FFI Norwegian Defence Research Establishment

24/00357

FFI-RAPPORT

LandX23

– target acquisition and engagement

Dan Helge Bentsen
Ole Martin Asak
Lorns Harald Bakstad
Eivind Bergh Nilssen
Sven Bjerke
Per Dalsjø
Katrine Mygland Dybwad
Oddmar Eiksund
Sander Folke-Olsen
Sondre Holm Fyhn
Trym Vegard Haavardsholm
Morten Hanevold
Håkon Hellemo
Christian Horn
Anders Imenes
David Kolden
Martin Vonheim Larsen
Kim Mathiassen
Robert H. Macdonald
Mathias Minos-Stenerud
Niels-Hygum Nielsen
Martin Normann Nielsen
Olav Rune Nummedal
Lars Erik Olsen
Morten Paulsmoen
Gard Inge Rosvold
Marta Lill Sele
Sindre Løining Skaar
Aleksander Skjerlie Simonsen
Torjus Spilling
Håvard Stien

LandX23 - target acquisition and engagement

Dan Helge Bentsen
Ole Martin Asak
Lorns Harald Bakstad
Eivind Bergh Nilssen
Sven Bjerke
Per Dalsjø
Katrine Mygland Dybwad
Oddmar Eiksund
Sander Folke-Olsen
Sondre Holm Fyhn
Trym Vegard Haavardsholm
Morten Hanevold
Håkon Hellemo
Christian Horn
Anders Imenes
David Kolden
Martin Vonheim Larsen
Kim Mathiassen
Robert H. Macdonald
Mathias Minos-Stenerud
Niels-Hygum Nielsen
Martin Normann Nielsen
Olav Rune Nummedal
Lars Erik Olsen
Morten Paulsmoen
Gard Inge Rosvold
Marta Lill Sele
Sindre Løining Skaar
Aleksander Skjerlie Simonsen
Torjus Spilling
Håvard Stien

Norwegian Defence Research Establishment (FFI)

22 May 2024

Keywords
Autonomi
Deteksjon
Eksperimentering
LandX
Militær teknologi
Ubemannede Systemer

FFI report
24/00357

Project number
1678 (and 1579, 1612, 1668, 1672, 1688)

Electronic ISBN
978-82-464-3528-2

Approvers
Lorns Harald Bakstad, *Research Manager*
Halvor Ajer, *Director of Research*

The document is electronically approved and therefore has no handwritten signature.

Copyright

Summary

LandX is the Norwegian Defence Research Establishment's (FFI's) yearly two-week collaborative event focusing on experimental technologies in the land domain. LandX23 was its fourth edition.

Over the years, the complexity of the LandX experiments has gradually increased, starting with Situational Awareness (SA) in 2020, going into Manned-Unmanned Teaming (MUM-T) in 2021 and including military personnel and Counter Unmanned Aerial System (C-UAS) in 2022. This year included effectors in addition to the previous themes.

LandX23 featured several projects and many different systems developed at FFI, including:

- technologies for increased situational awareness for unmanned ground vehicle (UGV)-operators, and a safety-approved mobility emergency stop over IP networks as well as secure communication between the UGV and its operator.
- technologies for remotely operated distributed sensor networks.
- a prototype multi-unmanned aerial vehicle (UAV) system, including C-UAS.
- a synthetic prototyping testbed to enhance system development, train personnel or develop operational concepts.
- networked lightweight and low-cost passive RF sensor for SA in the electromagnetic spectrum.
- a light short-range anti-tank guided missile (ATGM).

In this report, we describe each of the activities that was part of LandX23 in more detail. There is also a comprehensive description of the demonstration at the end of this report.

Sammendrag

LandX er FFIs årlige samarbeidseksperiment med vekt på eksperimentelle teknologier innenfor landdomenet. LandX23 var fjerde gang det ble avholdt.

Gjennom årene har bredden i LandX-eksperimentene gradvis økt. I 2020 var det bare snakk om situasjonsforståelse (SA), men allerede i 2021 ble LandX utvidet til å dekke også fellesoperasjoner mellom bemannede og ubemannede systemer (Manned-Unmanned Teaming – MUM-T). Videre, i 2022, ble operativt militært personell og antidronesystemer (Counter Unmanned Aerial System – C-UAS) inkludert, og i 2023 kom effektorer til blant de tidligere områdene.

Årets LandX inkluderte flere FFI-prosjekter og mange forskjellige systemer, blant annet:

- teknologier for økt situasjonsforståelse for operatører av ubemannede kjøretøy (unmanned ground vehicle – UGV), sikkerhetsgodkjent nødstopp over IP-nettverk og sikker kommunikasjon mellom ubemannede kjøretøy og operatører.
- teknologier for fjernopererte sensorer over distribuerte nettverk.
- en prototype av et multidronesystem (multi-unmanned aerial vehicle (multi-UAV) system), inkludert et antidronesystem C-UAS.
- et testmiljø for syntetisk prototyping for å forbedre systemutvikling, trene personell eller utvikle operative konsepter.
- passive RF-sensorer i nettverk og med lav kostnad for økt situasjonsforståelse i det elektromagnetiske spekteret.
- et nytt bærbart kortholdsmissil.

I denne rapporten beskriver vi hver av aktivitetene som var en del av eksperimentene på LandX23. Det er også en omfattende beskrivelse av demonstrasjonen mot slutten av rapporten.

Contents

1 Introduction

LandX is FFI's yearly collaborative experiment focusing on experimental new technologies in the land domain. The first experiment was held in 2020 [1], and was a collaborative experiment and demonstration where four FFI projects participated. It was initiated by the FFI project *P1400 Situational awareness and active protection systems*. As it was relevant for other projects, the experiment was expanded the following years to include relevant projects within the research programmes *Combat systems* and *Autonomous systems*. This included the FFI projects *P1505 Autonomy* and *P1514 Unmanned ground vehicle - technology project*. Over the years, this arena has evolved to include research activities from many research programs and departments at FFI, still focusing on land domain issues [2][3]. The LandX event is held at Camp Rena (week 39 and 42), supported by the facilities at ICE worx Rena. ICE worx Rena is one of three innovation arenas within the ICE worx innovation centre.

Over the years, the complexity of the LandX experiments has gradually increased, starting with Situational Awareness (SA) in 2020, going into Manned-Unmanned Teaming (MUM-T) in 2021, and including military personnel and counter-unmanned aerial system (C-UAS) in 2022. The theme for 2023 was expanded to include additional effectors. Figure 1.1 illustrates the development for the LandX experiment series.

With LandX, we are able to focus the activities in several projects towards a common goal. A two-week field test is a very efficient way to test many technologies in a more operational setting and expose military users to new technology. LandX has become a meeting arena to discuss new technology, research, and future land warfare with military leaders. In addition, industry partners participate with their existing and new products, making this a triangle cooperation.

The LandX experiment series has grown over time to include more and more different research activities. But even if new topics are included, it is important to remember that all parts are constantly improving. The development never stops; it is open-ended.

This report is organized as follows: Initially, in chapter 2, we briefly describe the infrastructure and facilities at LandX. Subsequently, in chapters 3-8, we introduce all the different contributions to this year's LandX, including lessons learned and further work. Finally, in chapter 9, the final demonstration is described.

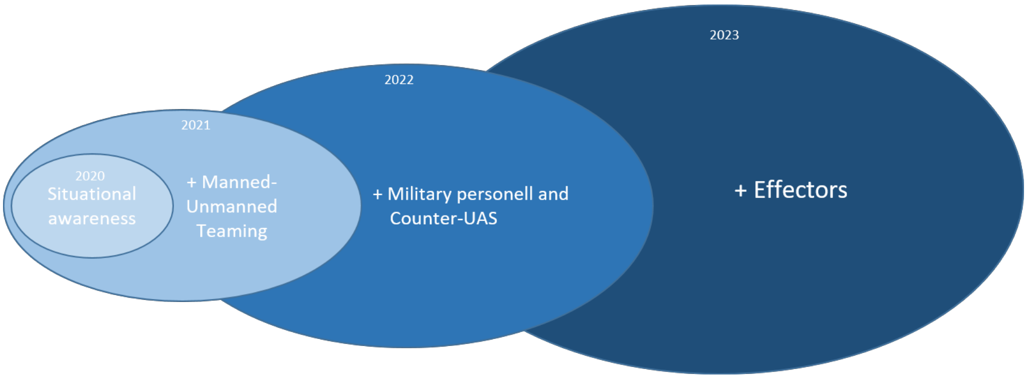


Figure 1.1 Development of the LandX experiment series.

2 The ICE worx innvation centre

FFI has established innovation arenas at Rena, Horten, Rygge, and Kjeller (fig. 2.1). The arenas are physical locations in Norway strategically placed close to key military user communities or relevant infrastructure. The purpose is to contribute to faster and increased operational efficiency by facilitating for experimentation and rapid innovation in collaboration within the "Defence Triangle Model" [4].

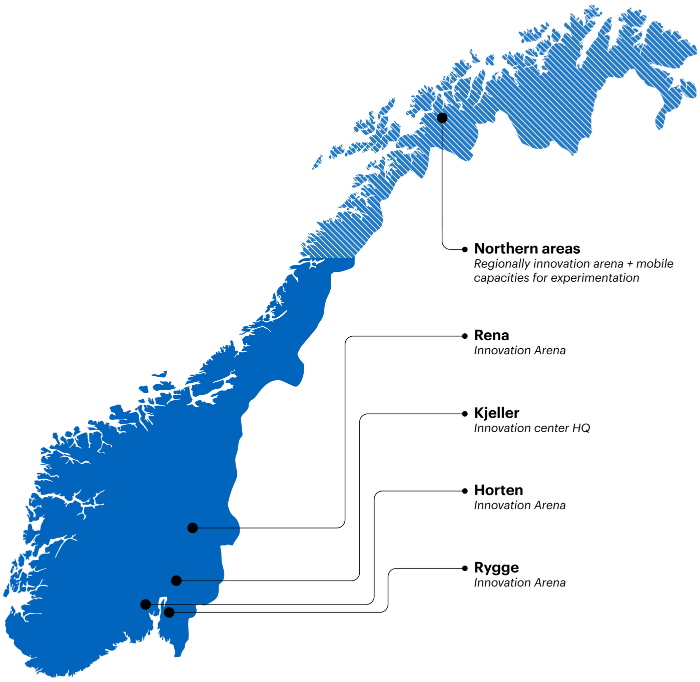


Figure 2.1 A map showing the different ICE worx sites in Norway

The sites are organised as follows:

- **Kjeller** is ICE worx headquarters.
- **Horten** is the location for maritime systems. It is co-located with FFI Horten.
- **Rygge** is the location for air systems, located at the Rygge Airfield. The site is close to the air force staff, and focuses on air Command, Control, Communications, Computers, Intelligence and Surveillance (C4IS) and base defence technologies.
- **Rena** is the location for land systems, close to the Norwegian Army at Rena.
- **Northern Areas** is a mobile experiment capacity to support live exercise experimentation with the Armed Forces.

2.1 ICE worx Rena

ICE worx Rena is the most mature innovation arena. It was built specifically to support future land warfare experiments, both on the ground and in the air. The location is within the army proving grounds adjacent to Camp Rena. Camp Rena is the home base of Telemark Battalion, Special Operations Command and Norwegian Army Land Warfare Centre. ICE worx Rena hosts experiments several times each month, and is also frequently used by the Norwegian Army for testing, experimentation, and as a meeting place with industry partners.

Figure 2.2 An overview of the main command buildings at the ICE worx Rena site.

At Rena, and all the other innovation arenas, an unclassified infrastructure and communications technology (ICT) innovation infrastructure is currently being established. The purpose of this infrastructure is to streamline integration with the Defence Tactical Platform TYR (FSP TYR), reduce the threshold and time required for field experimentation, and drive innovation in the future digital foundation for the Defence sector.

2.2 The arena infrastructure

An unclassified infrastructure is currently being established across the different sites. Figure 2.3 depicts the generic design of the infrastructure, implemented using FSP TYR incorporating services such as:

- Infrastructure Manager
  - Dynamic Host Configuration Protocol (DHCP)
  - Domain Name System (DNS)
  - Domain Controller

- Norwegian Command and Control Information System (NORCCIS)
- Norwegian Battlefield Management System (NorBMS)
- jChat (eXtensible Message Protocol (XMPP))
- Tactical Voice System (TVS) (Voice over Internet Protocol (VoIP) and Session Initiation Protocol (SIP))
- XOMail

The various locations are interconnected using Software-Defined WAN (SD-WAN), which enables flexible and secure Virtual Private Network (VPN) between each location across different carriers such as fiber, 4G, 5G, satellite, etc., facilitating data transfer among the different locations.

Based on project requirements, the project network can either be an isolated network at a single location (see Project 1 in fig. 2.3) or an integrated network (see Projects 2 and {n} in fig. 2.3). A project integrated into the innovation infrastructure can be configured to communicate with the services in FSP TYR, other projects, and/or other locations. An isolated project network can utilize the physical infrastructure at the location and will have its own logically isolated network through a virtual local area network (VLAN).

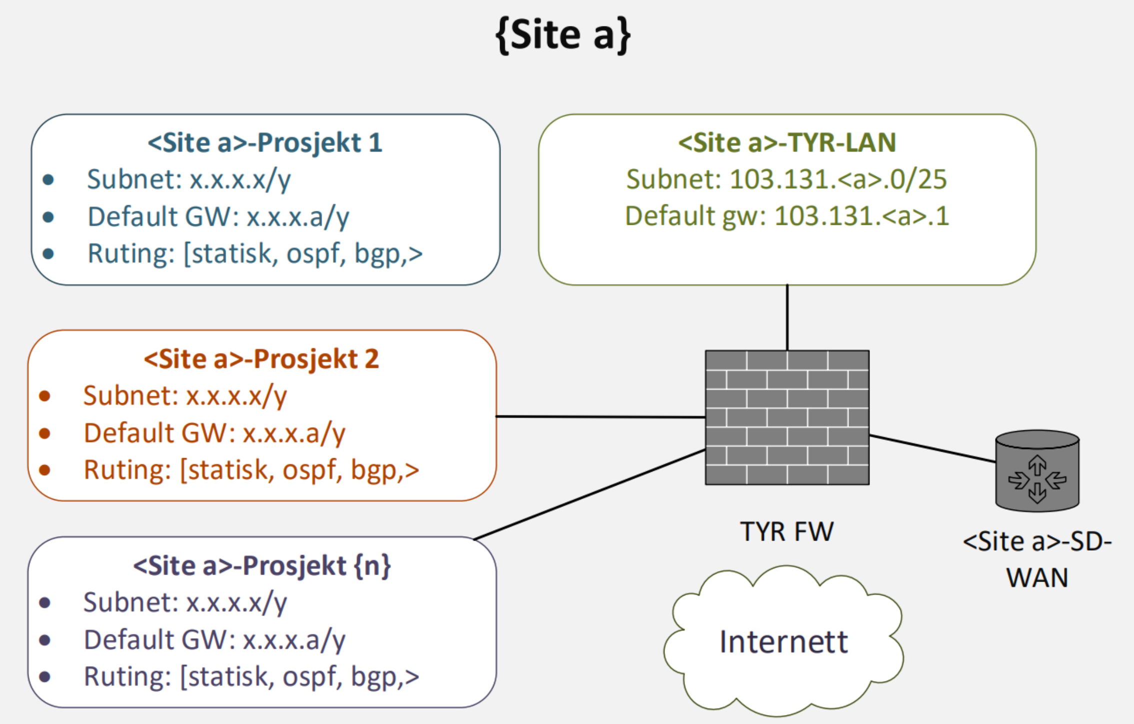


Figure 2.3 Generic network drawing.

During LandX23, the infrastructure was utilized to interconnect various projects, enabling the exchange of information across different research networks, e.g. the simulation environment (Ground Combat Lab) at Kjeller was integrated into the FSP TYR node at Kjeller, and simulated data was showcased in NORCCIS at Rena.

3 Manned-Unmanned Teaming

Engaging with the enemy and assuming exposed firing positions are among the most dangerous tasks for combat units. In such scenarios, employing an expendable unmanned ground vehicle (UGV) equipped with remotely operated weapons presents a viable solution to mitigate the risk to human life. This approach not only elevates personnel safety, but also bolsters the overall combat effectiveness of the unit by synergizing the respective strengths and weaknesses of manned and unmanned elements [5].

At LandX22 [3][4], we showcased technology capable of safely operating the Remote Weapon Station (RWS) and managing the mobility aspect of the UGV through the NATO-standardized UGV protocol known as Interoperability Profiles (IOP) [6][7]. This operation was executed from a Kongsberg Defence & Aerospace (KDA) RWS operator station via a wideband Silvus radio. While conducting experiments, particularly during LandX22 [3] and other trials [8][9], we identified several challenges and technology gaps related to MUM-T in manoeuvre contexts.

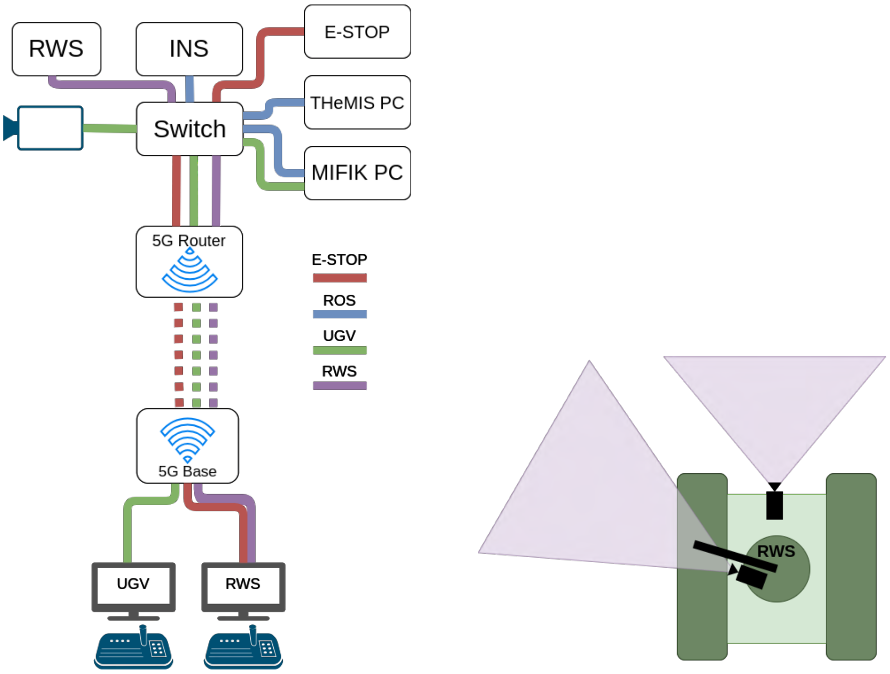
During LandX23, FFI and KDA collaborated on addressing the following issues:

- **SA for UGV operators.** As of now, UGV operators struggle with poor SA. This is because the operators most of the time only has a video stream and, if lucky, a position in a 2D map. Typically, the video stream has low resolution and can have significant frame drops and latency. Improving video stream quality proves exceptionally challenging due to the limited capacity of the radio link, dictated by the laws of physics. In fig. 3.1, an image can be seen of the consequence of a UGV operator with poor SA. In order to mitigate the SA issues with video streaming, we plan to experiment with visualizing additional sensor data for the operator that requires less network capacity.
- **Safety-Approved Mobility Emergency Stop over IP networks.** Our previous emergency-stop solution utilized a separate radio link, but its limited range required the person with the emergency stop to be in close proximity to the UGV, contradicting the essence of unmanned vehicles. Another downside is the increased complexity of having two radio systems. Ideally the emergency stop solution should run over an IP network, so it can run on the same network infrastructure as the UGV control network.
- **Secure Communication between the UGV and its Operator.** Ensuring a secure communication link between the UGV and its operator is paramount in operational settings. LandX23 was the first LandX where we focused on both the security and the safety aspects of MUM-T.
- **Distance Between the Operator and the UGV.** A notable limitation of UGVs is the required reliable stable radio connection to the operator, limiting operational range. At LandX23, we explored the feasibility of using a 5G network as an alternative communication solution to the Silvus Wideband radio we normally use.

Figure 3.1 Top image: The UGV, Siv, firing with the Kongsberg remote weapon station. Bottom image: An UGV driven into a mud-pit because the operator misjudged the drivability of the terrain displayed on the video-stream.

3.1 System description and setup

At LandX23 the Milrem THeMIS UGV, called ***Siv***[8], was equipped with a 5G Router used for communication, a Kongsberg RWS and an IP network based emergency-stop solution developed by Kongsberg. The 5G router on Siv used a secure 5G link directly to the 5G base station, and as the UGV/RWS operator stations was directly connected with an ethernet cable to the 5G base station, it meant that the UGV/RWS operators had a secure connection to the UGV/RWS. The data flow of the network setup is illustrated in fig. 3.2a. The remote fire safety approved RWS solution was similar to the one demonstrated at LandX22, except that the LandX23 solution was modified to work over a 5G network. The IP-based emergency-stop solution were based on the safety solution for the RWS and used the same 5G network as the RWS and UGV control solution. Siv was also mounted with an IP camera in front of the UGV that streamed video to UGV operator. The RWS has both a day camera and a thermal camera. The video for these two cameras was streamed only to the RWS operator, due to time limitations, but it would only have been a minor job to also provide these streams to UGV operator. The field of view for the various camera systems on Siv are illustrated in fig. 3.2b.



(a) Network data flow between Siv and the operator control unit.

(b) Camera field of view for the driving camera and the RWS camera.

Figure 3.2

Previous experiments regarding UGV teleoperation have shown that an operator requires a sufficient understanding of both the UGV’s state and its environment in order to manoeuvre it safely. These experiments stem from situations where a single video feed as a primary source of information has proven insufficient for the operator [8][9]. As a result of these experiments, FFI has started the development of a control station that intends to present relevant data in the form of an interactive experience. One of our primary goals is that this control station will provide new insights into improving SA of UGV operators.

The control station *Verdande*, under development by FFI, is based on a 3D interactive environment, mainly by utilizing the game development software *Unreal Engine 5*. This environment allows for the creation of a virtual representation of the real world by using digital assets such as 3D maps and models that might be created or updated by using sensor data. For LandX23, MUM-T used a 3D model of a Milrem THeMIS UGV, as well as a 3D map of the experiment environment generated from images by Kartverket [10]. The control station, as it were used during the demonstration at LandX23, is shown in fig. 3.3. To control the UGV via Verdande, an Xbox-controller was connected to the control station, with control signals being sent via 5G to the actual UGV. Navigational data was also sent in return to the control station in order to update the position and heading of the virtual UGV.

In addition to the 3D environment consisting of models and terrain, a Heads-up display (HUD) was developed. The HUD include:

- **Heading indicator.** A figure which displays the relative angle offset between the UGV body and the camera direction. This is to let the users know if they have the camera facing in a different direction than where the UGV is pointing, minimizing the chance of driving off in the wrong direction.
- **Platforms list.** A list of other controllable or observable entities on the network, such as other UGVs. If available, the user would be able to select to take control of other entities.
- **Map list.** A list of available maps, allowing the user to switch between different maps or to enable/disable them. The user would also be able to add other maps available on the network to the list by adding their URLs.
- **Compass bar.** A compass bar which displays the heading of the current camera view.

There are also several elements planned for future development and implementation for the *Verdande* HUD. These are based on both inspiration from other control stations and experiences from previous UGV experiments. A concept sketch, including a few such elements, can be seen in fig. 3.3 and include:

- **Bottom right corner:** An expanded heading indicator to include more information about the physical state of the UGV:
  - This might include velocity, RWS/camera directions, fuel and battery levels.
  - Vertical bars on each side of the icon showing a belt slippage indicator.
- **Bottom left corner:** A simplified 2D map centered on the current UGV's current location:
  - Include map information about buildings, roads and map elevation.
  - Include Battle Management System (BMS) information such as other friendly units.
  - Include other available map layers such as trafficability (e.g. snow, ground humidity or snow levels).
- **Bottom center:** An integrated video feed from cameras mounted on UGV.
- **3D Canvas/View:** Augmented reality overlay with indicators of friendly and hostile units (sourced from the BMS).

Figure 3.3 Verdande control station at LandX23.

3.2 Testing and demonstration

At the end of the first LandX23 week, KDA performed tests that involved using a 5G network for communication with the RWS mounted on the UGV as well as the UGV's emergency stop. In one test, the UGV was remotely controlled and driven northbound on the east side of the exercise area before driving back down the main road. The maximum distance from the 5G base station was about 600 meters. While driving, one person operated the RWS from a KDA control station while receiving video feed from the RWS. The operator reported that both the controls and video feed proved stable for the duration of the test and that the video feed was consistently of high quality. When nearing the base upon return, KDA also performed a test of the remote emergency stop via RWS, with the emergency stop of the RWS being connected to the UGV's systems. Both the UGV and the RWS performed a successful emergency shutdown when triggered. For a second test, the UGV was loaded onto an open trailer and taken down the exercise area on the main road in order to test the 5G range limit. The operator located at the base station reported a complete loss of contact with the RWS upon reaching an aerial distance of approximately 2600 meters. It should be noted that it was a small field of trees that blocked direct line-of-sight to the antenna at this point.

On the day of the demonstration, KDA and MUM-T performed a joint demo where KDA started off by presenting their emergency stop system. The UGV was then controlled by using *Verdande* and driven to a position away from the crowd, where KDA could perform a firing demonstration with the RWS using training ammunition. After finishing this demonstration, the UGV was driven back to the starting position. In addition to the *Verdande* control station, the MUM-T operator also had a live video feed available from the front mounted IP camera. Both were used during the demonstration, allowing the operator to maintain an overview of the UGV's location using *Verdande* while using the video feed for an inspection of the actual terrain lying ahead. This sequence was completed successfully for each of the four groups of spectators.

4 Fjernsyn - a remotely operated distributed sensor network

Surveillance and area access control is traditionally a personnel demanding task, where soldiers manned with binoculars or some kind of digital sensor systems are deployed to cover a mission area and report back with observations. The FFI project *1612- Remotely operated sensor network for land warfare* [11] is tasked to replace the manned positions with sensors and connect everything together in a network. The sensors are controlled from one or more operators connected to the network. Together with Teleplan Globe, the project has developed a system we call *Fjernsyn*. The *Fjernsyn* system is a combination of existing software already in use in the Armed Forces such as the NorBMS and the Tactical Media Suite (TMS), and new custom software components only used in *Fjernsyn*.

4.1 Architecture

The *Fjensyn* system is a distributed sensor network (fig. 4.1) that allows the user to deploy sensor nodes at different locations and with various sensors to solve a mission. The sensor types currently supported are:

- Cameras (EO and thermal)
- Acoustic sensors
- Radar
- Observation Targeting and Surveillance Systems (OTAS) (sensor and targets) on a CV90
- Valkyrie unmanned aerial vehicle (UAV) Swarm (chapter 5)

The sensor nodes are connected together in a network through a suitable communication solution. Currently *Fjernsyn* support ethernet (copper and fiber), IP radios (e.g. Silvus) and 4G/5G/internet together in the same sensor network.

4.1.1 Varde

The actual sensors are integrated into the *Fjernsyn* system through an adapter. The adapter communicates with the sensor in its (often proprietary) language and translates the data to *Fjernsyn*'s own protocol called *Varde*. The *Varde* protocol is designed to abstract the details of each sensor from the network by focusing on the capabilities of each sensor. This allows us to share sensor data in a uniform way in the network.

4.1.2 Sensor Service

The heart of the sensor node is called *Sensor Service*. *Sensor Service* maintains the state of the sensor node and its connected sensors and communicates with the network. All communication from *Sensor Service* is done through the *Varde* protocol, and Sensor Service uses a software component called *Edge Gateway (EdgeGW)* to access the network.

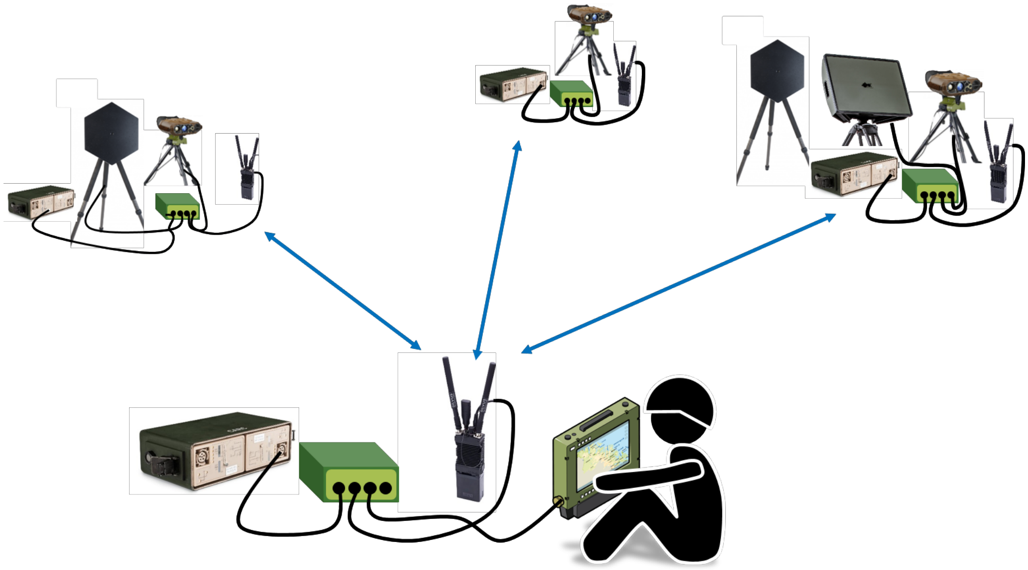


Figure 4.1 Illustration of a distributed sensor network with three sensor node locations and one operator. The sensor nodes can use a variety of different sensors, e.g. Jim compact EO and thermal camera, Squarehead Discovair G2 acoustic sensor and Squire Radar.

4.1.3 EdgeGW

EdgeGW is a software component that handles all network related issues. It can connect to multiple network interfaces (both LAN and WAN) and it can automatically discover other instances of EdgeGW on the network. It offers network access to all locally connected services and creates a virtual service network where the services can communicate with each other across different networks. EdgeGW offers solutions for discovery, assured delivery, packet segmentation and reassembly, routing and encryption. *EdgeGW* is developed by the *Fjernsyn* project, but it has many use cases outside the project.

When connecting an *EdgeGW* node to a WAN (the internet/4G/5G), a cloud instance of EdgeGW is used to relay data between the nodes. The EdgeGW node needs to know the URL of the EdgeGW in the cloud to discover other nodes.

Video streams are not sent using the *Varde* protocol. Instead, already well established video streaming protocols such as Secure Reliable Transport (SRT) are used. Video is handled locally on the sensor node by a media server or a video forwarder which is part of the TMS. The Media Server or Video Forwarder communicates with Sensor Service to collect additional data about the video stream to enrich the stream with metadata so it can be transmitted as a STANAG 4609 compatible video stream. When connected to a WAN, the SRT stream(s) out of the node is forwarded though a SRT forwarder service in the cloud.

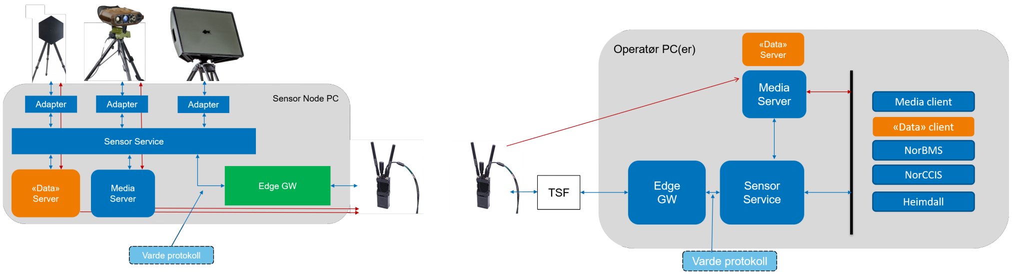


Figure 4.2 Illustration showing software components and dataflows within sensor nodes and operator nodes. The Data Server/client is work in progress and was not part of the LandX experiment.

4.2 LandX experiment

The Fjernsyn project had four main goals when participating in the LandX experiment:

- Test EdgeGW in a large heterogeneous network including 4G/internet and compare performance between 4G/5G and Silvus.
- Integrate AI-functions into the network.
- Include a CV90 in the sensor network.
- Integrate to Valkyrie UAV swarm.

4.2.1 Setup

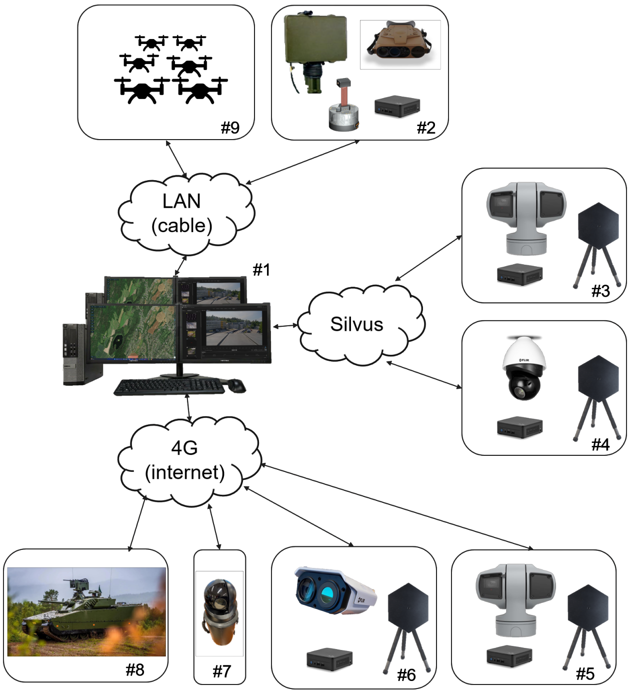
To test EdgeGW, we built the largest network we were able to with the hardware we had at our disposal. We ended up with seven sensor nodes, and two OP nodes. The network is illustrated in fig. 4.3.

4.2.2 AI

The *Fjernsyn* project is cooperating with FFI project 1579 – "Future Manouvre Systems" to integrate the work being done within the topic of situational awareness. Their software is called *Sentry* and consists of functions for detection and classification of objects in a video stream, together with a function for tracking objects with data from several sources [1]. Parts of this functionality was used on the Fjernsyn data network. The Sentry system learned about available camera feeds though Sensor Services and the Varde protocol, which enabled Sentry to connect to a video feed and start analysing it. All detections made by Sentry were communicated to the Fjernsyn network using the Varde protocol.

4.2.3 CV90

At LandX23 we wanted to integrate a CV90 with OTAS (surveillance camera on a mast). However, the vehicle we were assigned for the experiment had the wrong firmware version (too old), and



Common for all nodes (except #9) is a computer running Fjernsyn SW + power supply (battery- or grid-power)

1. 2 x Operator stations
2. ARSS1 radar, JimCompact, Zippermast
3. Axis PTZ camera, Squarehead Discovair G2 acoustic sensor
4. FLIR Quasar PTZ camera, Squarehead Discovair G2 acoustic sensor
5. Axis PTZ camera, Squarehead Discovair G2 acoustic sensor
6. FLIR FH625 camera (EO + Thermal), Squarehead Discovair G2 acoustic sensor
7. Mobotix camera (computer, 4G modem and batteries all in one)
8. CV90
9. Valkyrie UAV swarm

Figure 4.3 LandX Fjernsyn network setup

we were not able to connect to it. We were later assigned a new CV90 with the correct firmware version, but this CV90 did not have the OTAS camera system. Instead of using the CV90 as a sensor in our network, we were able to send detections to the vehicle so the CV90 could slew its cannon or RWS to the target.

4.2.4 Valkyrie UAV swarm

The swarm integration works in a different way than the other sensor integrations. The Valkyrie UAV swarm is a standalone system. The *Fjernsyn* integration allows for the *Fjernsyn* operator to send positions, axis or area of interests to the swarm operator. The swarm operator can send detections, images, and video back to *Fjernsyn*.

4.3 Results

The Fjernsyn system worked very well during the experiment. We made many small improvements and found some bugs to fix. The results after LandX are:

- EdgeGW works very well in a heterogeneous network. The *Fjernsyn* operator(s) had contact with all sensor nodes on the three different networks. Symmetric encryption of data works well and was used when data was sent over internet (4G).

- The integration of *Sentry* works very well. Sentry was able to connect to a camera stream and could detect cars driving along the road and report detections to the Fjernsyn network.
- The expected CV90 integration did not work as planned. We could not integrate sensor feed from the OTAS system because the CV90 assigned to the experiment had too old software installed. We were assigned a new CV90 with newer software but it did not have the OTAS sensor. We successfully integrated the CV90 as an effector and could share targets to the CV90.
- We successfully integrated Fjernsyn and the Valkyrie UAV Swarm. We could send points, axis and areas of interest to Valkyrie, and received detections, pictures and video streams in return.

Figure 4.4 *Screenshot from NorBMS showing sensor nodes (as blue circles) sensor directions (as sectors from sensor nodes), detections (as red lines emitting from sensor node), radar tracks (as green squares), detections (as yellow "flower") and a target (as red diamond)*

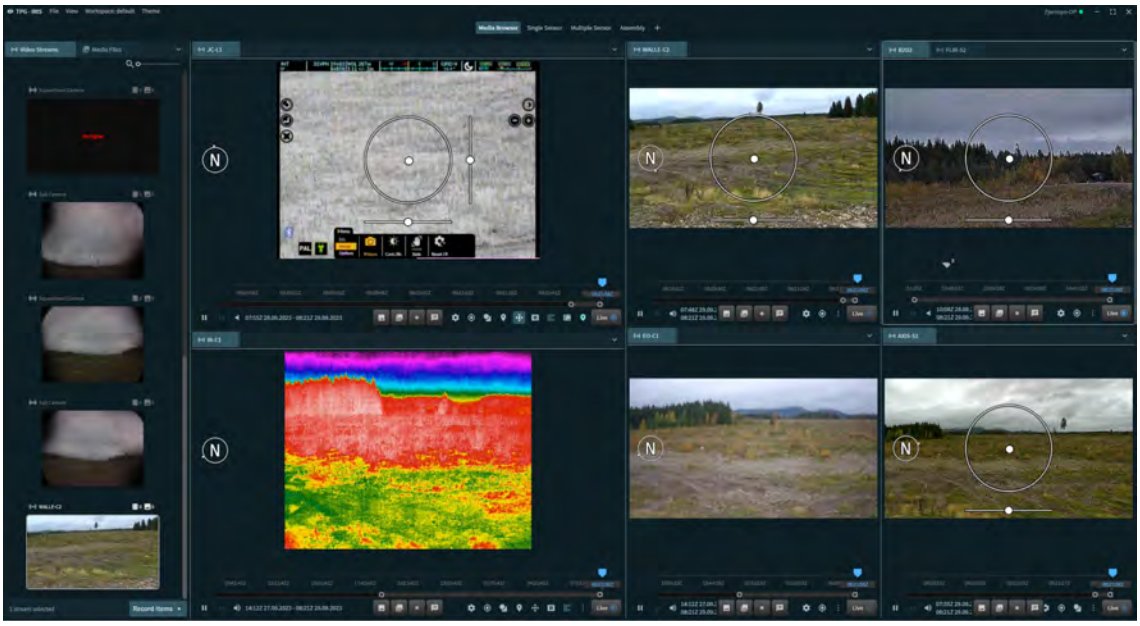


Figure 4.5 *Screenshot from the TMS media klient. To the left, is a list of thumbnails from connected vide0 streams. The six larger images are live video streams. The user interface offers a circle with a dot in the middel for panning, and a bar below for zooming if the video sensor support this.*

4.4 Future work

The Fjernsyn project will continue for another two and a half years with a renewed mandate in 2024. Our main efforts will be in:

- Continue development of the Fjernsyn distributed sensor network.
- More AI integration.
- AI on the sensor nodes to reduce radio communication.
- AI across sensor nodes to improve tracking.
- Develop alarm-philosophy to aid operator in crowded environments.
- Help in the development of hardware solutions (computer and power) for use in the sensor network.
- Integrate to effector systems.
- Support operationalization of Fjernsyn.

5 Swarm

FFI project 1688 - Cooperating Autonomous Systems participated with the prototype multi-UAV system *Valkyrie* developed at FFI. Valkyrie comprises autonomous drones, a mesh radio network and a Ground Control Station (GCS) computer. The drones currently integrated in the Valkyrie system are also developed at FFI. So far, the system supports two different types of drones: The *Flamingo* drone used for Intelligence, Surveillance, Target Acquisition, and Reconnaissance (ISTAR) and the C-UAS interceptor drone *Svale*. The Valkyrie system includes an on-board autonomy module that comprises sensor processing systems, tracking software, collision avoidance controllers and decision autonomy. Lastly, the Valkyrie system has a custom Graphical User Interface (GUI) for controlling and monitoring a multi-UAV system with an arbitrary number of drones, as displayed in fig. 5.4. A swarm consisting of eight Flamingos is displayed in fig. 5.1

Figure 5.1 Eight Flamingos operating in the swarm.

The Valkyrie swarm is controlled by a single operator. This is possible due to on-board autonomy that reduces the cognitive load for the operator. The project aims to control and utilize the UAVs on a higher abstraction level than how UAVs are usually operated today, where one operator controls one UAV. To effectively manage several UAVs simultaneously, it is essential that the UAVs process sensor data internally and present results to the operator, rather than overflowing the operator with unprocessed sensor data. Similarly, instead of traditional vehicle control by manipulating the vehicle's thrust and orientation using a Remote Controller (RC), the UAVs are provided high-level tasks they have to solve themselves. Typical high-level tasks are coordinated axis screening or area search. A simplification of different layers of abstraction for sensor processing and for vehicle control is displayed in fig. 5.2.

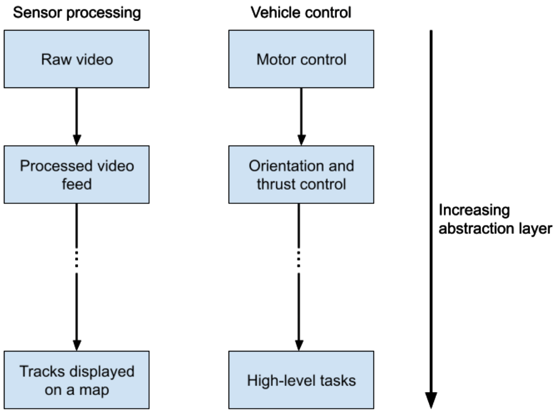
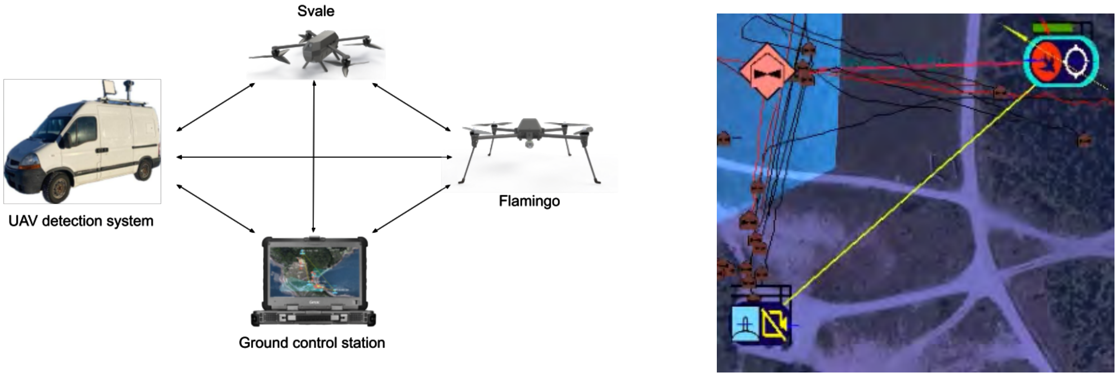


Figure 5.2 Increasing abstraction level for sensor processing and vehicle control.

5.1 Counter-UAS

The project propose, using an interceptor UAV in collaboration with a SA system, to counter hostile UAVs. The interceptor drone, *Svale*, and the SA system, *Sentry*, are incorporated in the Valkyrie multi-UAV system. The communication between the different systems within Valkyrie is illustrated in figure 5.3a. As Sentry is integrated in the Valkyrie system, it is providing both the UAVs and the GCS with target information, as can be seen from the GCS screenshot in figure 5.3b, where the active communication is verified with the yellow link between Sentry and Svale.



(a) Communication in the Valkyrie System.

(b) Screenshot of the GCS with Sentry, Svale and the hostile UAV.

Figure 5.3 Sentry and Svale communication.

Once a hostile UAV is detected, it will appear as a target in the GCS and the UAV operator is able to task Svale to intercept the target. Svale will then calculate a collision trajectory based on information provided by the UAV detection system and adjust its trajectory as updated target information becomes available. In fig. 5.3b, the Svale's velocity direction (yellow arrow over the Svale icon) can be seen pointing north of the target, as Svale will engage to the estimated collision area. Once Svale detects the hostile drone with its onboard electro-optical camera using an object detection neural network, it will track the target itself and enter the terminal phase of the intercept, where higher precision is required. A challenge with this approach is that Svale will need to adjust its heading (and thereby its onboard camera) independently of its velocity direction, as it will approach the intercept point, but face the hostile UAV. It is essential to detect and track the target UAV as early as possible since the system are reliant on the increased precision achieved when Svale tracks the target itself.

5.2 Contribution to LandX23

During LandX 2023, Flamingo and Svale operated in a heterogeneous swarm and were concurrently controlled by a single operator. At the final demonstration, four Flamingos were tasked to search for threats in a given area. Two Flamingos found a combat vehicle and cross-referenced their respective estimated target position to increase the overall precision. The remaining two drones were tasked to screen two incoming road axes, while the target data were streamed to the NorBMS system for Digitally Aided Fire Support (DAFS).

Figure 5.4 shows a screenshot from the Valkyrie GCS during the demonstration. The video feed is centred on the target and the two yellow symbols in the map indicate two independent estimates from two Flamingos tracking the threat. The red symbol in the middle is the cross referenced target estimate that was sent to the NorBMS system for further processing in the firing chain.

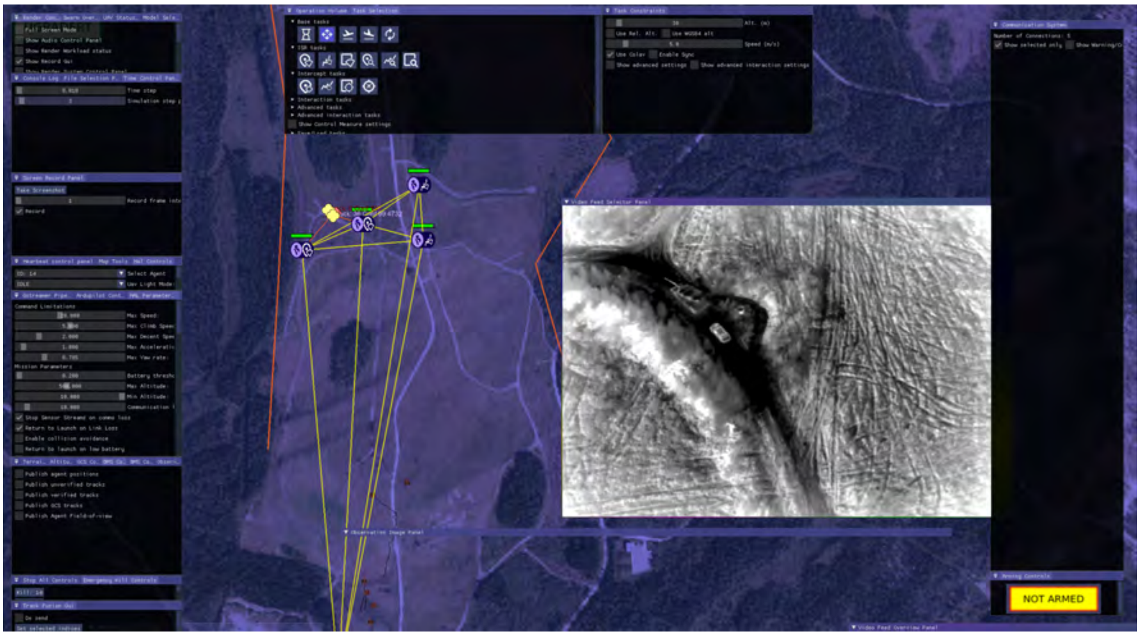


Figure 5.4 Screenshot from the GCS where 4 Flamingo drones simultaneously track a hostile threat and screen the nearby axes.

While the Flamingos were still tracking the target and the road axis, two Svales were launched as an incoming hostile UAV was detected by *Sentry* [1]. As the hostile UAV appeared in the GCS, the UAV operator simply tasked one Svale to engage the target. While Svale engaged the hostile UAV, the operator monitored the situation and verified the target with the live video feed provided by Svale. Svale successfully hit the target and all UAVs returned to their launch positions. Figure 5.5 is taken moments after the UAV interception.

Figure 5.5   Moments after UAV interception.

6 Synthetic Prototyping

At LandX23, the FFI Ground Combat Lab showcased a synthetic prototyping testbed, showing multiple operational systems interconnected with a simulation runtime. The setup consisted of the simulation system Virtual Battlespace (VBS), along with Valkyrie GCS (see chapter 5) and the Norwegian C2 system NORCCIS. The testbed was set up as a distributed system, with the simulation infrastructure located at the Kjeller location and Valkyrie GCS located at Rena.

The FFI Ground Combat Lab is a project-independent lab facility for FFI projects to study the impact of new technologies on military ground combat operations at operator and small unit level. It was formally launched June 2023, but has been under development since 2021.

The objective of the LandX demonstration was to showcase how integrating simulation systems with various real-world systems (i.e. Synthetic Prototyping) can enhance system development, train personnel and be used to develop or evolve operational concepts. This is particularly important in situations were the systems are in experimental phase or under development.

In addition to the demonstration, the activity had three other goals:

1. Experiment with distributed systems across the network, including over 5G.
2. Experiment with different C2 interfaces and protocols (e.g. Variable Message Format (VMF) and NATO Friendly Force Information (NFFI)).
3. Experiment with Live, Virtual and Constructive (LVC) simulations with the other actors in the experiment.

Furthermore, participation in the experiment is another step in the process to explore the validity on using synthetic prototyping as a part of a project's development strategy.

6.1 System setup

The setup at LandX represented an operator position of a drone UAV swarm operator. It consisted of the Valkyrie GCS as the main system for the swarm operator, and NorCCIS and NorBMS as the C2/BMS. There were also two simulation components. The first being MASIM (drone swarm simulator), which is an integrated module of Valkyrie GCS, and VBS. VBS simulated the scenario, including red and blue forces, and also served as the image generator (IG) for the Valkyrie Ground Controls Station. The VBS component was localised at Kjeller for the experimentation, but was moved to the local network at Rena for the demonstration. An example of this setup can be seen in fig. 6.1 and fig. 6.2.

Figure 6.1 Valkyrie GCS with a synthetic sensor image (1) detecting a group of synthetic vehicles in a forest (2). This observation is pushed to NORCCIS on TYR.

6.1.1 Valkyrie Ground Control Station

The real Valkyrie system was used as the ground control station for the synthetic swarm. The only real difference between the real system and the one used for synthetic prototyping is that the image target tracking and detection algorithms are not implemented on the synthetic image stream. The target detection in the synthetic setup is done in the simulator engine core. In principle, an algorithm could also be trained to use a synthetic image.

6.1.2 Virtual Battle Space

VBS is an interactive three-dimensional synthetic environment for land, air and sea operations, developed by Bohemia Interactive Simulations (BISim), a subsidiary of BAE Systems. VBS is developed specifically to serve the military simulation and training domain, and it is used by the Norwegian Army and FFI, along with several other NATO nations.

VBS contains a vast library of military units and weapon systems along with a global terrain server (VBS World Server). This enables a user to rapidly create military scenarios in a geo specific terrain, in this instance Rena. It also has a developer API (VBS Simulation SDK) which enables a developer or an integrator to develop plugins or customize functionality within VBS, and also connect a third-party software or service to the simulation runtime.

6.1.3 NorBMS/NorCCIS

NORCCIS is the Norwegian C2 system for battalion level and above, typically used at a command facility at a desktop. NorBMS is a BMS used at lower echelons, typically vehicle based at platoon and company level. An example of NORCCIS can be seen in fig. 6.2.

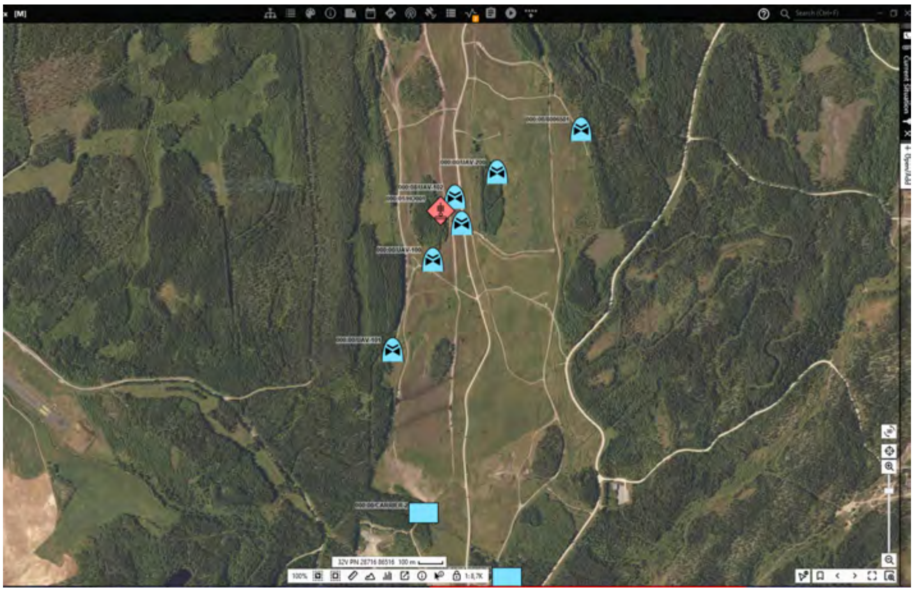


Figure 6.2 Synthetic drones is sent to NORCCIS along with observations.

6.2 Future Work

The experimentation and demonstration at LandX further validated that the use of simulation in conjunction with real operational systems can be used to enhance system development and to train personnel. It is viable to stimulate operational C2 systems with synthetic information at their native protocols, but to pull data from those systems can be difficult. We discovered the need to pull operational/tactical plan overlay from NORCCIS as an overlay in Valkyrie GCS would be beneficial for the swarm operator. Furthermore, the use of native C2 protocols (in this case VMF) can be time consuming.

The experiment and demonstration resulted in several identified areas of potential further work:

- Merge live, virtual and synthetic in same system.
- Bridging with the Norwegian Army Simulation Facilities at Rena.
- Embedded Training.
- Prototyping and concept development.
- Interfacing the fires chain (ODIN FSS[1]).

---

[1] https://www.kongsberg.com/kda/what-we-do/defence-and-security/c4isr/odin-fire-support-system/

7 Elinor

The use of the electromagnetic spectrum includes RF sensors (like radar), radio based communication and time synchronization from satellites, all critical in modern warfare. For that reason, control in this spectrum is necessary to efficiently conduct own operations as well as to map the presence and manoeuvre of an adversary. Passive RF sensors are the primary mean to create situational awareness of the the electromagnetic spectrum. Elinor is a FFI developed custom passive RF sensor used for this purpose.

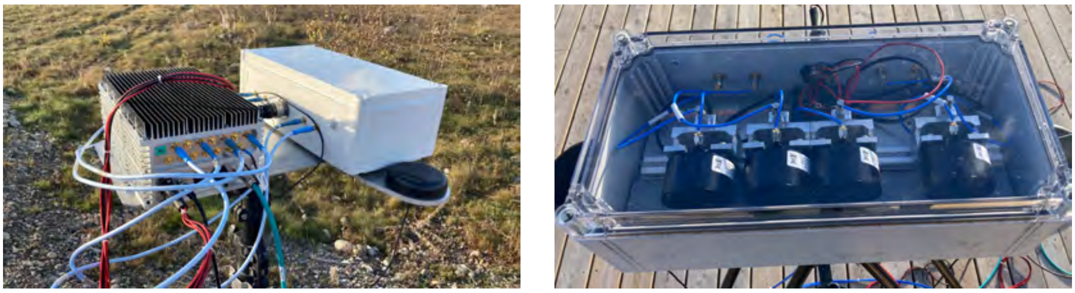
Elinor can be described as a lightweight and low-cost passive RF sensor. It can operate alone or together with other Elinor sensors in a network. One sensor alone can find the correct bearing from itself to an emitter within its coverage area. Two or more sensors in a network can find the position of the emitter.

The interface of the sensor is based on civilian open standards for data exchange, which makes it easy to test Elinor within the framework of scientific experimentation and testing. The civilian standards are flexible enough to enable the development of software add-ons that support military grade systems and protocols.

Software-defined radio (SDR) and Field Programmable Gate Arrays (FPGA) technologies enables in-depth adaptations in Elinor in accordance with specific user needs. This can be done as an initial adaptation with cooperation from operational end-user experts. Since the design of the system is open, the Armed Forces can further develop or modify the system as needed.

Although there are many products of this type on the market, FFI choose to develop its own due to specific technical performance requirements (specifically the number of channels, processing performance and frequency bandwidth). This enables the development and use of current algorithms within passive RF.

The passive RF group at FFI used experience from the development of passive RF sensors from multiple satellite projects (e.g. NorSat-3 and SMART Milspace 2) as a foundation for the development.



(a) An Elinor passive RF sensor node on LandX23 *(b) The Elinor antennae with a bearing accuracy of approximately 0.1 degrees*

Figure 7.1

During the LandX23 experimentation, networked Elinor sensors were deployed to detect radar emissions at exercise area. A radar was geo-localized with high precision, paired with metadata of the detection, and visualized to the user in near real time in a tactical map application. In addition, a number of other radio emissions were detected in the spectrum, but were not geo-localized during LandX23.

Figure 7.2 A tactical map image from LandX23 showing two Elinor sensors (marked a.) with a geolocalized radar (marked b.) at the intersection of the two bearing lines.

It is plausible in the future to create a passive RF sensor coverage to establish a wide and robust situational awareness in the electromagnetic spectrum, but it will require many sensors. Low unit cost is therefore an important prerequisite. The use of military personnel to test operational use-cases with passive RF sensors is also an important aspect to increase the validity of the research done at FFI.

8 Light short-range missile

FFI project 1432 "Light short-range missile" explores the use of modern, readily available components in portable anti-tank guided missile (ATGM) to accelerate development and reduce costs. Parts of the project have been carried out in collaboration with input from Norwegian Army Land Warfare Centre which has provided valuable input. Current systems, like the Javelin, are closely related to technology developed in the 80's. This has led to the weapon system having a high unit cost, further development is challenging, and increasing production capacity is difficult.

The goal of the project was to develop a lightweight image-homing missile demonstrator with a range of about 1000 m and lethality comparable to traditional shoulder launched weapons like Nammo's M72 LAW. The limited range was specified to focus the research activities on a cost-effective lightweight missile concept. If developed into a product, the weapon system will have a longer range than traditional shoulder-fired unguided rockets and lower costs than existing ATGM. Table 8.1 shows some guiding specifications used in the project.

Table 8.1 Guiding specifications for the lightweight portable image-homing missile.

Main capabilities:	Fire-and-forget Day and night capability Static and moving targets Operated by single soldier
Effective range	>1000 m
Warhead penetration	450 mm RHA
System weight	<7 kg
System length	800 mm

The project's hypothesis was that easily available Commercially Off-The-Shelf (COTS) components can now be implemented in the complex subsystems of an image-homing missile. Key components and technologies worth mentioning are uncooled Long Wavelength Infrared (LWIR) cameras, small form-factor supercomputers and Micro Electro-Mechanical Systems (MEMS) Inertial Measurement Unit (IMU).

In contrast to legacy systems, which required specifically developed components, this project embraced an iterative design approach, leveraging readily available COTS components and other easily available technologies. This strategy aimed at facilitating multiple full design cycles, enhancing the overall development process.

A small team of people were tasked with developing all the missile subsystems. While this presented notable challenges, it also offered a dynamic environment where requirements could be continuously traded and optimized. The same team also performed both testing and manufacturing, providing an important high fidelity feedback loop to improve the design and processes.

8.1 Description of the missile demonstrator

Since the first test with a crude test vehicle in late 2018 the project has developed three different test vehicles. The fourth, Raven-II demonstrator is shown in fig. 8.1.

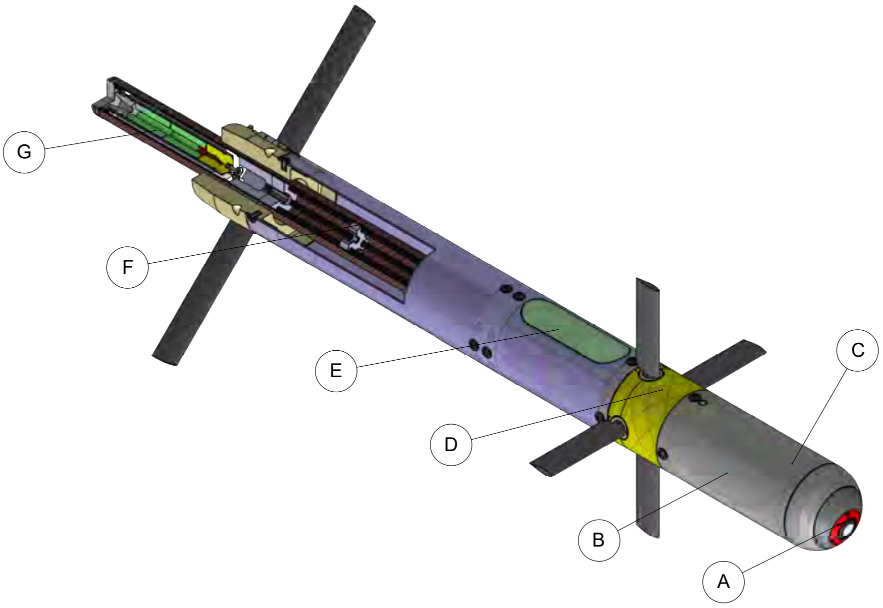


Figure 8.1 Illustration of Raven-II.

The general aerostructure consists of a spherical nose, a cylindrical body with diameter 80 mm, four control wings in a plus-configuration, and four fixed tail fins in a cross-configuration. The control wings are positioned approximately slightly ahead of the center of mass, and thus the vehicle can be classified as a hybrid between a wing and canard configuration.

The seeker (A) is integrated into the nose and consists of a visible light machine vision camera (A LWIR version of the seeker is being developed). The seeker is an integral part of the control section (B), consisting of a miniature supercomputer running a target tracker, an autopilot, a telemetry radio and a power supply (C). The tracker, which is tightly integrated with an Inertial Navigation System (INS), is built around a deep learning-based visual appearance model and -detector. The target tracking and navigation estimate feed into the guidance algorithms, which generate commands into the low-level control loops for the actuators that drive the control wings integrated in control actuation section (D).

To potentially enable reuse of the vehicle, a parachute recovery system (E) is implemented instead of a warhead. This uses the gas from a CO_2 cartridge to deploy the parachute.

Aft of the parachute recovery system the vehicle has an outer fuselage with the four tail fins and an inner carbon fiber tube (F). This tube is inserted into the barrel of a pneumatic gun, which is used to launch the missile. After a given delay the solid rocket motor (G) housed inside the tube is ignited to accelerate the missile as shown in fig. 8.2. Modified commercially available rocket motors have been used, which have allowed a gradual increase of the missile's maximum velocity, and in turn the complexity.

Shoulder launched missiles use a launch motor and a boost and flight motor that ignite after approximately 5 m. By using only the pneumatic gun, and no motors with energetic materials, numerous low speed flight test at a local firing range has been possible. This approach has been essential in achieving a rapid and effective iterative design process.

8.2 Test results

The latest tests of Raven-II were performed under LandX23. Five missiles were tested over two days. Figure 8.2 shows a sequence of images showing the launch of the missile with the pneumatic gun followed by motor ignition. The target in these tests, seen at the right side of the image, was made from a simple blue tarp mounted to a suspended net used to recover the missile. The target can be seen in closer detail in fig. 8.3.

Figure 8.2 Image showing the launch and powered flight towards the (blue) target.

Of the five missiles, two hit the target at 550 m. Two missiles were also fired at a moving target at 900 m. The motors in both these missiles failed, resulting in limited thrust and a crash after only a few hundred meters. The final and fifth missile failed due to an error in the control section.


(a) (b)

Figure 8.3 (a) Image showing the missile impacting the target. (b) The view from the seeker as the missile approaches the target.

8.3 Summary

The recent tests conducted at LandX 23 have marked a significant milestone, successfully meeting the primary objectives of the project. A key achievement is the demonstration of the feasibility of incorporating easily available COTS components into this type of missiles. Furthermore, the project has effectively utilized an iterative design approach, characterized by continuous refinement and optimization of requirements and the methods and process used. This methodology has proven instrumental in the project's success, allowing a small team to develop a complex system with considerably fewer resources than traditionally required.

9 The LandX 23 demonstration

The LandX23 demonstration was a comprehensive event, showcasing various technologies and capabilities to a broader audience from the defence sector. The key components of the demonstration included:

1. Introduction to technologies:

- The event started by dividing the audience of approximately 100+ people into four groups.
- Each group rotated through four different stands, where they received short but comprehensive introductions to various technologies. This setup allowed participants to get a closer look at different aspects of the various defence-related technologies.

2. Composite tactical demonstration:

- After the initial rotation, the entire audience was gathered.
- A composite demonstration took place, where the showcased technologies were integrated into a tactical mission scenario. This involved simulating real-world scenarios to demonstrate how the technologies work together in a cohesive manner in a tactical context.

3. Live-fire demonstration of a short-range missile:

- The final part of the demonstration involved the entire audience moving to another range.
- A live-fire demonstration in a controlled environment showcased a short-range missile developed by FFI.

Overall, this format allowed the audience to gain theoretical knowledge about different technologies and to witness their practical applications in both tactical missions and live-fire scenarios. It provided a comprehensive overview of the capabilities and functionalities of the showcased defence technologies. In the final hours leading up to the broader audience demonstration, LandX 23 had the privilege of conducting a trial of the demonstration setup for the Army commanders of Denmark, Finland, Norway, and Sweden. (fig. 9.1)

Figure 9.1 The Army commanders from Finland (left), Denmark, Sweden and Norway being briefed by the LandX 23 commentator, Lieutenant Colonel Sven Bjerke, and FFI Research program manager Katrine Dybwad.

9.1 Introduction to technologies

This part of the demonstration introduced the audience to four different technologies in 20 minutes rotations:

- Manned-Unmanned Teaming
- Synthetic Prototyping
- Remotely operated distributed sensor network (Fjernsyn)
- Elinor

These technologies are described in more detail in previous chapters of this report.

9.2 The composite tactical demonstration

The purpose of the tactical demonstration was to offer the participating scientific personnel a tactical scenario for testing their technologies and to present the broader invited audience with a conceptual solution demonstrating how a company-level unit could address a defensive mission by leveraging new technology. Most of the action in this demonstration occurred either beyond the spectators' view or in the digital domain. To enhance the audience's understanding, a very large digital screen (15 m^2/ 6000 nits) was installed at the range, and the audience was organized to have a clear view of the screen. As the demonstration progressed, a commentator assisted the audience in comprehending the various live digital information displayed on the screen, as well as the tactical developments.

Figure 9.2 The audience gathering in wait for the composite tactical demonstration to start.

To carry out the demonstration, a fictional Future Combat Unit (FCU) was formed. The FCU, a company-sized armoured combat unit representing the Army of Tomorrow, had command and control over various participating technologies. For this operation, the commander FCU had at their disposal: (1) Remotely operated distributed sensor network (Fjernsyn) with multiple nodes of ground sensors (acoustic, optical, thermal, radar), (2) Swarming capable quad-copter type drones with thermal image cameras (Valkyrie), and (3) Counter unmanned aerial systems interceptor drones connected to a ground-to-air surveillance system (Svale). All these capabilities were digitally linked with the NorBMS, which, in turn, was digitally linked with the Norwegian command and control system for indirect fires, ODIN. A fictional brigade's indirect fires capabilities supported the FCU.

9.2.1 Tactical situation

The FCU was placed within a simplified tactical scenario, which outlined an attacking mechanized enemy force halted on the main axis of advance by blocking positions established by own brigade after a delaying battle. The FCU's mission was to screen the flank of the brigade, where an alternative enemy axis of advance had been identified, with the aim of safeguarding the brigade main force against potential enemy flanking attacks or envelopment.

9.2.2 Mission execution - the demonstration

To ensure early warning of any enemy advance, Commander FCU deployed forward several sensor nodes with intersecting surveillance areas across the area of responsibility, allowing them to keep FCU manned capabilities in the rear. This course of action reduced the risk of exposure to enemy offensive actions and retained combat power.

The forward deployment of sensor nodes offered the necessary situational awareness, initially allowing the grounding of all drones, but with them remaining on high alert. Keeping the drones grounded guaranteed that if the need arose to launch them, the drones could be utilized to their fullest operational capacity, as well as maintaining a low profile on the FCU position.

As enemy reconnaissance advanced along the alternative axis of advance under FCU observation, an acoustic sensor detected the lead vehicle of the enemy. The sensor operator was alerted that something was happening. Contact was subsequently confirmed when the enemy entered the observation sector of the optical sensor of the same node as the acoustic sensor.

The intersecting chain of sensor nodes tracked the enemy movement closing in on FCU positions. Before the situation became critical, necessitating the alerting of the FCU combat force, the enemy vehicle turned off the road it was following and disappeared behind a wooded area.

Figure 9.3 Example of Fjernsyn control station displaying the current situation. Similar screen capture was shown on screen and explained to the audience.

When the vehicle failed to be detected by subsequent sensor nodes in the network, and the acoustic sensor lost contact with the vehicle, the sensor operator informed the FCU commander that the enemy vehicle most likely had taken up a position in the area behind the woods. The commander evaluated the situation, considering the possibility of the enemy establishing a forward observer or deploying dismounted troops, and concluded that the issue needed attention. Consequently, the commander directed the deployment of drones to locate and identify the enemy threat. The Fjernsyn operator designated a target area for the drones directly on the map shown on the Fjernsyn control screen and digitally transmitted this information to the Valkyrie operator.

[Valkyrie GCS display was shown on screen and explained. Drone swarm took off 30 meters in front of spectators.]

Upon receiving the digital target area, four drones were tasked with locating and identifying the enemy threat. They took off and flew to the designated target area to initiate their reconnaissance mission.

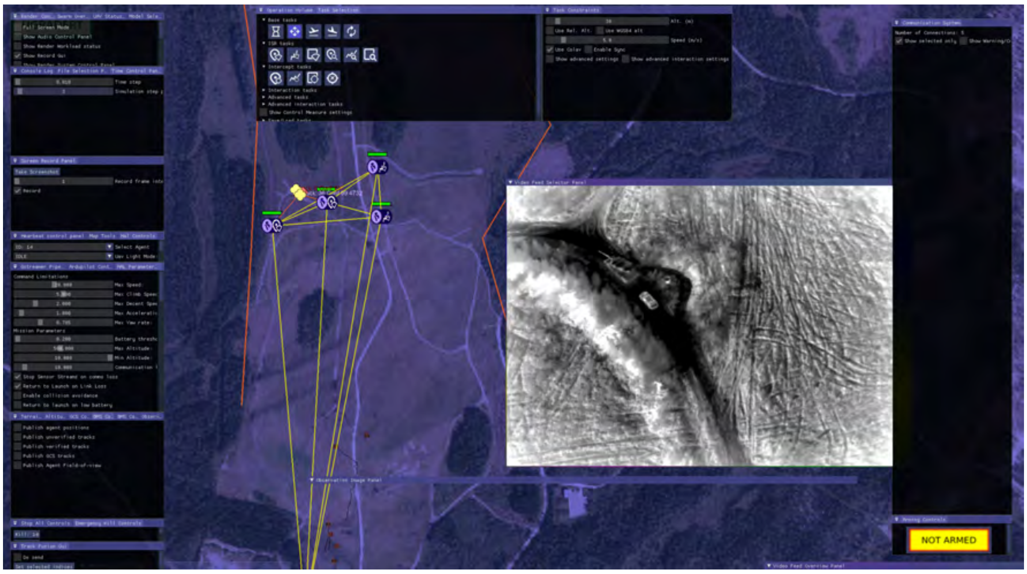


Figure 9.4 This image shows a screenshot from Valkyrie GCS. Four Flamingo drones have been dispatched to search for threats in the given area. At the moment of the screenshot, two of the drones are tracking a hostile tank and is cooperating to estimate its exact location digitally and relay the target information back to the operator. The yellow markers in the map indicate the individual drones respective estimate of the target location and the red symbol between them indicate the combined and more precise estimate. The target can be seen in the live video feed in the lower-right part of the window. The two other drones are screening the western and eastern tree lines and the orange lines indicate.

Shortly after reaching the assigned target area, the drone swarm identified the position of the enemy vehicle. Confirming it as a threat the FCU commander opted to engage the enemy vehicle using indirect fire. The Valkyrie operator pinpointed the position of the enemy vehicle and transmitted this information digitally to NorBMS.

[NorBMS display was shown on screen and explained.]

In NorBMS, the FCU attached Forward Observer (FO) organized the target data into a request for fire and digitally forwarded it in the ODIN system to the Brigade Joint Fire Support Element (JFSE).

[ODIN display was shown on screen and explained.]

At the JFSE, the request for fire received priority, leading to the swift issuance of a digital order for a fire-for-effect when ready to one of the Brigade's 155 mm howitzer batteries. Subsequently, firing commenced, resulting in the destruction of the target.

While the indirect fire engagement was underway, the ground-to-air surveillance system picked up an incoming drone threat, prompting the FCU commander to order the deployment of interceptor drones. Controlled by the Valkyrie operator, two Svale interceptor drones took off immediately. One Svale drone was tasked with carrying out the intercept, while the other remained in reserve.

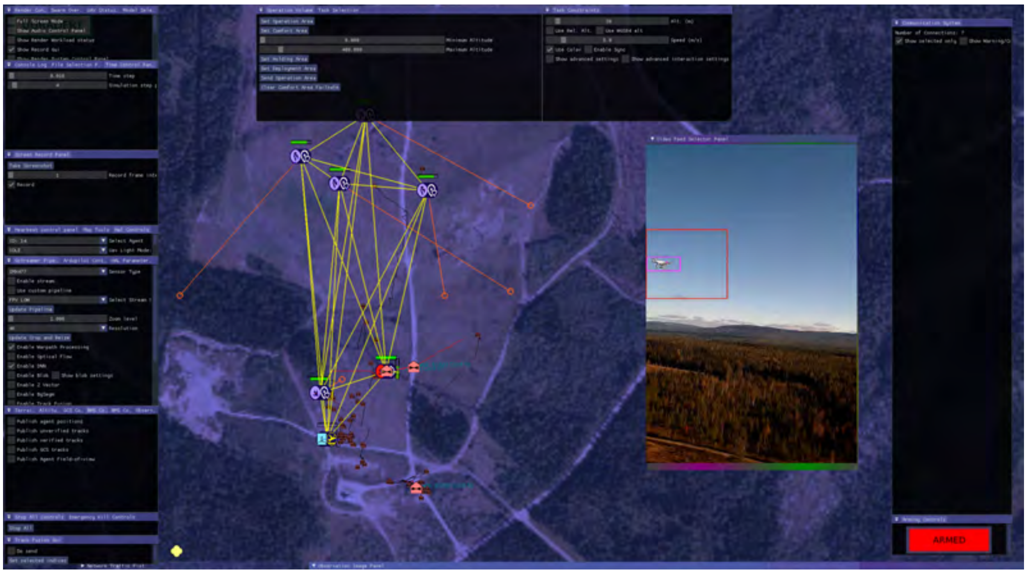


Figure 9.5 This image shows a screenshot from the Valkyrie GCS during the intercept mission.The red hostile drone marker is the target as indicated by the ground-to-air surveillance system and the red circle close to it indicates a Svale *that is in its terminal phase of its engagement mission.The video feed in the rightmost part of the interface shows the live video stream from the engaging interceptor moments before impact.*

Guided by the ground-to-air surveillance system, the intercepting drone closed in on the incoming drone threat until its onboard target acquisition system identified it. Using the target information, the interceptor drone calculated the intercept vector and speed, successfully executing the intercept. Incapacitated by the intercept, the threat drone crashed to the ground. Since no additional drone threats were identified, both Svale drones were recalled and returned to their ready state.

The successful intercept of the threat drone concluded the tactical part of the demonstration. At this point, the third part of the LandX23 demonstration was initiated with instructions to the audience on how to transport themselves to another range (Live Fire Range B1), approximately 5 km away, to take part in the live-firing demonstration of the FFI developed short range missile.

9.3 Live-fire demonstration

At range B1, the audience was given a brief introduction to the conceptual idea behind the research leading to the construction of the short-range missile. The missile is composed of mostly commercial off the shelf components found in other branches than military. This approach has provided a fairly capable missile at a very low cost, but it has not been rugged for military use (chapter 8).

Figure 9.6 FFI principal scientist Per Gisle Dalsjø preparing the short range missile for launch.

Following the introduction, the missile was then fired at a target 600 meters away. The missile launched correctly. The rocket igniting after launch fired as expected, but sadly, at this demonstration for an audience, due to an error in the control section, the missile failed and crashed before reaching its target.

10 Summary and conclusion

The LandX series started with experimentation on SA in 2020, going into MUM-T in 2021, expanding to counter-unmanned aerial system (C-UAS) and cooperation with military units and personnel in 2022. The addition of this year was to include additional effectors on top of the previous themes.

This year, together with industry and military partners, FFI demonstrated six different technology areas with a potential to impact how the Norwegian Army may conduct operations in the future. Each of these technology areas are on different Technology Readiness Levels (TRL), but most of them are ready for small unit testing. Furthermore, systems like Fjernsyn and the Valkyrie drone swarm, are more mature systems ready for operational testing and experimentation.

LandX has become an important meeting arena to discuss new technologies, research and future land warfare with military leaders and industry partners. The LandX arena continues to grow. More and more FFI-projects are participating to showcase their technologies in a land warfare setting.

References

[1] K. Mathiassen, M. Baksaas, I. Dyrdal, B. G. Eikanger, F. Gulbrandsen, D. Gusland, M. V. Larsen, E. Mentzoni, M. Minos-Stensrud, J. Moen, E. B. Nilssen, O. R. Nummedal, T. Nygaard, S. Rolfsjord, A. Simonsen, M. Thoresen, L. H. Bakstad, D. H. Bentsen, C. Eggesbø, E. S. Grimstvedt, T. V. Haavardsholm, M. Halsør, Ø. Hoelsæter, D. Kolden, T. R. Krogstad, R. H. Macdonald, N. H. Nielsen, G. Nonsvik, E-L. M. Ruud, R. A. Seehuus, M. S. Wiig and E. Østevold. *"LandX20 Experiment Report - experiment for future land warfare capabilities with focus on increased situational awareness and unmanned systems"*. FFI-rapport 22/00274. Norwegian Defence Research Establishment, 2022.

[2] L. H. Bakstad, M. Baksaas, K. M. Dybwad, B. Eikanger, D. Gusland, M. Hauge, T. V. Haavardsholm, F. T. Johnsen, D. Kolden, M. Vonheim Larsen F. Mancini, K. Mathiassen, E. Mentzoni, M. Minos-Stensrud, N. H. Nielsen, O. R. Nummedal, T. Nygaard, L. E. Olsen, S. Rolfsjord, R. A. Seehuus, A. Simonsen, M. Strand and M. Thoresen. *"LandX21 - teknologi i framtidas stridsfelt"*. FFI-rapport 24/00481. Norwegian Defence Research Establishment, 2024.

[3] E. A. Mentzoni, M. Baksaas, S. Bjerke, K. M. Dybwad, S. Fyhn, K. Mathiassen, M. N. Nielsen, N. H. Nielsen, L. E. Olsen, G. I. Rosvold, A. Simonsen and S. L. Skaar. *"LandX22 - Experimentation with uncrewerd systems in a future battle force"*. FFI-rapport 24/00480. Norwegian Defence Research Establishment, 2024.

[4] *"FFI Viten - Teknologisk innovasjon i Forsvaret"*. FFI-Viten 1.2022. Norwegian Defence Research Establishment, 2022.

[5] E. Østevold, L. H. Bakstad, D. H. Bentsen, S. Bjerke and M. Halsør. *"Fremtidens kampenhet – operativt og teknologisk grunnlag"*. 23/00338. Norwegian Defence Research Establishment, 2023.

[6] *"ROBOTIC AUTONOMOUS SYSTEMS – GROUND INTEROPERABILITY PROFILE - AEP-4818 EDITION A"*. STANREC 4818. North Atlantic Treaty Organization, 2023.

[7] K. Mathiassen, F. E. Schneider, P. Bounker, A. Tiderko, G. D. Cubber, M. Baksaas, J. Główka,
R. Kozik, T. Nussbaumer, J. Röning, J. Pellenz and A. Volk. 'Demonstrating interoperability between unmanned ground systems and command and control systems'. In: *International Journal of Intelligent Defence Support Systems* 6.2 (2021), p. 100. ISSN: 1755-1595. DOI: `10.1504/ijidss.2021.115236`.

[8] M. Thoresen. *"Eksperimentering med ubemannet bakkekjøretøy på Bardufoss mai-juni 2022"*. 23/01311. (Exempt from public disclosure). Norwegian Defence Research Establishment, 2023.

[9] M. Baksaas, B. Eikanger, E. Sørlundsengen, M. Thoresen, M. Hanevold, M. Paulsmoen (FMA), N. H. Nielsen and R. Smestad. *"Eksperimentering med ubemannet bakkekjøretøy sammen med Hæren - sommerkampanjen 2023"*. 24/00505. (Exempt from public disclosure). Norwegian Defence Research Establishment, 2024.

[10] Kartverket. *Norge Digitalt.* 2023. URL: `https://www.kartverket.no/geodataarbeid/norge-digitalt` (visited on 12/12/2023).

[11] K. Dybwad, L. E. Olsen, G. I. Rosvold, M. N. Nielsen and S. Folke-Olsen. *"Fjernopererte sensorer for Landstrid - sluttrapport"*. FFI-rapport 24/00349. Norwegian Defence Research Establishment, 2024.

Forkortelser

ATGM	anti-tank guided missile
BISim	Bohemia Interactive Simulations
BMS	Battle Management System
C-UAS	counter-unmanned aerial system
C4IS	Command, Control, Communications, Computers, Intelligence and Surveillance
COTS	Commercially Off-The-Shelf
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
EdgeGW	Edge Gateway
FCU	Future Combat Unit
FO	Forward Observer
FPGA	Field Programmable Gate Arrays
FSP TYR	Defence Tactical Platform TYR
GCS	Ground Control Station
GUI	Graphical User Interface
HUD	Heads-up display
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
IOP	Interoperability Profiles
ISTAR	Intelligence, Surveillance, Target Acquisition, and Reconnaissance
JFSE	Joint Fire Support Element
KDA	Kongsberg Defence & Aerospace
LVC	Live, Virtual and Constructive

LWIR	Long Wavelength Infrared
MEMS	Micro Electro-Mechanical Systems
MUM-T	Manned-Unmanned Teaming
NFFI	NATO Friendly Force Information
NorBMS	Norwegian Battlefield Management System
NORCCIS	Norwegian Command and Control Information System
OTAS	Observation Targeting and Surveillance Systems
RC	Remote Controller
RWS	Remote Weapon Station
SA	Situational Awareness
SD-WAN	Software-Defined WAN
SDR	Software-defined radio
SIP	Session Initiation Protocol
SRT	Secure Reliable Transport
TMS	Tactical Media Suite
TRL	Technology Readiness Levels
TVS	Tactical Voice System
UAV	unmanned aerial vehicle
UGV	unmanned ground vehicle
VBS	Virtual Battlespace
VLAN	virtual local area network
VMF	Variable Message Format
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
XMPP	eXtensible Message Protocol

About FFI

The Norwegian Defence Research Establishment (FFI) was founded 11th of April 1946. It is organised as an administrative agency subordinate to the Ministry of Defence.

FFI's mission

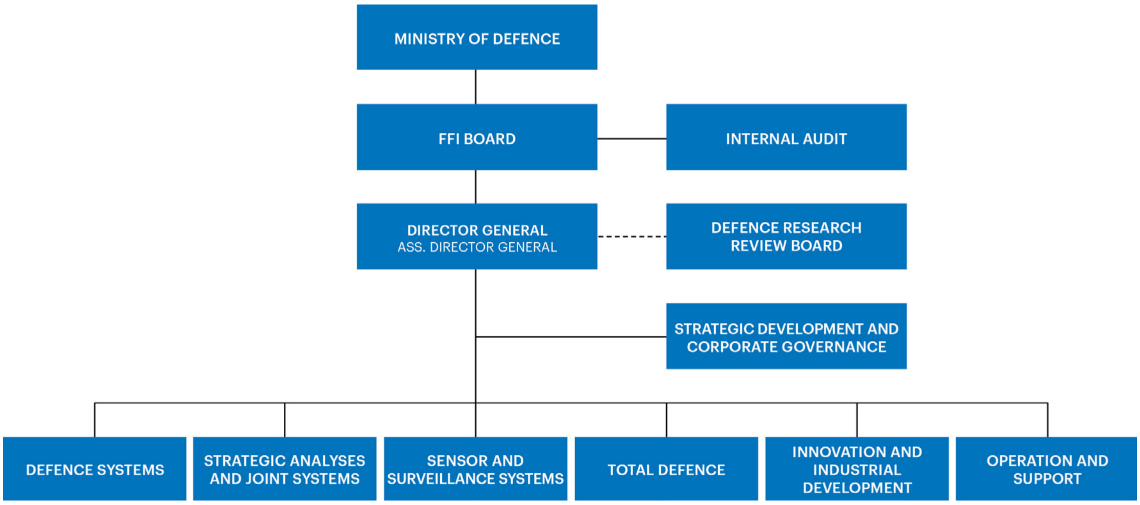
FFI is the prime institution responsible for defence related research in Norway. Its principal mission is to carry out research and development to meet the requirements of the Armed Forces. FFI has the role of chief adviser to the political and military leadership. In particular, the institute shall focus on aspects of the development in science and technology that can influence our security policy or defence planning.

FFI's vision

FFI turns knowledge and ideas into an efficient defence.

FFI's characteristics

Creative, daring, broad-minded and responsible.



Forsvarets forskningsinstitutt (FFI)
Postboks 25
2027 Kjeller

Besøksadresse:
Kjeller: Instituttveien 20, Kjeller
Horten: Nedre vei 16, Karljohansvern, Horten

Telefon: 91 50 30 03
E-post: post@ffi.no
ffi.no

Norwegian Defence Research Establishment (FFI)
PO box 25
NO-2027 Kjeller
NORWAY

Visitor address:
Kjeller: Instituttveien 20, Kjeller
Horten: Nedre vei 16, Karljohansvern, Horten

Telephone: +47 91 50 30 03
E-mail: post@ffi.no
ffi.no/en