

SYSTEM FOR THE VERIFICATION OF AUTHENTICITY OF AUTOMATIC
IDENTIFICATION SYSTEM (AIS) SIGNATURES BY MEANS OF REMOTE
SENSING

5 The present application relates to the Automatic Identifica-
tion System (AIS), which has been used by most large ships or
vessels for avoiding collision. In particular, the applica-
tion relates to a system and to a method for verifying au-
thenticity of AIS messages.

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Vessel or ship detection using remotely sensed data has been
studied extensively. The remotely sensed data can be obtained
from a sensing device that is not in physical or in intimate
contact with the vessel.

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In particular, many remotely sensed data include Synthetic
Aperture Radar (SAR) data, since operation of this active im-
aging systems does not depend on the time of day or on the
weather. A wide spatial coverage of the SAR data can be ob-
20 tained using a so-called ScanSAR imaging mode. Information of
the detected vessel can be used for real-time maritime secu-
rity and for safety surveillance.

A throughout review of vessel detection is given in Crisp
25 (2004); The State-of-the-Art in Ship Detection in Synthetic
Aperture Radar Imagery; Technical report: DSTO Information
Sciences Laboratory.

Document Corbane, C., Pecoul, E., Demagistri, L., Petit, M.
30 (2009); Fully automated procedure for ship detection using
optical satellite imagery; Proceedings of the SPIE, 7150, pp.
71500R-71500R-13 also shows optical imagery being used for
ship detection.

The problem of classification, and to certain degree identification, of vessel detection is addressed by

- Tsagaris, V., Panagopoulos, G., and Anastassopoulos, V.

5 (2008); Using synthetic aperture radar data to detect and identify ships; SPIE Remote Sensing Newsroom, DOI: 10.1117/2.1200802.1062 and by

- Margarit, G., Barba Milanes, J. A., Tabasco, A. (2009); Operational ship monitoring system based on synthetic aper-

10 ture radar processing; Remote Sensing, 1(3), pp. 375-392 respectively. Both works use the AIS messages to verify processing results.

Commercial maritime information systems, such as AISLive system from "Lloyd's Register - Fairplay", use the AIS messages to verify data authenticity in general and the AIS messages in particular by checking databases for data inconsistencies and for data anomalies.

20 It is an object of the application to provide an improved Automatic Identification System (AIS). The AIS system is used by most large ships or vessels for avoiding collision and by vessel traffic services for identifying and for locating vessels.

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It is believed that AIS messages of a vessel or ship can be authenticated using an objective or actual observation of the vessel.

30 An AIS device or transceiver of the vessel produces AIS messages, which include, among other information, navigation status, longitude, latitude, speed, heading, type, and dimensions of the vessel. In the context of this application, an

AIS signature includes a part of the vessel AIS message or is derived from the vessel AIS message. The AIS message is also called here as an AIS data.

5 The objective observation is made by a remotely operating and sensing platform, as known as an observation platform, using a remote sensing means. The observation platforms can include a ground-based station, a vessel, and an airborne or space-borne platform, but is not limited to these. The remote sensing refers to observing or sensing of objects from a distance
10 or a remote place. Sensors used for the remote sensing are not in direct contact with the observed objects. Such sensors can include optical, infrared, sonar, or radar means. As one example, unmanned submarines can use the sonar means. The
15 output of the remote sensing is often an image representing the observed object.

The verification of the AIS message serve to identify vessels that pose a possible security threat to other vessels, to
20 man-made installations, to environment, and even to society. Vessels that threaten security may manipulate their AIS messages to impersonate, to decoy, or to represent other vessels by hiding their identity. Hence, authentication of the AIS messages is rather crucial.

25 In practice, the verification can be performed by the observation platform or by another entity, which receives the AIS messages and information of the objective observation and which verifies the AIS messages using the objective observation information.
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The verification includes identifying a part of the AIS messages to serve as an AIS signature. An appropriate character-

istic is extracted or is derived from the objective observation information. The characteristic can include observed speed, heading, or dimensions of the vessel. The AIS signature is verified using the corresponding characteristic. Any
5 verification mismatch is raised as alarms or alerts and can be communicated to a central entity for further verification or action.

This is unlike other observation platforms that treat vessel
10 AIS messages as correct such that the AIS messages can be used as ground truth to validate results, such as image analysis, which is computed or is produced by the observation platform. The ground truth refers to information collected at a location of the vessel.

15 The verification has the advantage of increasing the size of a safety zone for protected installations. This is especially important for critical installations. The remote verification of the vessel AIS messages enable the installation safety
20 zone to be extended beyond a Very High Frequency (VHF) communication range of the vessel AIS. The vessel AIS messages can be verified outside of this AIS VHF communication range. The AIS messages can then also be checked earlier for inconsistencies and anomalies. This is unlike other systems where its
25 safety zone is limited to the VHS communication range of its AIS.

The application provides an AIS message verification device. The device includes a remote sensing device, an AIS receiver,
30 a processing unit, a communication port. The remote sensing device is used for producing remote observation information of a vessel. The AIS receiver is used for receiving AIS messages of the vessel. The processing unit is used for verify-

ing the vessel AIS messages using the vessel observation information. The communication port is used for sending an alert about the received AIS messages when a verification mismatch occurs.

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The remote sensing device can include different types of sensors for different purposes. In one implementation, the remote sensing device includes an optical sensor for producing remote observation information of a vessel. In another implementation, the remote sensing device includes a sonar sensor for producing one or more sonar images of an underwater hull of the vessel. An unmanned submarine can use the sonar sensor. In a further implementation, the remote sensing device includes an infrared sensor for producing one or more infrared images of the vessel. In a yet further implementation, the remote sensing device includes radar means for producing one or more radar images of the vessel. These images can be used to derive an observed AIS characteristic of the vessel, such as vessel speed, location, heading, and size.

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The application provides a remote sensing platform. The platform includes an AIS message verification device that is described above.

25 The remote sensing platform can include a seaborne platform or vessel. Alternatively, the remote sensing platform can include an airborne platform that can include an aircraft. The remote sensing platform can also include a static platform, such as a ground-based station.

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The application provides a method for verifying AIS messages. The method includes a step of receiving AIS messages of a vessel. Remote observation information of the vessel is then

generated whilst a vessel characteristic is later derived from the remote observation information. Following this, the AIS messages are verified using the derived vessel characteristic.

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Often, the method includes a step of sending an alert when a verification mismatch occurs.

In the following description, details are provided to describe the embodiments of the application. It shall be apparent to one skilled in the art, however, that the embodiments may be practised without such details.

Figs. below have similar parts. The similar parts have the same names or similar part numbers. The description of the similar parts is hereby incorporated by reference, where appropriate, thereby reducing repetition of text without limiting the disclosure.

Fig. 1 illustrates an improved AIS system,
Fig. 2 illustrates an observation platform of the AIS system of Fig. 1, and
Fig. 3 illustrates an AIS verification flow chart.

Fig. 1 shows an improved AIS system 10. The AIS system 10 includes a vessel or ship 12, which is at sea and which is at a distance from a mobile seaborne observer 14, a mobile airborne/space-borne observer 15, and a static observer 16.

The static observer 16 is on land. In addition, an AIS enabled relay entity 18 is also in the sky whilst a central coordination entity 19 is on the land.

The vessel 12 has AIS message links 13 with the seaborne observer 14, the relay entity 18, and the static observer 16. The seaborne observer 14 has AIS communication links 21 with the relay entity 18, the vessel 12, and the static observer
5 16.

Functionally, the vessel 12 serves as an observed vessel. The static observer 16 serves a ground-based station. The ground-based station, the vessel 12, and the airborne/space-borne
10 observer 15 serve as observation platforms. The airborne/space-borne observer 15 can include an aircraft or a satellite. The relay entity 18 can also include a satellite.

In practice, the vessel 12 has an AIS transceiver that uses
15 the message links 13 to provide AIS messages or data to the seaborne observer 14, the relay entity 18, and the static observer 16. The AIS messages include navigation status, longitude, latitude, speed, heading, type, and dimensions of the vessel 12.

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The vessel AIS messages are used by other vessels for avoiding collision and by vessel traffic services for identifying and locating vessels. The identification is used for establishing identity of vessels, which can pose a possible security threat to other ships, to man-made installations, to environment and to society.
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Such vessel AIS messages may be not reliable. A vessel threatening security may manipulate its AIS messages to present a false identity. Two different manipulations of the
30 vessels AIS messages are possible. Firstly, its dynamic data, such as speed and direction, can be modified and, secondly, its static ship data, which can include size and owner infor-

mation, can be changed. The latter data can be protected from changing by using un-erasable AIS device programming through trusted authorities. However, this can be overcome using uncertified AIS transceivers that permit unrestricted AIS
5 transceiver changes. As one example, a freight ship loaded with dangerous goods can use a pleasure craft AIS message to present a false identity. Alternatively, it can manipulate its speed information to show that it is slowing down, while it is in fact progressing at full speed. The verification of
10 the AIS message is thus rather important and crucial.

The static observer 16, the seaborne vessel 14, or the airborne/space-borne observer 15 can receive the AIS messages of the vessel 12. They also act as observation platforms for
15 making an objective observation of the vessel 12. The observation can include optical, infrared, sonar, or radar image data. The observation platforms are also intended for verifying autonomously, within their own system parameters, the received vessel AIS message using the objective observation.

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The seaborne observer 14 can issue an observation request 23 of the vessel 12 to the airborne/space-borne observer 15 or the static observer 16 to initiate the verification. Alternatively, the central coordination entity 19 can initiate the
25 verification by issuing an observation request 23 of the vessel 12 to the static observer 16, or to the airborne/space-borne observer 15. The static observer 16 can also initiate the verification by issuing an observation request 23 of the vessel 12 to the airborne observer/space-borne 15.

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The relay entity 18 acts to receive AIS messages from the seaborne observer 14 and from the vessel 12 as well as to

transmit the received data to the airborne observer/space-borne 15.

Fig. 2 shows an AIS authentication device 30 for an observation platform of the AIS system 10 of Fig. 1.

The authentication device 30 includes a processing unit 32 that is connected to a memory unit 34, to a remote sensing device 36, to an AIS receiver 37, and to a communication port 10 38.

Functionally, the remote sensing device 36 is used for observing or sensing of an AIS vessel or ship from a distance or a remote place. The remote sensing device 36 is not in direct contact with the observed vessel and it outputs image 15 data for the memory unit 34. The AIS receiver 37 is used for receiving AIS messages of the observed vessel and for sending the received AIS messages to the memory unit 34.

20 The memory unit 34 is used for storing the image data that are produced by the remote sensing device 36 and the AIS messages that are received by the AIS receiver 37. The processing unit 32 uses a program to verify authenticity of the stored AIS messages using the stored image data. The processing unit 32 is also intended for triggering an alarm when 25 the verification produces a mismatch and for sending the alarm via the communication port 38 to another entity for further action.

30 In summary, the embodiment provides an objective verification of the vessel AIS message or signature by means of remote sensing data. The embodiment comprises stationary as well as

mobile entities that can be integrated in an AIS framework without interfering with existing AIS transceivers.

One method of verifying an authenticity of the vessel AIS message is described below. The method includes a step of extracting a characteristic of the observed vessel 12 from the objective observation. The AIS message is verified using the extracted characteristic. The verification is performed by one of the observation platforms 14, 15, and 16 or is performed jointly with between observation platforms 14, 15, and 16. Verification mismatches, which can refer to inconsistencies or anomalies, are then raised as alarms and are communicated to the central entity 19 for further verification or action.

The authenticity of the vessel AIS message is verified remotely, which provides an advantage of increasing a size of a safety zone around protected installations. The safety zone can extend beyond the Very High Frequency (VHF) communication range of the vessel AIS. The verification can also be performed earlier.

Existing AIS systems do not need to be changed to implement this embodiment, which would facilitate acceptance and implementation of the embodiment. Moreover, the AIS messages are received by the observation platforms or observing entities without changing existing AIS transceivers or installation. In other words, the existing AIS transceivers remain intact without operational changes. The present wide utilization of AIS system in the maritime shipping industry would result in an immediate operation of the embodiment.

Fig. 3 shows an AIS verification flow chart 45.

The flow chart 45 includes a step 47 of an AIS receiver receiving AIS messages from a vessel. The AIS messages are then extracted, as shown in a step 47.

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A remote sensing device provides observations in a step 50. The image geo-references or extracted characteristics are then produced from the observations, as shown in a step 52.

10 The extracted AIS messages are compared with the extracted characteristics to verify location of the vessel, as shown in a step 54. Similarly, the extracted AIS messages are compared with the extracted characteristics to verify vessel feature, such as vessel size and dimensions, as shown in a step 56.

15 The extracted AIS messages are compared with the extracted characteristics to determine vessel characteristics, such as vessel speed, as shown in a step 58. The extracted AIS messages are compared with the extracted characteristics to determine vessel type, as shown in a step 60.

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When a comparison mismatch occurs, an alert is generated, as shown in a step 62.

25 An example of location verification using single and Polarimetric Synthetic Aperture Radar is described below.

Ship detection involves four main steps: 1) land masking, 2) pre-processing, 3) pre-screening, and 4) discrimination. The first step is to mask out land areas since only ships in the water area are of interest. Moreover, this can help to reduce false detections caused by land cover features. In the second step, image enhancement is carried out, which is optional provided that a constant false alarm rate detector is em-

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ployed for the subsequent pre-screening. Then the pre-screening step locates potential ship pixels in the masked input image. The final step, i.e. discrimination, is to reduce the false alarm rate. For example, the observation of a ship wake can be employed to confirm the presence of a moving ship target.

In polarimetric SAR (POLSAR) data, each pixel includes a 3x3 Hermitian polarimetric covariance matrix [cf. J.-S. Lee and E. Pottier, *Polarimetric Radar Imaging: From Basics to Applications*, CRC Press, Boca Raton, 2009, page. 146]:

$$\mathbf{C} = \begin{bmatrix} \langle |S_{HH}|^2 \rangle & \langle \sqrt{2} S_{HH} S_{HV}^* \rangle & \langle S_{HH} S_{VV}^* \rangle \\ \langle \sqrt{2} S_{HV} S_{HH}^* \rangle & \langle 2 |S_{HV}|^2 \rangle & \langle \sqrt{2} S_{HV} S_{VV}^* \rangle \\ \langle S_{VV} S_{HH}^* \rangle & \langle \sqrt{2} S_{VV} S_{HV}^* \rangle & \langle |S_{VV}|^2 \rangle \end{bmatrix}, \quad (1)$$

where S_{rt} denotes to the scattering element of the received polarisation r and transmitted polarisation t . The subscripts H and V represent horizontal and vertical polarizations, respectively. The matrix elements in the diagonal (also known as variances) are the intensities of different polarizations, namely HH, HV, and VV. The intensity is related to the radar cross section σ_{rt} of a distributed target by $\langle \sigma_{rt} \rangle = 4\pi \langle |S_{rt}|^2 \rangle$. The phase differences, which provide the information about the propagation delays in the electric path caused by the illuminated scatterers with respect to different polarizations, are embedded in the off-diagonal elements.

The Hermitian matrix $\mathbf{A} = \mathbf{LC}$ is shown to follow a p -variate ($p = 3$) central complex Wishart distribution for a homogeneous area, where L refers to the number of looks in POLSAR data [cf. J.-S. Lee and E. Pottier, *Polarimetric Radar Imaging:*

From Basics to Applications, CRC Press, Boca Raton, 2009].
The probability density function (pdf) of $\mathbf{A}$ ($L \geq p$) is given as

$$p(\mathbf{A}) = \frac{|\mathbf{A}|^{L-p}}{\Gamma_p(L)|\Sigma|^L} \exp\{-\text{tr}(\Sigma^{-1}\mathbf{A})\} \quad (2)$$

- 5 The operator tr refers to the matrix trace. The complex multivariate gamma function $\Gamma_p(L)$ is defined in [A. T. James, "Distributions of matrix variates and latent roots derived from normal samples," Ann. Math. Statist., volume 35, no. 2, Jun. 1964, page 487] as

$$\Gamma_p(L) = \pi^{p(p-1)/2} \prod_{i=1}^p \Gamma(L-i+1). \quad (3)$$

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To detect ship targets in C- and L-band single-polarization intensity data, a direct statistical modelling of ship targets is ideally preferred. However, the modelling is difficult since ship targets are relatively rare. Thus, sea clutter is chosen instead of ship targets in order to describe the opposite. The corresponding histograms are then constructed individually for the intensity component of different polarizations and are fitted separately with the gamma and lognormal distributions. The pdf of the gamma distribution is given as

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$$f(x) = \frac{1}{\theta^\beta \Gamma(\beta)} x^{\beta-1} \exp\left(-\frac{x}{\theta}\right), \quad (4)$$

where x is the random intensity value and $\Gamma(\cdot)$ denotes the gamma function. The scale parameter α and shape parameter β

are estimated by using all the pixels in the selected training area.

The pdf of the lognormal distribution can be expressed as

$$g(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left\{-\frac{(\log x - \mu)^2}{2\sigma^2}\right\}. \quad (5)$$

5 The parameters μ and σ are the mean and standard deviation of the intensity's natural logarithm, which are also estimated by using all the pixels in the training area. From the evaluation, it can be seen that the gamma distribution is found to be better fitted for sea clutter compared with the lognormal
10 distribution.

In order to detect potential ship targets from the C- and L-band fully polarimetric SAR data, a constant false-alarm rate detector is introduced based on Wilks' lambda, i.e.

$$\Lambda = |\mathbf{X}|/|\mathbf{X} + \mathbf{Y}|. \quad (6)$$

15

Both random matrices $\mathbf{X}$ and $\mathbf{Y}$ have independent p -variate central complex Wishart distributions $CW_p(n, \Sigma)$ and $CW_p(q, \Sigma)$. The number of degrees of freedom (or the number of looks) for $\mathbf{X}$ and $\mathbf{Y}$ are denoted separately by n and q . Andersen *et al*
20 [cf. H.H. Andersen, M. Højbjerg, D. Sørensen, and P.S. Eriksen, Linear and Graphical Models for the Multivariate Complex Normal Distribution, Springer-Verlag, New York, 1995, page 61] showed that the Wilks' lambda distribution is a distribution of a product of p independent beta-distributed random
25 variables. Since $p = 3$ for polarimetric data (assuming $HV \cong VH$), the Wilks' lambda is distributed as the product of

three independent beta-distributed random variables B_1 , B_2 and B_3 with $\text{beta}(n - 2, q)$, $\text{beta}(n - 1, q)$ and $\text{beta}(n, q)$, respectively. The pdf of the product $w = B_1 B_2 B_3$ can be obtained based on theorem 4.4.1 in [M. D. Springer, The Algebra of

5 Random Variables, John Wiley, New York, 1979, pages 105–107], which is derived through the Mellin integral transform. Following the method of derivation proposed by Schatzoff [M. Schatzoff, "Exact distributions of Wilks's likelihood ratio criterion," Biometrika, volume 53, no. 3/4, pages 347–358,

10 Dec. 1966], Gupta [A. K. Gupta, "Distribution on Wilks' likelihood-ratio criterion in the complex case," Ann. Inst. Stat. Math., volume 23, no. 1, 1971, pages 80–81] gave the exact pdf and cumulative density function of the Wilks' lambda for $p = 3$. The asymptotic distribution of the Wilks' lambda is

15 shown by Khatri [C. G. Khatri, "Classical statistical analysis based on a certain multivariate complex Gaussian distribution," Ann. Math. Statist., volume 36, no. 1, Feb. 1965, pages 109–110] as

$$\Pr(-m \log \Lambda \leq T) = \Pr(\chi_{2pq}^2 \leq T) + \frac{r}{m^2} [\Pr(\chi_{2pq+4}^2 \leq T) - \Pr(\chi_{2pq}^2 \leq T)] + O(m^{-3})$$

(7)

20 where $m = 2n + p - q$ and $r = pq(p + q^2 - 2)/3$. For large values of n and with the first approximation, $-m \log \Lambda$ is distributed asymptotically as χ^2 with $2pq$ degrees of freedom.

For detecting potential ship targets, the processing steps

25 are outlined below:

step 1)

Compute $\mathbf{X}$:

$$\mathbf{X} = \sum_{i=1}^N L \mathbf{C}_i, \quad (8)$$

where $\mathbf{C}_i$ refers to the covariance matrix of a pixel i in the identified training region of sea clutter. The variable N denotes the total number of pixels in the training region.

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step 2)

Compute $\mathbf{Y} = L \mathbf{C}_j$, where $\mathbf{C}_j$ represents the covariance matrix of a test pixel j .

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step 3)

Compute $-m \log \Lambda$, where Λ is given in (6).

15 step 4)

Mark the test pixel j as a ship pixel if the following criterion is fulfilled:

$$-m \log \Lambda > T_\alpha. \quad (9)$$

20 The critical value T is obtained from the chi-squared distribution with a desired significance level α . Note that $n = NL$ and $q = L$ in this test.

step 5)

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Move to next test pixel and repeat Steps 2-4. Terminate the execution if there are no more test pixels to be processed.

REFERENCE NUMBER

	10	improved AIS system
	12	vessel
5	13	message link
	14	seaborne observer
	15	airborne/space-borne observer
	16	static observer
	18	AIS enabled relay entity
10	19	central coordination entity
	21	communication link
	23	observation request
	30	AIS authentication device
	32	processing unit
15	34	memory unit
	36	remote sensing device
	37	AIS receiver
	38	communication port
	45	flow chart
20	47	step
	49	step
	50	step
	52	step
	54	step
25	56	step
	58	step
	60	step
	62	step

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CLAIMS

1. An Automatic Identification System (AIS) data verification device comprising
 - 5 a remote sensing device for producing observation information of a vessel,
 - an AIS receiver for receiving AIS data of the vessel,
 - a processing unit for verifying the vessel AIS data using the vessel observation information, and
 - 10 a communication port for sending an alert about the AIS data when an authentication mismatch occurs,
 - wherein the remote sensing device comprises radar means for producing at least one radar image of the vessel,
 - 15 the radar image is provided for deriving data of the vessel.
2. The Automatic Identification System (AIS) data verification device according to claim 1, wherein
 - 20 the remote sensing device comprises an optical sensor for at least one optical image producing observation information of a vessel.
3. The Automatic Identification System (AIS) data verification device according to claim 1, wherein
 - 25 the remote sensing device comprises a sonar sensor for producing at least one sonar image of the vessel.
4. The Automatic Identification System (AIS) data verification device according to claim 1, wherein
 - 30 the remote sensing device comprises an infrared sensor for producing at least one infrared image of the vessel.

5. A remote sensing platform comprising
an Automatic Identification System (AIS) data verification device according to one of claims 1 to 4.
- 5 6. The remote sensing platform according to claim 5, wherein
the remote sensing platform comprises a seaborne platform.
- 10 7. The remote sensing platform according to claim 5, wherein
the remote sensing platform comprises an airborne platform.
- 15 8. The remote sensing platform according to claim 5, wherein
the remote sensing platform comprises a static platform.