Preliminary Design of Imaging Microsatellite for Preventing Illegal Fishing in Indonesia

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Abstract. A constellation of imaging microsatellite system using Synthetic Aperture Radar (SAR) and Automatic Identification System (AIS) has been developed to prevent illegal fishing in Indonesia. The constellation of microsatellite is shown to be able to cover the entire area of Indonesia during 24 hours duration. Each satellite is capable of taking pictures with minimum resolution of 3 meter per pixel and swath width of 28.55 km. AIS equipped in each satellite will collect data of the ships operating on sea area of Indonesia. The information about the ships collected by AIS will then be compared to the picture captured by SAR to determine if the ships are fishing illegally or not. To support the mission, each satellite is equipped with sun sensors, earth sensors, and GPS to precisely determine its attitude and position. In addition, each satellite also equipped with Control Moment Gyros (CMGs) capable of precision pointing and high slew rate maneuver with low power consumption. The payload communication of the satellite will use VHF and X-band while the TT&C will use S-band. Furthermore, each satellite requires a total of 838 W to operate which correspond to 6 m² of solar panel and 8.8 kg and 590 Wh of batteries. Finally, it is concluded that each satellite has 95 kg of total mass and costs around $5.4 million to develop.

1. Introduction
Indonesia is the biggest island country in the world with great maritime potential especially fisheries. Because of this maritime potential, Indonesia also susceptible to illegal fishing. According to the Ministry of Maritime Affairs and Fisheries (KKP), Indonesia’s losses as a result of illegal fishing reach Rp. 300 trillion per year [1]. Moreover, there is also deficit from fuel subsidy, as the perpetrator of illegal fishing possibly uses the fuel subsidy [1]. KKP estimated that the deficit from fuel subsidy reaches Rp.7 trillion [1]. Therefore, it is necessary to improve the surveillance in maritime sector to reduce or possibly prevent further loss from illegal fishing as improving the security of maritime sector may potentially increases national income.

Since 2014, KKP collaborated with BAKAMLA (Maritime Security Agency), Indonesian Marine, Ministry of Finance, Ministry of Law, as well as local authority to conduct security and safety patrols in Indonesia’s sea area and Indonesia’s jurisdiction. Furthermore, KKP also used VMS technology (Vessel Monitoring System) installed on ships with minimum gross tonnage of 30. This VMS technology is integrated with satellite radar, coastal radar, air surveillance, and AIS (Automatic Identification System) to aid the surveillance in maritime sector [1]. Therefore, the use of satellites might
appear as an alternative solution for improving the security of maritime sector in Indonesia. Satellite’s position at an altitude of more than 500 km from the surface of the earth makes satellites capable of observing wider area makes it more advantageous than any other form of surveillance. The use of satellites to observe Indonesia’s sea area has long been developed. LAPAN collaborated with KKP ( Ministry of Maritime Affairs and Fisheries) to produce satellite that has the capability to observe a region and detect ships. In 2015, LAPAN launched a satellite LAPAN-A2 which implemented AIS instrument for maritime sector monitoring [2]. AIS was originally an instrument to prevent collisions between ships. The AIS system detects the identity, position, time and direction of the ships. In its use, AIS can be used to track foreign ships that are not registered on the database of permitted ships. The use of AIS in the world can arguably successful in detecting illegal fishing.

Then based on national capabilities, a micro satellite has been successfully developed, LAPAN-A3 / IPB, with a mass of 115 kg as a monitor of ship activities [3]. Furthermore, Indonesia has the capability in terms of financing for launching micro satellites to low earth orbit (LEO) with a height of between 200 km up to 2,000 km. Finally, there is a national program for satellite launch vehicle development which might possible for Indonesia to launch its own satellite in the future. This opens opportunities for Indonesia to develop satellites to improve security and prevent the occurrence of illegal fishing in the territory of Indonesia.

In this paper, we conducted the preliminary design of surveillance system using imaging microsatellite to prevent illegal fishing in Indonesia. The satellite will operate in a constellation and provides 24 hours coverage on Indonesia sea area and has 5 years of lifetime. The satellite will be called PN-136 Sat which stands for “Penjaga Nusantara”.

2. Design Requirements and Objectives (DRO)
The design process of PN-136 Sat is driven by the requirements and objectives which will determine the concept of operation, constellation and subsystems of the satellite. The objective of this design is to obtain a constellation of microsatellite for preventing illegal fishing in Indonesia sea area. For this purpose, the requirements of the constellation of microsatellites are then derived as

- The satellite must cover the entire territory of Indonesia during 24 hours duration with no blackout, as the illegal fishing may also happen at day and night
- The constellation of microsatellite is designed to able to perform the mission for 5 years
- The cost of the satellites must be kept within national capabilities; therefore, the size of each satellites must be restricted to the class of microsatellite with less than 100 kg of mass
- The satellite must be capable of detecting ship with minimum gross tonnage of 30
- The Bit Error Rate (BER) of each satellite must not exceed $10^{-5}$ while the data rate will be adjusted based on the concept of operation

3. Concept of Operation and Constellation Design
3.1 Concept of Operation
Preliminary design of satellite-based surveillance system starts with the study of concept of operation for the satellite constellation. As stated previously, the constellation of satellite must be designed to reduce or prevent illegal fishing in Indonesia territory. Therefore, the satellite will perform a surveillance mission above the territory of Indonesia and has the capability of detecting ship with minimum gross tonnage of 30. For this purpose, we designed the payload of the satellite consists of Automatic Identification System (AIS) and Synthetic Aperture Radar (SAR). Basically, AIS alone is actually enough for detecting ship, however it is not enough to determine which ship perform the illegal fishing. To complement AIS, another method must be added and, in this case, we choose imaging.

For this mission, AIS will be responsible for detecting ships operating in Indonesia territory and Imaging system will provide real-time image of the ships. The data from both of the system will be processed in ground station with close proximity to the region in which the image was taken to determine
which ship performs illegal fishing. Ground station will then notify local authority to perform on-site check to the ship suspected of illegal fishing. However, to be able to perform this mission, the imaging system must have the capabilities of detecting ship with minimum gross tonnage of 30 which estimated to be minimum 4 m of resolution, operating during daytime and nighttime as well as any weather condition. One of the choice that fulfill the requirements is SAR, therefore we choose SAR as a payload alongside AIS.

![Concept of operation of the microsatellite constellation](image)

**Figure 1.** Concept of operation of the microsatellite constellation

3.2 Satellite Constellation

The satellite constellation must be designed to fulfill the requirement of full Indonesia coverage in 24 hours duration therefore we restrict the altitude of each satellite at LEO orbit of 200-2000 km. Furthermore, as Indonesia located near the equator, we also choose the orbit of the satellite to be near-equatorial with low inclination for more frequent and longer access time. The design iterations for the constellation and orbital parameter of the satellites were performed in System Tool Kit (STK) software [4]. It is obtained that the optimum orbital parameter with highest coverage and access time to be 630 km of altitude and 9 degree of inclination. Furthermore, for 24 hours full coverage we set the total number of satellites within the constellation to be 12 satellites. Each satellite then divided into 4 group in 4 orbital planes, each group will consist of 3 satellites (see table 1). Each group or orbital planes were separated by Right Ascension of Ascending Node (RAAN) difference of 90 degrees, and each satellite in the group was also separated by true anomaly difference of 120 degrees. This constellation is called walker-star and by using this constellation, the satellites will be able to provide full coverage in Indonesia territory and have 14 access a day as shown in figure 3.

**Table 1.** Satellite’s orbit parameter.

| Parameter                      | Group 1 | Group 2 | Group 3 | Group 4 |
|-------------------------------|---------|---------|---------|---------|
| Altitude (km)                 | 630     | 630     | 630     | 630     |
| Inclination (deg)             | 9       | 9       | 9       | 9       |
| RAAN (deg)                    | 0       | 45      | 90      | 135     |
| Number of Satellite           | 3       | 3       | 3       | 3       |
| True Anomaly Separation (deg) | 120     | 120     | 120     | 120     |
4. Subsystem Sizing and Analysis

4.1 Payload

4.1.1 Automatic Identification System (AIS)
As mentioned previously, for the purpose of preventing illegal fishing, each satellite will be equipped with AIS receiver. Basically, AIS is automatic tracking system equipped on ship to view marine traffic and prevent collision but in 2008, the application of AIS in satellite has been experimented [5]. The first satellite equipped with AIS was AIS-Sat 1 launched on 2010 [5]. Since then many space agency and company have launched AIS equipped satellite for maritime security application such as AprizeSat-3 and 4 [6].
During its operation, AIS use Self-Organized Time-Division Multiple Access (SOTDMA) which uses time slot. Each time slot consists of data package containing static and dynamic information, mission of the ship and short message about safety (weather condition or navigation). However, as the mission of the satellite is specified to only prevent illegal fishing in Indonesia thus only relevant information will be received or processed by the AIS on each satellite. In this case the AIS on each satellite will only receive and process the data package regarding static and dynamic information of ships. The static and dynamic information will be used to obtain the position of the ships and then the obtained information will be compared to image data from SAR in ground station. For PN-136 Sat, we choose AIS receiver STS-200 [7] developed by SpaceQuest which consists of 6 channels and operates in VHF. STS-200 AIS needs 1.5 W of power to operate with about 1.04 kg of mass.

4.1.2 Synthetic Aperture Radar (SAR)

Synthetic Aperture Radar (SAR) a type of radar that uses radio waves to create an image of the area. PN-136 Sat uses SAR as one of the payloads along with AIS as a surveillance system for preventing illegal fishing. SAR will take successive image of Indonesia sea area during operation and then the images will be sent to ground station. The ground station will compare the images taken from SAR with data received from AIS to determine which ship is suspected of illegal fishing. One way to determine illegal fishing is if the image from SAR confirms the presence of ship but the data received from AIS shows no ship in the corresponding area. This information will be forwarded to nearby authority or marine for further action. However, the use of SAR for microsatellite application is still new, one of the SAR satellites already in orbit is ICEYE-X1 with resolution of 10 m and the other which is still under development in Japan, MicroXSAR, SAR [8]. MicroXSAR is designed to be able to take images with minimum resolution of 3m. Moreover, the mission of PN-136 Sat requires each satellite to be able to take images of the ship with 30 of gross tonnage which estimated to correspond with minimum 4 m of resolution. Therefore, as the SAR technology for microsatellite that fulfill the mission requirement is not available on the market thus, for the preliminary design for PN-136 Sat, we choose the SAR from MicroXSAR as it fulfills the minimum resolution of 4 m. Based on MicroXSAR specification [8], the SAR will have minimum resolution of 3 m with swath width of 28.55 km. The SAR will have span of 4.6 m with 7 kg of weight and will consume about 600 W of power.

4.2 Communication

The communication subsystem for PN-136 Sat is designed for 3 purposes, AIS communication, Telemetry Tracking and Command (TT&C) and SAR image downlink to ground station. To fulfill these purposes, the communication subsystem is designed in 3 different frequency range. For AIS communication, VHF will be used as the AIS receiver also operates in VHF frequency. For SAR image downlink however require higher data rate as the image size is about 135.9 MB, which quite big. Therefore, we decided to use higher frequency, X-band, to send images data to ground station. Lastly, for TT&C we decided to use S-band as the regulation from International Telecommunication Union (ITU) specified that S-band is the frequency range used for communication from ground station to satellite and between satellite. This frequency range is also used by other satellites with similar mission as PN-136 Sat. The communication subsystem in PN-136 Sat is designed using store and forward architecture [9]. This architecture is chosen as the satellite in LEO moves at high velocity relative to ground therefore the ground station only has 5-7 minutes of access to the satellite [9].

For the antenna system, based on the requirements, PN-136 Sat needs 4 antenna for each satellite, 2 antennas for AIS data downlink in VHF frequency range, 1 antenna for TT&C in S-band and 1 antenna for SAR images downlink in X-band. Moreover, because the frequency range of each antenna is different then, the types of the antenna will be different as well. For AIS antenna, monopole antenna will be used. The antenna will be tuned to the available frequency on STS-200 AIS receiver in this case we choose the frequency of 161.975 MHz and 162.025 MHz. For the TT&C, patch antenna will be used.
as it has compact size and does not require a lot of space. Based on ITU regulation, patch antenna will operate at 2540 MHz of frequency. Lastly for SAR images downlink, parabolic antenna will be used. The preliminary calculation for antenna sizing to fulfill the design requirement is shown in table 2

| Antenna Type | Frequency (MHz) | Power (W) | Mass (m) | Dimension (mm) | Function          |
|--------------|----------------|-----------|----------|----------------|------------------|
| Monopole     | 161.975        | 2         | 0.4      | -              | 463 8.3          |
|              | Monopole       | 162.025   | 2        | -              | 462.9 8.3        |
| Patch        | 2540           | 4         | 0.251    | 31.96 63.02    | 25.44 -          |
| Parabolic    | 8000           | 46        | 0.275    | -              | 23 44 SAR        |

**Figure 5.** Monopole antenna (left) and patch antenna (right). [10, 11]

**Table 2.** Antenna specification of PN-136 Sat.

4.3 Attitude Determination and Control System (ADCS)

The Attitude Determination and Control System (ADCS) is designed to be able to provide attitude and position estimation of each satellite as well as performing 3 axis maneuvers with high precision. Attitude and position estimation were provided using sun sensor, earth sensor, magnetometer and GPS while the attitude maneuver will be performed using momentum-based actuator. Basically, during its mission, each satellite will perform 3 pointing mode. The first one is detumbling which is the process to stabilize the spacecraft by removing the tumbling or reducing the angular rate of spacecraft to zero. This mode will be performed after launch phase and remove the tumbling during orbit insertion. The second mode is sun pointing which has the purpose of pointing the spacecraft towards the sun. This mode is usually performed for energy harvesting where the solar panel will be arranged orthogonally to the sun. Lastly, the third mode is nadir pointing or earth pointing which points the satellite towards nadir or earth surface. This mode is performed when each satellite passes Indonesia territory where the SAR will be pointed towards nadir or in this case Indonesia territory to take images of the sea area.

**Figure 6.** Sun sensor (left), Earth sensor (middle), and GPS receiver (right). [12, 13, 14]
Each satellite will be equipped with 2 sensors mounted orthogonally to provide accurate position of the sun for sun pointing purpose while earth sensor will also be used to estimate nadir vector for nadir pointing. The GPS receiver will be used to perform initial orbit determination as well as providing information about the position of each satellite. Furthermore, the position of each satellite can be used to obtain accurate timing for antenna deployment or attitude maneuver.

![ISIS Magnetometer and magnetorquer](image1)

**Figure 7.** ISIS Magnetometer and magnetorquer. [15]

Attitude maneuver will be performed using Single-Gimbal Control Moment Gyro (SGCMG) with the capability of generating high amount of torque with relatively low power [16]. Steering algorithm will also be implemented to overcome singularity problem that might be encountered during attitude maneuver [17]. SGCMGs used in PN-136 Sat are the CMG developed by Honeybee robotics as it is the only CMG available for microsatellite applications. These CMGs are capable of generating maximum of 0.1 Nm torque with 2W of power and 0.6 kg of mass each. For this preliminary design, four CMGs arranged in pyramid configuration will be used as it provides equal torque authority in 3 axis [16]. Furthermore, magnetorquer will also be used mostly for desaturation of CMG momentum.

![Honeybee robotics CMG](image2)

**Figure 8.** Honeybee robotics CMG. [18]
4.4 Electrical Power System

![Figure 9](image)

**Figure 9.** Power system architecture during daylight (left) and eclipse (right).

**Table 3.** Power budget of PN-136 Sat.

| No | Subsystems  | Components          | Power (W) |
|----|-------------|---------------------|-----------|
| 1  | Payload     | On-Board Computer   | 10        |
|    |             | SAR                 | 600       |
|    |             | AIS                 | 3         |
| 2  | Telecommunication | S-Band Antenna(s)  | 4         |
|    |             | X-Band Antenna      | 46        |
|    |             | AIS Antenna(s)      | 1         |
|    |             | S-Band Transceiver  | 5         |
|    |             | X-Band Transceiver  | 10        |
| 3  | ADCS        | CMGs                | 10        |
|    |             | Magnetorquer and Earth Sensor | 1.5 |
|    |             | GPS Receiver        | 7         |
|    |             | Sun Sensor          | 0.5       |
|    |             | Actuators           | 40        |
| 4  | Power       | Battery Charger     | 100       |
|    |             | **TOTAL**           | **838**   |

Electrical Power System of PN-136 Sat is designed by considering the power budget and mission of the satellite. Based preliminary calculation of each subsystem power consumption (see table 3), each satellite is estimated to require at most about 838W of power to operate and perform its mission. Based on this information, we decided that PN-136 Sat will use parallel power system architecture (see figure). The spacecraft was designed to generate power through retractable solar panel SP-X developed by SpaceQuest with efficiency of 18-29.5% and able to generate 1.2 W/cell with mass of 10g/cell (see figure 10) with a total area of 6 m². The solar panel will be mounted on linear actuator with the capability to be arranged towards optimal angle to the sun.
Furthermore, to support satellite during eclipse where no power can be generated through solar panel, battery will be used. The battery is estimated to be able to supply 738W of power so that the satellite could operate and perform its mission independently without power generated from solar panel during eclipse. To fulfill this requirement, each satellite will be equipped with lithium polymer battery from Space Vector (see figure 11) with power density of 134.1 Wh/kg and capacity of 590 Wh. we decided to use 2 group of this battery total mass of 8.8 kg.

![Space Vector Li-Po battery](image)

**Figure 11.** Space Vector Li-Po battery. [20]

### 4.5 Structure

The structure of PN-136 was designed based on the mass budget of the satellite (see table 4) as well as the load during launch phase. The structure of PN-136 satellite needs to be designed so that the total mass of each satellite does not exceed 100 kg and able to endure the load and vibration from launch phase estimated to be maximum of 9G. Therefore, to fulfill the requirements PN-136 Sat structure will consist mainly of standard aerospace aluminum. Figure 12 show the external layout of the satellite during launch and after the solar panel and SAR have been deployed. Figure 13 show the internal layout of PN-136 Sat as well as the subsystems of the satellite.
Table 4. Mass budget of PN-136 Sat.

| No | Subsystems | Components          | Mass (kg) |
|----|------------|---------------------|-----------|
| 1  | Payload    | On-Board Computer   | 2         |
|    |            | SAR                 | 7         |
|    |            | AIS                 | 2.08      |
| 2  | Telecommunication | S-Band Antenna(s)   | 0.251     |
|    |            | X-Band Antenna      | 0.275     |
|    |            | AIS Antenna(s)      | 0.4       |
|    |            | S-Band Transceiver  | 0.75      |
|    |            | X-Band Transceiver  | 0.75      |
| 3  | ADCS       | CMGs                | 3.1       |
|    |            | Magnetometer and Magnetorquer | 0.196 |
|    |            | Sun Sensor          | 0.75      |
|    |            | Linear Actuators    | 8.352     |
|    |            | GPS Receiver        | 1.2       |
|    |            | Earth Sensor        | 0.066     |
| 4  | Power      | Batteries           | 8.8       |
|    |            | Power Control Unit  | 4         |
|    |            | Solar Cell          | 6.6       |
| 5  | Structure  | Structure           | 48.57     |
|    | TOTAL      | TOTAL               | 95        |

Figure 12. External layout of PN-136 Sat retracted (left) and deployed (right).

Figure 13. Internal layout of PN-136 Sat.

Furthermore, to evaluate if the structure is able to endure load during launch as well as the vibration, we perform structural analysis using finite element method. During launch, it is estimated that the
maximum load applied to satellite is from launch acceleration which is around 9G. Moreover, the natural frequency of the satellite needs to be higher than the vibration during launch. Table 5 shows the lateral and longitudinal vibration for several launch vehicles. Based on the vibration data, if we assume worst case scenario, then the satellite needs to have natural frequency higher than 90 Hz. In addition, for the FEM analysis, we simplify the structure of PN-136 Sat for faster running time (see figure 14).

Table 5. Vibration frequency for various launch vehicles. [21]

| Vehicle  | Lateral Axis | Longitudinal Axis |
|----------|--------------|-------------------|
| Vega     | ≥ 15 Hz      | 20 Hz ≤ F ≤ 45 Hz |
| Soyuz    | ≥ 15 Hz      | ≥ 35 Hz           |
| Dnepr    | ≥ 10 Hz      | ≥ 20 Hz           |
| Ariane 5 | ≥ 90 Hz      | ≥ 45 Hz           |
| PSLV     | ≥ 90 Hz      | ≥ 45 Hz           |

Table 6 shows the natural frequency of PN-136 Sat, it can be seen in the table 6 that the vibration modes of PN-136 Sat are higher than the requirement of 90 Hz. Therefore, the designed structure fulfills the requirement in term of vibration mode or natural frequency. Moreover, for the structural analysis of PN-136 Sat during launch, it can be seen in figure 14 that the maximum stress applied to the structure of PN-136 Sat is 23.2 MPa which corresponds to load caused by 9G acceleration. This maximum load is still lower than the yield strength of Aluminum which is 270 MPa, therefore the structure will not fail during launch. In conclusion, based on the results obtained from finite element method, the structure of PN-136 Sat has fulfilled the vibration requirement as well as capable of withstanding load during launch.
Table 6. Natural frequency of PN-136 Sat’s structure.

| Vibration Mode | Frequency (Hz) |
|----------------|---------------|
| 1              | 110.44        |
| 2              | 115.12        |
| 3              | 125.73        |
| 4              | 126.80        |
| 5              | 130.14        |
| 6              | 133.45        |

Figure 15. Finite element analysis result of PN-136 structure.

5. Conclusion and Future Works

The new satellite-based surveillance system for preventing illegal fishing in Indonesia has been designed at preliminary stage that met the design requirements & objectives which estimated cost is around $5.4M. PN-136 Sat operates in a constellation of 12 satellites and placed in near equatorial Low Earth Orbit (LEO) with 630 km of altitude. PN-136 Sat is capable of operating for 5 years and provides 24 hours of coverage in Indonesia. Each satellite is equipped with Automatic Identification System for ship monitoring in Indonesia and Synthetic Aperture Radar for sea area surveillance. The information from AIS will be compared to images taken by SAR to determine which ship is suspected of illegal fishing. Figure 15 shows the illustration of PN-136 Sat while table 7 shows the specification.

Figure 16. PN-136 Sat illustration.
Table 7. PN-136 Sat specification.

| PN-136 Sat       |                                      |
|------------------|--------------------------------------|
| Satellite dimension | 70 x 40 x 72 cm                      |
| Total Mass        | 95 kg                                |
| Peak power consumption | 838 Watt                           |
| Lifetime          | 5 years                              |
| Unit cost         | $5.4 M                               |
| Payload           | AIS and SAR                          |
| Payload Frequency | VHF and X-band                       |
| TT&C Frequency    | S-band                               |
| Solar Panel       | 6 m$^2$ of Retractable Solar Panel   |
| Battery           | 590 Wh Lithium Polymer               |

For future works, this preliminary calculation and data could be used for more detailed analysis in the next stage. Furthermore, market study should be conducted to investigate potential alternative imaging system other than SAR with the same capability because the microsatellite compatible SAR still under development and not yet available on the market. Moreover, using other imaging system could potentially reduce the power consumption as well as the mass of the satellite which ultimately leads to further cost reduction. Lastly, the structural optimization should be conducted in term of geometry or using alternative material for further weight and cost reduction.

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