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Satellite imagery support to NATO Response Force operations

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Summary

NATO is in the process of implementation of NATO Response Forces (NRF). Such NRF should be capable of deployment within days anywhere world wide, typically to execute crisis response operations. In the past 10-15 years, the unavailability and/or inaccessibility of accurate and up-to-date geographic and intelligence information have proven to be a continuing problem. Despite effort made to improve this situation, map products in map scales suitable for preparation and execution of operations are a scarce resource. Today's operations, such as NRF missions, are undertaken at short notice and consequently provide limited preparation times to the military. This makes the unavailability and/or inaccessibility of accurate information an increasingly important issue.

In this paper, an integrated receiving and processing ground station – tailored for support of NRF operations – will be presented, as well as typical examples of information products generated. The results and lessons learned from the participation by the ground station in exercises Low Lands and Allied Warrior will be discussed. In addition, recommendations will be made for further technical work and suggestions for political actions to enable uptake of ground stations in national and international military operations.

Contents

(17 pages in total)

1 Introduction

In the GISMO project, funded under the Dutch military National Technology Program, the use of satellite imagery to support today's military operations has been investigated, demonstrated and evaluated in an operational environment. This project has combined the NLR RAPIDS ground receiving station, COTS image processing and exploitation software tools, together with results from R&D programmes and best practices. The resulting solution is an integrated mobile ground receiving and processing station optimised for NRF operations. The mobile ground station was fielded during autumn 2004 in military exercises Low Lands and Allied Warrior (see figure 1) to support the Dutch 103ISTAR battalion and the Dutch-German army corps (1GNC, NATO NRF) with near real-time ortho-images, change detection maps and thematic maps. These products are all based on real-time high-resolution EROS and SPOT commercial satellite imagery.

Fig. 1 RAPIDS mobile ground receiving station deployed during exercise Low Lands

2 NRF operations

Time between a decision on an NRF operation and the actual deployment is very short, ranging from a few days to 1-2 weeks at most. Geographic information available at that time typically is limited to a (near) full coverage of the operations area by outdated maps in scales 1:250.000 and sometimes 1:100.000. Low-resolution archive imagery (~25m resolution) is often available for most of the area to provide a planning overview. These can sometimes be supplemented with high-resolution imagery, but the intended deployment sites will most often not be covered. As a consequence, an urgent need exists for additional detailed imagery for deployment planning purposes. The geographic reference is poor (~25m) in this phase. A local ground receiving station has limited value in this preparation phase, although it can speed up the process of data collection.

The rapid mapping process using high-resolution imagery continues during the initial phase of the deployment. The acquired imagery will be used increasingly for intelligence applications as well, helping to establish an operational picture. On-site collection of more accurate geographic reference data helps to improve the precision and quality of geographic and intelligence products.

3 Ground receiving station

The NLR RAPIDS ground receiving station has been used in several military demonstration projects and exercises (reference [1]). Its ability for very rapid deployment and quick on-site installation (typical turnaround time 4 hours, excluding the actual transportation) makes it very attractive for such use (see figure 2). For ease of road transportation during exercises, all ground receiving and processing station equipment was integrated into a single small army truck (see figure 1). Training for system operations requires no more than 1-2 days through the usage of intuitive software user interfaces. A ground station crew of 2 persons – educated at intermediate level – is sufficient to handle tasking requests and to install and operate the system.

The major drawback of the original RAPIDS system was the resolution of imagery that it was capable of receiving; the best giving a 10m ground sampling distance (GSD). To provide relevant information to day-to-day military operations, the system was upgraded to receive EROS-A imagery, providing a GSD in the range of 1m to 1.8m. A priority access service contract with Imagesat International is in place to ensure real-time high-priority direct access to the EROS-A satellite.

Fig. 2 Deployment of RAPIDS mobile ground receiving station using an RNLAF C-130 transport aircraft

4 Image processing station

Based on a user requirements analysis, the following key products were defined based on satellite imagery:

- near real-time ortho-images with single pixel geometric accuracy; latency between image data capture and ortho-image availability should be less than 2 hours
- change detection vector maps based on archive imagery and newly acquired image data
- land cover maps showing land cover in main classes

The image processing ground station should provide an intuitive and uniform user interface to all processing tools to generate the products listed above. In addition, it should provide functionality for import/export of imagery products and access to data sets via a catalogue.

Another result of the user requirements analysis is the separation between processing and analysis. The image processing ground station is limited to processing, providing intermediate products to image analysts. Analysis and interpretation of ortho-images, change detection maps and land cover maps requires specific military knowledge and training. It cannot be implemented in a ground station with a high level of automation, as is the case for example with ortho-rectification.

The graphical user interface of the image processing station named GISMO-DIRECD is implemented in Erdas Imagine, a COTS image-processing package (see figure 3). It provides access to native functionality of the COTS package as well as third-party tools. It has been optimised to generate products according to the requirements listed above.

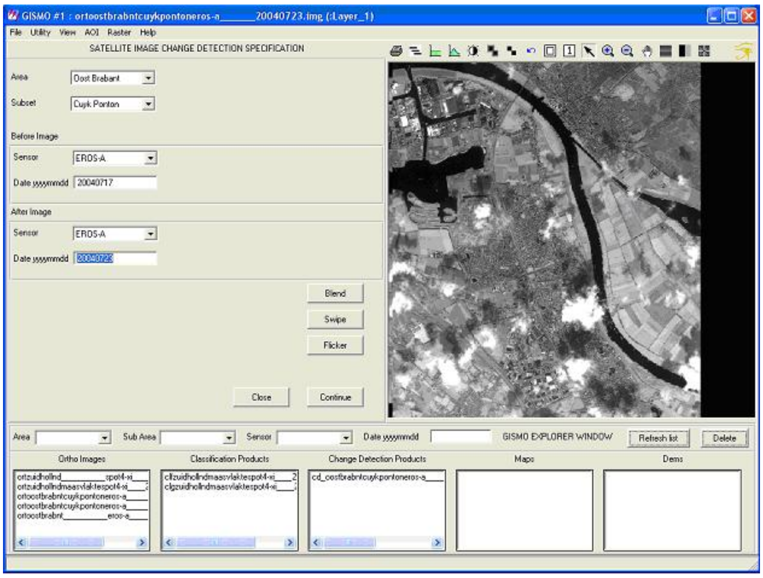

Fig. 3 GISMO-DIRECD user interface, definition of a change detection job

In the image processing ground station, functionality is clustered into 3 groups:

- prepare, consisting of
  - import of raw imagery of a wide range of sensors
  - catalogue raw imagery
  - orthorectification of EROS-A and SPOT-4 raw imagery
  - storage of ortho images into COTS package native file format
- process, consisting of
  - subset to cut ortho-images to the area of interest
  - change detection between ortho images
  - land cover classification using SPOT-4XI multi-spectral imagery
- export images and products in raster or vector (shape) format.

Precise orthorectification of raw imagery is crucial for all onward processing and data analysis. Geo-spatial co-ordinates are the only link between images. Real-time imagery comes with ephemeris data of low to medium accuracy, providing only a coarse estimate of the image co-ordinates. Time for manual (and consequently time consuming) orthorectification is not available and requires additional expertise. As a consequence, software tools are required to rapidly and automatically ortho-rectify raw imagery using low to medium accuracy ephemeris data. However, such capabilities are not commonly available.

The SIP/Ortho software is a package that can handle this problem and it was therefore customised for integration into GISMO-DIRECD. It is based on an explicit geometrical sensor model coupled to a database of so-called image chips (miniature ortho-images of distinct areas) and correlation techniques. Using SIP/Ortho, the accuracy of the ephemeris data is improved to such an extent that a precise co-ordinate can be calculated for each image pixel. In a fully automatic mode it attempts to correlate the image chips with the raw image using only the coarse estimate of the image co-ordinates. In case of an unsuccessful attempt, the operator can provide guidance by pinpointing 1 or 2 ground control points (GCP) with moderate accuracy (~10 pixels error), equivalent to a first order correction of the ephemeris data. This is sufficient for the automatic process to succeed. This automated process is shown schematically in figure 4.

Using SIP/Ortho as an integral element in the GISMO-DIRECD image processing ground station, raw EROS-A and SPOT-4 satellite images can be ortho-rectified to single-pixel accuracy within 15 minutes using a standard laptop PC.

Precise ortho-images are an intermediate product for all onward processing such as change detection and land cover classification. However, near-real-time ortho-images are a product as well. These images are a contributor to Special Forces (SF) operations where visibility is an important issue. A last-minute update over the area of interest provided by an ortho-image enables a verification of line-of-sight analysis. This applies in particular – but is not limited – to urban operations.

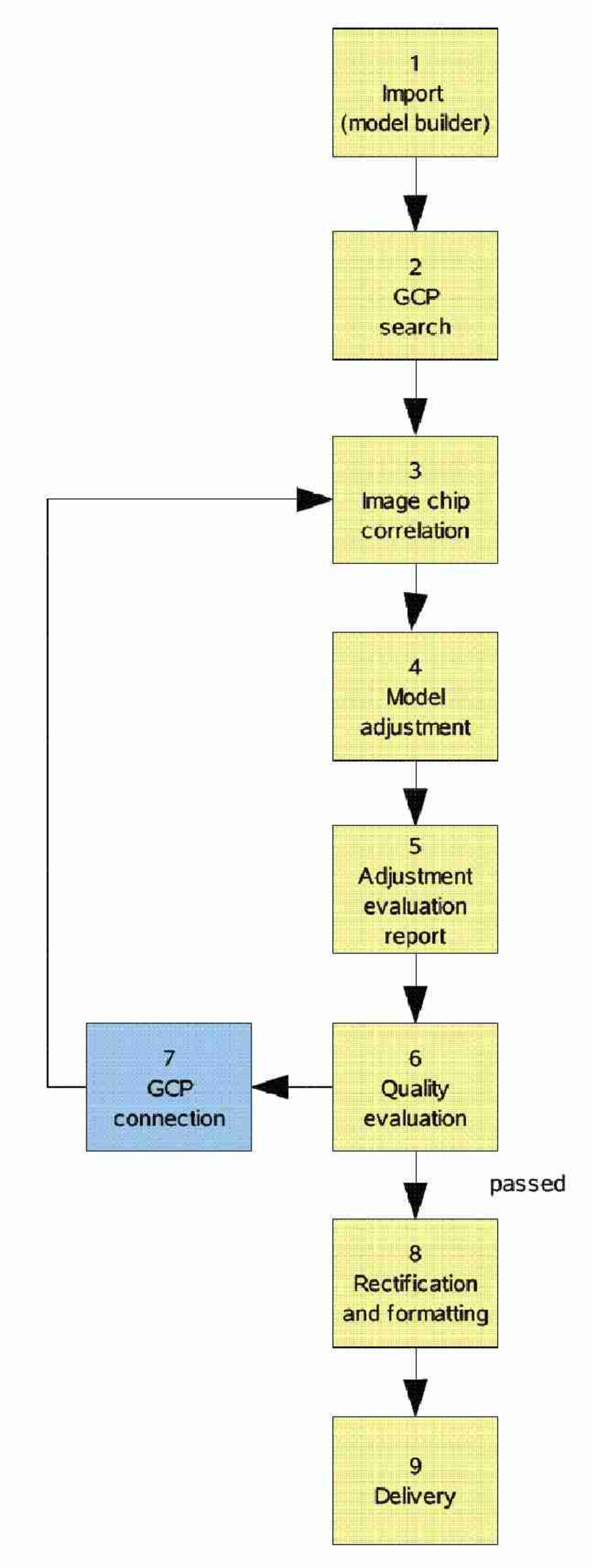

Fig. 4 Flow diagram for automatic ortho-rectification

Change-detection functionality is based on a combination of several COTS image processing package’s native capabilities supplemented with image-to-image fine registration (co-registration of images to minimise residual geographic errors) and thresholding techniques. Based on interactive setting of thresholds for positive and negative changes, and filter setting for elimination of false detections, a vector layer is generated of changes with corresponding attributes. A continuously updated preview of the change detection output at current threshold settings gives the user an intuitive insight and feedback.

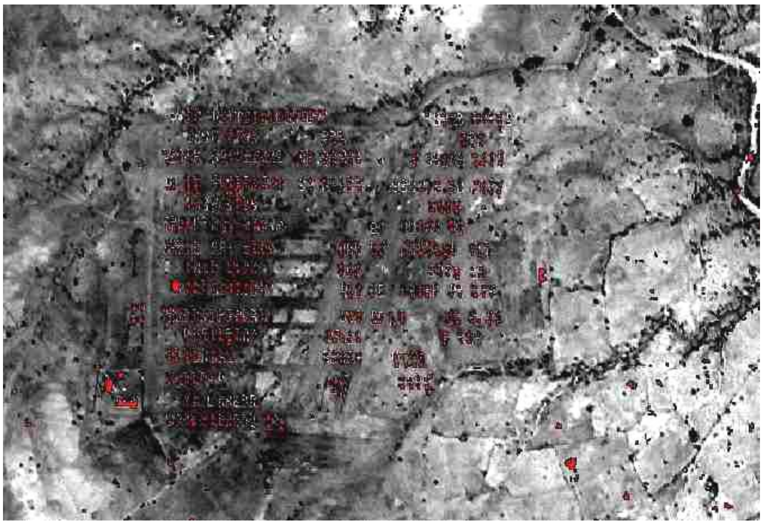

Fig. 5 Refugee camp (red annotation) near Nyala (Darfur, Sudan) automatically detected in an EROS-A image (background image) taken 8th November 2004 using a SPOT-5 image dated 8th February 2004 as a reference

The change-detection tool has been shown to be a valuable assistant in detecting changes with respect to a reference image set. In this way a rapid update is provided of the environmental and operational picture. The generated vector layers can be easily imported in GIS and decision support systems (e.g. C2).

An example of a change-detection product is given in figure 5. Through comparison of 2 images taken 9 months apart an update can quickly be obtained of the environmental and operational picture. In this case a refugee camp is easily detected near the city of Nyala (Darfur, Sudan). Note that objects as small as individual tents show clearly.

Land cover classification is performed using in-house developed algorithms. Based on segmentation of pixel clusters in the 4-dimensional spectral space, the main land cover types are derived. In addition to a fully automatic classification into 8 main classes, the operator can adjust the spectral segmentation using a set of 7 slider bars. Even here, a continuously updated preview of the classification output at current settings gives the operator an intuitive insight and feedback.

The classification tool helps to quickly generate land cover maps of extended areas, the latter being an important input for cross-country movement analysis. An example is shown in figure 6, showing a land cover map (8 main classes) of the Greater Tunis area (Tunisia) based on a SPOT4-XI image (20m resolution).

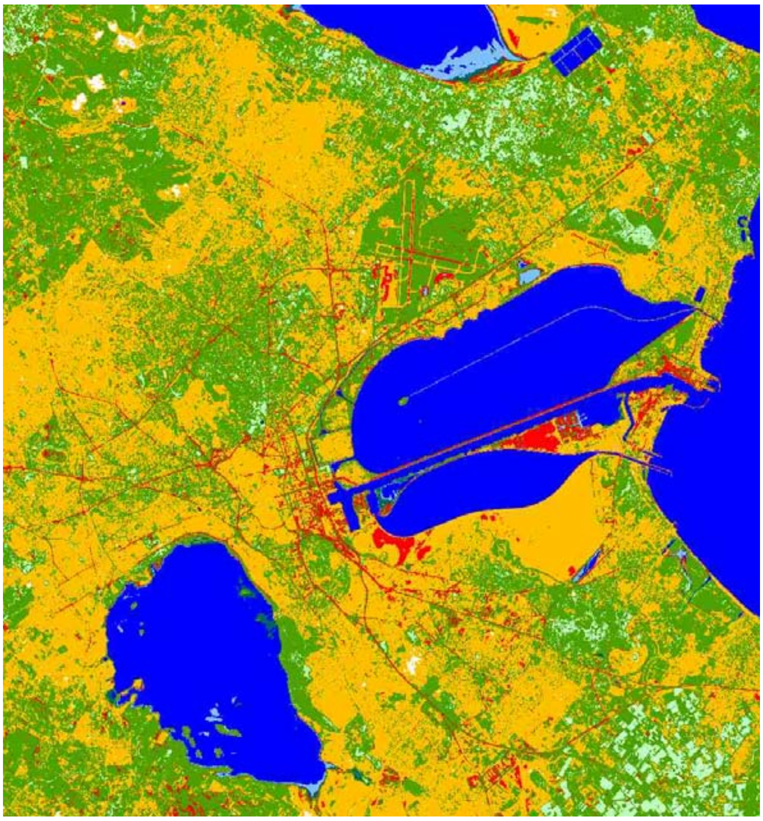

Fig. 6 Land cover map of Tunis based on a SPOT4-XI image taken 11th July 2003

5 Operational benefit and lessons learned

In the GISMO project reducing the time lag between request and product delivery was a primary focal point. This applied not only to data reception and processing – as described above – but also to communication with satellite operators, tasking procedures and delivery of the raw imagery. The latter contribution can be influenced to lesser extent than the first due to contractual restrictions. Prior to the exercises, licensing terms and tasking procedures were negotiated with Imagesat International (EROS-A), Space Imaging EUSI & SIEA (IKONOS) and with Spotimage (SPOT-4). Under the established non-exclusive contracts for all three satellites typically a 2-day advance notification is required for data acquisition. In individual cases, requests sent 24 hours prior to data acquisition could still be accepted. The tasking requests could be given by telephone call or via email. Data was delivered directly and without delay to the RAPIDS ground station or via ftp for those situations where delivery to the RAPIDS ground station was not possible (area of interest outside ground station footprint). In that case, necessary delivery via ftp took 12 hours (EROS imagery) to 24 hours (IKONOS imagery) using a 250 kbps download link (raw image size is ~ 100…300 Mbytes). Note that such a wide bandwidth link is not available in the field.

The entire cycle from request to delivery typically takes 50 hours (direct delivery to local ground station) or 60-75 hours (delivery via ftp, dependent on speed of Internet connection). Image processing time is only a very small fraction of this cycle. However, even though the majority of the time lapse is between the request and image capture by the satellite, the time between capture and delivery should also be minimised. Several applications require prompt availability of the imagery since the information contained loses value quickly. Co-location of the ground stations with image analyst units is required to minimise delivery time.

A significant step ahead would be a capability to task the satellite using an uplink via the local ground station (available for EROS satellites under exclusive access contracts). Tasking notification time would be reduced from days to hours. This requires clear insight in tasking procedures, time lines and satellite capabilities. Even under the current contracts, such insight in constraints is required at the ground station. Decisions on whether and when tasking requests are submitted are driven by these constraints. Satellite operators show an increasing acceptance of the need for local ground stations deployed close to the users (reference [4]). Hopefully procedures for tasking satellites will increasingly be optimised to accommodate last-minute requests.

A local Internet connection is highly desirable for ground station operations. A low-bandwidth GPRS connection is sufficient for email communication with satellite operators. For download of raw imagery via ftp a wide-bandwidth connections is required. Given the anticipated local infrastructure in NRF operation areas, such communication links must be provided using satcom. Even when such satcom connectivity is present, delivery of raw imagery via ftp takes 12-24 hours longer than a direct downlink to a local ground station.

Fig. 7 EROS-A imagery of Rotterdam harbour, 4th September 2004 (image courtesy Imagesat International)

A local ground station is today's only practical solution for (near) real-time access to satellite imagery for forces deployed in the field. If the information acquired is made available promptly it can be used for cross-cueing other assets. For home base applications a local ground receiving station has limited value since there is no need for real-time access to imagery. Image processing ground stations show their value both at home base as well as in the field. When such stations are tailored to specific needs, products can be produced much faster and in a reliable and repeatable manner. It has been demonstrated that the RAPIDS and GISMO-DIRECD receiving and image processing ground stations can be rapidly deployed in the field and require minimal operator training.

6 Road ahead

The RAPIDS and DIRECD-GISMO receiving and image processing ground stations are suitable for operational usage in their current form. However, there are requirements for extended ground station coverage and for reception of high-resolution imagery from additional satellites to provide more frequent imagery. The GISMO project team has started a development to meet these requirements. Such extended capability will generate even larger amounts of data. Handling of such large volumes of data is seen as a bigger challenge than building the satellites themselves (reference [4]) and should be a focal point for development projects.

Availability of precise geographic reference is an issue in NRF operations. In early phases of operations imagery products are processed using references with low accuracy, such as large scale maps or the worldwide Landsat mosaic. Geographic references are refined during operations, revealing inaccuracies of previously processed products, making these a potential source of error. If the orthorectification process refines sensor models and stores these together with the raw data (rather than re-sampling image data to a projection grid), an update of geographic references can be applied to all digital data with a click of a mouse. It would also overcome issues in using several geographic projection systems and transformations between these, since a transformation in this case is nothing more than an add-on to a sensor model. Such benefits become most explicit when users work with digital systems only, while hardcopies would still require reprints.

Fig. 8 GISMO-DIRECD image processing ground station in use by 103ISTAR battalion during exercise Low Lands

The technology for image processing can be applied not only to satellite imagery but also to imagery generated by aerial sensors (still and motion imagery). Issues associated with for example a highly oblique viewing geometry need to be solved. An enabler for true multi-sensor data fusion and analysis would be co-located ground receiving stations for various ISTAR assets, combined with the capability to process all imagery to a common reference grid. Access to imagery – versus access to reports based upon such imagery – from various ISTAR assets, facilitates synergy in the data processing. With integrated imagery from multiple sources, information contained in one source can help in processing data from another source in a more intelligent manner.

Improved centralised co-ordination / mission planning of a multi-platform ISTAR fleet is a possible next step in maximising outcome. A centralised – not necessarily meaning home based – ISTAR body with a responsibility for choosing the best ISTAR asset to meet the information requirement should oversee the capabilities of the allied forces. Obviously, intense international co-operation is required to do so, on the technical level in the space, air and ground segments, but even more so on the political level in granting access to and sharing authority over national assets. A combined air operations centre (CAOC) has this responsibility, but being remote to ISTAR platform operating units, co-ordination takes place mainly on an hourly basis rather than in near real-time.

Since co-operation the field of intelligence is a give-and-take trade, nations that do not operate their own assets have to fall back on commercial imagery to be able to trade. A truely common EU imaging system is unlikely within the next 10 years (reference [5]). The main obstacle is of a political nature. Nations should align their research & development and procurement programs better. By doing so a technical infrastructure will be established for co-operation on a bi-lateral basis between nations in an NRF framework, which eventually may spin off NATO-wide.

7 Conclusions and recommendations

High-resolution satellite imagery has a significant value in all phases of NRF operations to establish an environmental and operational picture. When made available promptly, it is valuable for intelligence applications and for cueing other (ISTAR) assets. Near real-time image processing ground stations play an enabling role in processing imagery into useable products. Ground receiving stations show their value most when deployed in the field close to operations. These have shown to be today's only practical tool for real-time access to satellite imagery. Systems as demonstrated in exercises under the GISMO project are as-built suitable for usage in operations.

Today's commercial satellite imagery resolutions are sufficient for usage in operations; higher resolutions may be required for strategic political studies. The decisive issue for effective use of ISTAR assets is the capability to handle large volumes of data and to analyse the multi-sensor, multi-temporal data sets as a set, not as individual sources without correlation. Linked to analysis of data sets is mission planning of a fleet of ISTAR assets, how to choose the best assets for the job, while taking restrictions (availability, authority) into account. Such a fleet includes satellites, unmanned aerial vehicles, and manned reconnaissance systems all capable of carrying EO, IR and radar imaging sensors acquiring still and motion imagery.

One of the most important attributes of imagery and derived information is its spatial co-ordinate. It is essential for correlation with any other source of information. For raster based calculations sub-pixel geometric accuracy is required. For correlation with other information of other sources (such as command & control systems, battle management systems), the accuracy is determined by the final application, typically requiring an accuracy of several meters or better. If the geometric precision of systems of warfare (e.g. delivery of weapons) increases, geometric accuracy of images and maps must improve accordingly. In the field of image processing ground stations more research and development is required to process both spaceborne and airborne still and streaming imagery with higher geometric accuracy.

Current and forthcoming ISTAR assets offer a wide spectrum of technical and operational capabilities for surveillance and intelligence. The biggest challenge for military organisations to benefit most from these opportunities is organising multi-national co-operation. The technical aspects of joining multi-national ISTAR assets into a single co-ordinated virtual fleet still need to be resolved. However, these can be addressed in R&D and procurement programmes. Co-operation on a bi- or tri-lateral basis (e.g. in WEAG and NRF frameworks) will result in a technical infrastructure suitable for experiments, demonstrations and exercises. The results eventually may spin off NATO-wide.

8 References

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