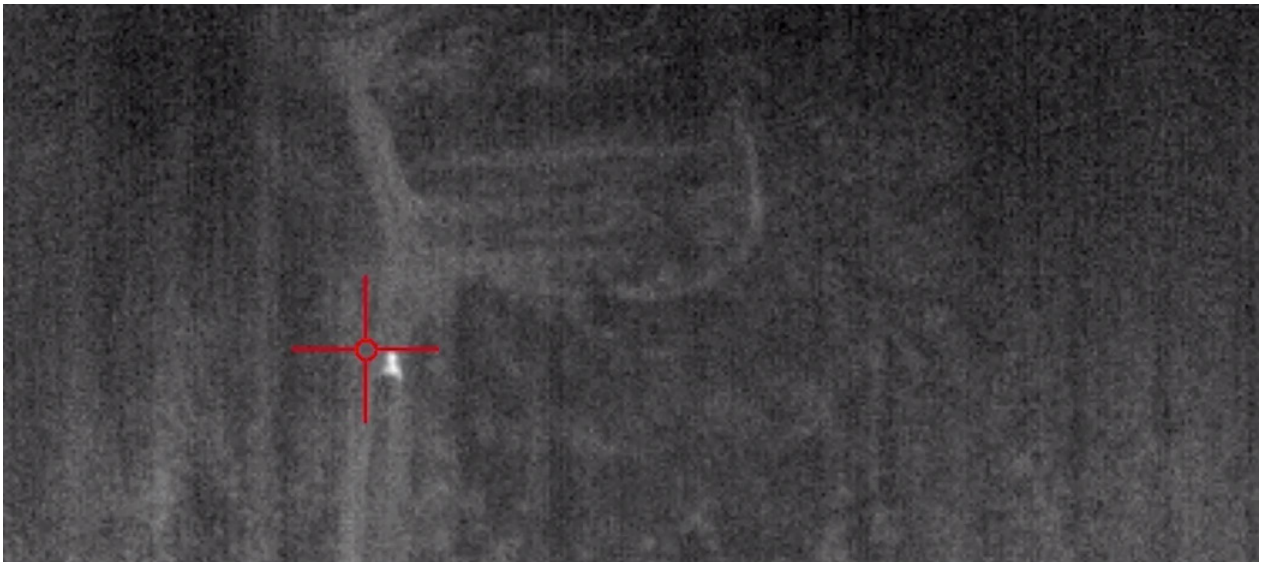
Caption 50: The target person on the right took the top most coat off to test the thermal traces, and is shown more brightly

Caption 51: The searcher observes the thermal image to locate the target person, before starting the chase

4.2.3 Border line

The research group did two flights in the border line to analyze how the target person could be detected from the different angles. First flight was monitored along the border and from the side of the border zone. The angle of view allows a wider view and a more explicit thermal trace. In this demonstration, the target was found immediately when she was moving over the border line. However, when she camouflaged and was hidden into the nature, the thermal trace disappeared.

Second flight was monitored from above the area. The flight height was around 50 meters. In this view of angle, the thermal trace was more explicit, offering the target a possibility to sneak away over the border line outside the camera's view. The target person was still also found from this angle. If the terrain was different, it could be possible the target person could not be detected.



Caption 52: Thermal trace of a target person at the border line

4.3 Energy consumption

The most critical aspect regarding the security of supply in this scenario is ensuring energy supply. The maximum flight time with one battery is approximately 27 minutes. However, as the camera is also dependent on the battery, it cannot last 27 minutes. The longest flight during the demonstrations was 17,15 minutes, and the average flight time 11,3 minutes. As the energy consumption is dependent on the camera, the average consumption does not provide relevant information. Instead, the table below (table 3) illustrates the average consumption per camera type. As not all flights were recorded with regards energy consumption and flight duration, we used the data available. This covered 15 flights out of 28, and included three flights with an ortho-camera, three flights with a video camera and nine flights with a thermal camera. As the weather was relatively constant in temperature, which has the most effect on battery duration, this data is comparable.

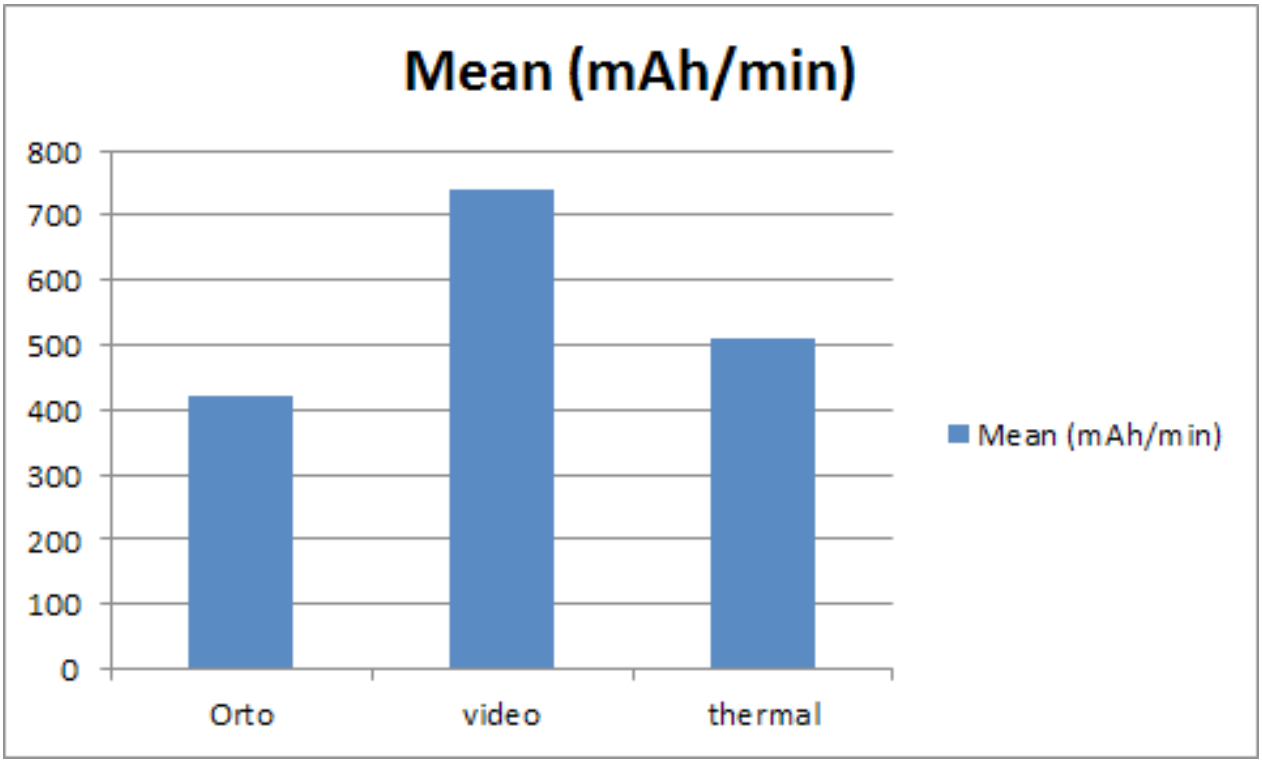
Even though the initial observations were that the thermal camera would consume the most energy during flights, the team was wrong. As illustrated in table 3 above, the video camera consumed the most energy. The data was processed with dividing the energy consumption with flight duration, and then calculating the means of each average.

The drone operator has an electric socket in his car for charging the batteries. However, he also pointed out that a portable aggregate is available for energy supply if the operation area is remote. One fuel tank lasts up to 6 hours of operation, and if the fuel supply is secured there is no challenges in energy supply chain.

4.4 Other issues and equipment

The GoPro camera was easy to use and light to carry. The diverse hanging harnesses for chest and head were useful and solid. However, the battery duration was relatively bad. Even with an additional battery, with both of the batteries use of in all three days, we gained 117.34 minutes (just under 2 hours) worth of good quality video with the camera being off in between filming.

Table 3: The average energy consumption by camera



5. FURTHER RESEARCH PROPOSALS

All further research proposals are gathered in this chapter. During the different video camera scenarios, the idea of the psychological point of view emerged. The question of the psychological aspect and the feelings of the target person during the demonstrations would be worth further research. Therefore, further research proposal will be based on these cases from psychological point of view. For example, how human behavior varies in a real-time situation? When an illegal immigrant feels exposed, could it be assumed that the person will not be able to act rationally. The results of this research might create a tool for border surveillance, and whether is it possible to improve the overall border management processes.

The other research proposal is to fly the drone during different seasons of the year. How different the gathered data and research observations will be during the fall colors? Or during summer or in winter time?

The main objective of the demonstrations was to test different cameras and consider how they could be used in border surveillance. In addition, the research group compared the cameras against each other in scenarios in order to analyze the usability of the cameras. As a result, the video and thermal camera had their own benefits and weaknesses. Therefore, one further research proposals would be the technological study of to use a "dual camera". This includes two lenses (video and thermal). The main functions of the dual camera would aid in border surveillance as the thermal camera would locate the target person and the video camera would be used for identification purposes. One further ENPI cooperation project would be to research how easily and what features the current photonics technology already has, that would enable the two-lens technology to be used in border surveillance with varying weather conditions.

As mentioned before, the thermal camera demonstrations had a great importance in order to get thermal camera footage for the first time. The nature created its own thermal traces. This was a surprise to the operator and the research group, especially during late fall. The thermal traces created their own challenges to monitoring as well. Thus, as a further research proposal, the demonstrations should be implemented in each season of the year in order to research how much the surrounding nature affects the thermal trace, and whether the noise could be controlled on site.

During the thermal camera demonstrations, the research group faced difficulties with the vanishing or disappeared thermal trace. The aim was to implement technology and operating models into border surveillance. Therefore, the problems appear if the target person is hidden in a difficult place or dense forest, and the drone is not able to find a thermal trace. How to guarantee that the drone with a thermal camera will add value into real-time search and rescue functions? In that case the thermal camera would need more pixels to ensure working in the varying circumstances. Before executing further research, the used technology should be improved to diminish the loss of the thermal trace or to avoid guiding the searcher towards her own thermal trace.

Therefore, another betterment on the camera would be the ability to lock the followed target person onto the camera. According to the operator, the locking option is mainly used in military drones, but would also be of use in search and rescue events.

What comes to technology with a higher resolution in a thermal camera, the target person would be found easier and at a higher altitude when monitoring directly over the target. According to the drone operator Mr. Mikkola, a technical improvement would be the thermal camera by FLIR Systems. The product from FLIR Systems is developed to search and rescue situations. However, the FLIR Systems' camera does not record video, but if necessary it takes still pictures. As further research proposal could be to study whether it would be helpful to the border guards if the camera could identify the traces of human and animal apart.

During the search and rescue scenarios, the research group observed that there is delay in the streaming of video to the monitor. Several times the command center was not able to guide the searcher in real-time towards the target person due to the delay in the stream. What comes to search and rescue functions, especially in the critical rescue situations, the delay in the streaming might be detrimental to the operation. Therefore, the technical study of the delay is an important further research proposal to establish the delay time, and whether it can be reduced.

6. CONCLUSIONS AND CRITIQUE

Photonics and drones may be applied in border surveillance. As technology is further developed it becomes cheaper and more available. However, many current limitations are caused by either inadequate technology or too high prices to implement technology into the border surveillance. Nevertheless, the research group found the advanced technology is useful in general.

The research group concludes that there should be further demonstrations of the surveillance technology. Also, the weather conditions and the time of the year have to be further studied. Even though some 4-6 months of a year the weather conditions are somewhat similar with the limited daylight and challenging weather conditions, which makes these demonstrations realistic, no data was gathered in the summer or winter time. During these time of the year, camouflaging and traces would be very different, as well as the differences in battery life and maintenance. On the other hand, these demonstration results would be something to benefit from as well as develop in the further research. The purpose is to develop border surveillance, so knowledge and understanding on how easy or hard it is to evade the drone by camouflaging, crawling or hiding in the area are useful.

The scenarios can be evaluated as realistic, but they have not been reviewed by the relevant authorities. The research group also experienced minor difficulties when choosing the terrains, but the inexperience was replaced with an intelligence field trip and many alternative locations. As the scenarios were evolved and redone based on the data review, many of them could simulate actual situations. Hence, the results can be taken into consideration with regards the drone implementation preparations.

The demonstrations were able to be executed with the used technology, even though the limitations of the technology emerged very clearly as well. For example, the average of the flight duration was less than 15 minutes. Under the current weather conditions, the battery of the drone did not last more than 18 minutes. Naturally, the duration of the battery caused challenges for the demonstrations. As an example, during the search and rescue scenario, the operator had to land the drone during the demonstrations for battery replacement. In order to implement the demonstration successfully, the charging option of the batteries is needed. Actually, the batteries had to be charged constantly. The charging station was implemented in the operator's car so the demonstration places had to be reached by car.

The other difficulties caused by the technology were the challenges with the adjustment and zooming. To get more accurate data, these features would be useful. The drone operator either had to lower the drone to get a closer picture, or use zoom. However, while using zoom the target person was lost from the screen, and, according to Mr. Mikkola, the remote was so sensitive that in order to relocate the target person onto the screen it was easier to undo the zooming option. This should be developed.

As mentioned in the further research proposals, the possibility to use the dual-camera in the drone would be worth a research. This research shows that with the combination of two cameras would achieve significant benefits; the thermal camera detects the target and the good quality video camera would monitor it in more detail. On the other hand, as this research presents, the dual-camera is not necessarily reliable solution due to the challenges in locating the target. As illustrated in table 3, the video and thermal camera consumed the most energy. To provide relevant technology for the authorities, the average flight duration 11,3 minutes is not enough. However, the current technology can operate under harsh circumstances. As a main conclusion, the research group suggests to develop a customized technology solution for border surveillance purposes. The border guards as end-users and the technologic manufacturers should participate in the development process. It is important that there is no mismatch between the needs of the end users and the abilities of the manufacturers.

Finally, the drone is useful and gives extra value to border surveillance, especially if the technical R&D is successful. As mentioned, the demonstrations gave valuable information of the guidelines to the technology development. Thus, the research group cannot recommend the direct implementation of the photonics technology and the technologicy which was used in these research demonstrations. The research results lead to a conclusion that the authorities should not invest in insufficient technology at the moment. The research group concludes that technology alone is not sufficient enough if the aim is to take advantage of the affordable solutions. Naturally, the military technology is the most efficient solution, but expensive.

All in all a comprehensive border management still requires the cooperation with the border guards and a dog. The weaknesses that the drones currently have and what a border guard is able to do will be completed by using a dog. For example, the dog is able to track the target person which was a problem during the demonstration. Hence, the most functional border surveillance solution would be based on a triple helix: the border guard, a border dog and the drone.

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The Cross-Border Photonics Initiative demonstration research report

Cross-Border Photonics Initiative project was funded by the South-East Finland-Russia ENPI CBC funding programme 2007-2013, with an economic development theme. The main objectives were knowledge and technology transfer, institutional cooperation and cooperation networks and scientific cooperation. The project aimed to foster photonics technologies for economic growth and to increase cross-border collaboration between universities and photonics companies. Project coordinator was ITMO University from Russia and the project partners were Optogan from Russia, Aalto University and Lappeenranta University of Technology. The main objectives of Laurea University of Applied Sciences were to develop and test systems of UAV platforms and sensors for automated border surveillance, and to implement innovative border surveillance systems.

This report discusses Laurea UAS' main contribution to Cross-Border Photonics Initiative project. This report describes how, by combining drones with photonics, new technology can be applied in border surveillance. The report describes the planning of the demonstration flights, including choosing the area and equipment, explaining the permit process and creating scenarios. The other chapters explain how the demonstrations were executed, how they went, what was learned and how the demonstrations were altered with the gained information in the scenario. In addition, the last chapters analyze the results, the research findings and further research proposals.