VOL 3, NO.1 (2023) 34-47
https://jagst.utm.my

JAGST
Journal of Advanced Geospatial Science & Technology

Small Remote Sensing Satellites of Malaysia: Past Experience and Future Directions

Kasturi Devi Kanniah[1,2*] and Ng Su Wai[3]
[1]Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
[2]Centre for Environmental Sustainability and Water Security (IPASA), Research Institute for Sustainable Environment (RISE), Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
[3]National Space Agency (ANGKASA), 42700 Banting, Selangor, Malaysia
*Email: kasturi@utm.my

***Abstract* -** Small remote sensing satellites offer cost-effective ways to monitor and map the Earth. The low cost involved in developing and launching small satellites allowed developing countries like Malaysia to own small satellites. Malaysia launched two small satellites (TiungSAT-1 and RazakSATTM) in 2000 and 2009, respectively. The satellites captured several hundred scenes before their operation ended unexpectedly due to electrical power problems and onboard computer malfunction. The government undertook various efforts to rectify the technical issues related to the remote sensing digital data and explore the potential applications of the datasets. However, no synthesis documents are available on the potential applications of the data by considering the satellites' launch and image acquisition capabilities. A review of the small satellites' technical competencies and possible applications is critical in designing future satellites. This review article aims to synthesize available literature on the potential application of Malaysia's small satellites. The review results show that both satellites have a high potential for earth resources evaluation and planning. However, the coarse spatial resolution and limited spectral bands of TiungSAT may have limited applications. RazakSAT™ data, on the other hand, are proven helpful in land use and utility planning in cities. Unfortunately, the multi-temporal data of RazakSAT™ were not processed to study environmental disasters such as floods or landslides in cities. Like TiungSAT-1, RazakSAT™ images have only four spectral bands that may limit their application for land cover classification and vegetation studies. Nevertheless, no successor satellites have been launched yet to overcome the technical and application issues found in TiungSAT-1 and RazakSAT satellites. The recently initiated public-private partnership in developing the space sector in Malaysia is expected to produce and launch more remote-sensing microsatellites in the near future.

Keywords - *Small satellites, TiungSAT-1, RazakSAT™, Remote sensing, Malaysia*

Article History: Received 14 February 2023, Accepted 27 March 2023, Published 31 March 2023

How to cite: Kanniah, K. D. and Ng, S. W. (2023). Small Remote Sensing Satellites of Malaysia: Past Experience and Future Directions. Journal of Advanced Geospatial Science and Technology. 3(1), 34-47.

1. Introduction

Space has always been seen as the final frontier of human exploration, and countries embark on a satellite programme for various purposes. In the late 1980s, a new trend in the space industry began with the launch of small satellites. Small satellites weigh between 500 and 1000 kg (Sweeting et al., 2001; Kramer and Cracknell, 2008). From 1980 to 2000, a total of 487 mini- (100-500kg) and micro (10-100 kg) satellites were launched into space by various countries in Asia, including Malaysia, Europe and the Middle East (Xue et al., 2008). Microsatellites are cost-effective in monitoring the Earth and detecting any changes occurred compared to medium to high-orbit satellites. Consequently, developing countries like Malaysia can develop and launch their satellites. Malaysia initiated a small satellite development programme in 1995. Over the past three decades, two small satellites, namely TiungSAT-1 and RazakSAT™, were launched by Malaysia in 2000 and 2009, respectively.

An international workshop (International workshop of Earth observation small satellites for remote sensing applications- 20-23 November 2007 in Kuala Lumpur) and a user group seminar (Conference of Tiungsat-1 user group – 24 September 2002 in Cyberjaya) were organised in Malaysia to discuss various aspects ranging from technical issues to application of small satellites (Cracknell et al., 2013). Nevertheless, no review document is available to provide an overview of Malaysia's small satellites, issues pertinent to their launch and image acquisitions, and potential applications of the datasets. However, a general review article is available on small remote sensing satellites (Kramer et al., 2008). Such details are highly required for the future design and launch of microsatellites and user requirements for datasets generated by the satellites. This is highly needed as the government ventures into launching other remote-sensing satellites in the future. The objective of this review article is to identify and summarise the efforts by Malaysia in venturing into remote sensing satellites and their potential applications in natural resources management and disaster prevention efforts. The following section provides the general methodology adopted to produce this review article.

2. Methodology

The study is conducted mainly by reviewing the existing published materials covering journal articles, conference papers and books. Some materials, particularly the books, are not cited in the Scopus database. However, they contain a lot of important information for this review. The Scopus database was searched with "Tiungsat", "Razaksat", and "Satellites and Malaysia" keywords. A total of five publications were returned by the search on "Tiungsat", from which 4 were conference proceedings, and one was published in a journal. The search using the

"Razaksat" keyword, however, returned a total of 49 documents from which 30 publications were used in this study.

All the abstracts of the publications were first scanned through to identify if the journals were relevant to the review manuscript, and the relevant publications were selected to be reviewed. A content analysis was performed on the documents by formulating research questions such as:

(i) What are the application areas of the satellite sensors?
(ii) What are the technical issues related to the failure of the RazakSAT satellite?
(iii) How can the issues related to the satellites' failure be overcome in the future?

The following section provides a brief background on remote sensing development in Malaysia.

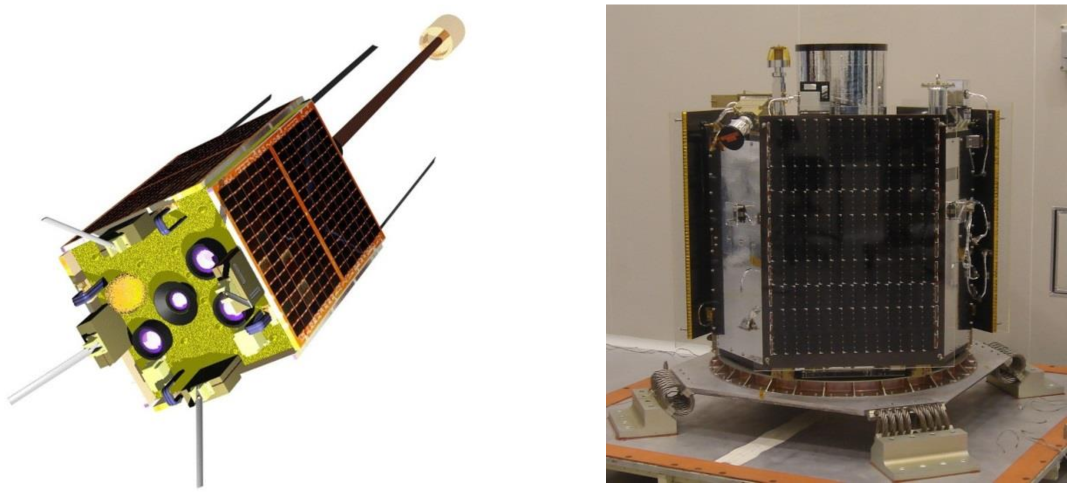
3. Remote Sensing in Malaysia

Remote sensing had a late start in Malaysia due to a lack of expertise, facilities and technology awareness. It had a notable start in Malaysia via the memorandum of understanding signed between the Australian government and the Ministry of Science, Technology and Environment, Malaysia, in 1985 (Kanniah et al., 2000). The Malaysian Centre for Remote Sensing (MACRES) was established in 1988 as part of the agreement and one of the components under the National Remote Sensing Committee at the Economic Planning Unit, Prime Minister Department. The establishment of MACRES promoted research in the field of remote sensing where in 2008, it was upgraded as Malaysian Remote Sensing Agency (a full government department) and led research and development in remote sensing and provided data services (standard and value-added) to the public (Othman, 2019). In 2019, the Malaysian Space Agency and the National Space Agency were merged to form the Malaysian Space Agency (MYSA), which aims to comprehensively develop and manage the Malaysian space sector (Othman, 2019).

The private sector's contribution is immense to the development of space technology in Malaysia. Astronautic Technology (M) Sdn Bhd (ATSB) was formed in 1996 to focus on the research, design and development of space systems (Arshad and Yusoff, 2014). ATSB has contributed to the development of space technology design (section 2.2), facilities to assemble and integrate spacecraft, electronic laboratories, and environmental test facilities (Arshad and Yusoff, 2014).

4. Small Satellites in Malaysia

Malaysia launched small satellites into space as early as 2000. First Malaysia's remote sensing satellite was a small satellite named TiungSAT-1. TiungSAT-1 was named after a small but chirpy bird, "Tiung" (common hill Myna), and the satellite weighs only about 50 kg. TiungSAT-1, as depicted in Figure 1(a), is a micro-class satellite. The satellite was jointly developed by Astronautic Technology (M) Sdn. Bhd. (ATSB), a wholly government-owned company by the government of Malaysia, and Surrey Satellite Technology Limited (SSTL), United Kingdom, through a technology transfer programme conducted by SSTL. This team of Malaysian and SSTL engineers spent nine months from June 1997 until March 1998 at SSTL to develop TiungSAT-1. In addition to observing the Earth, TiungSAT-1 was also aimed at the scientific Cosmic-Ray Energy Deposition Experiment (CEDEX) and simple communications applications (Mainura, 2019). Despite the fact that TiungSAT-1 carried multiple mission payloads on board for scientific research, the main objective of the satellite development programme was educational training. The goal of the technology transfer programme was to establish national capacity in building sophisticated microsatellites and minisatellites for various applications via academic education, short courses, technical lectures and technology training organised by SSTL (Sweeting et al., 2001). TiungSAT-1 was successfully launched into a 64^{o} inclined Low Earth Orbit at 650 km altitude on 26 September 2000. The main specifications of the TiungSAT-1 platform are listed in Table 1.



(a) (b)

Figure 1. (a) TiungSAT-1, and (b) RazakSAT™ (Images are courtesy of Malaysian Space Agency)

Table 1. Main Specifications of TiungSAT-1 and RazakSAT™ platform (Source: ATSB et al. 2001 and ATSB, 2006)

	TiungSAT-1	RazakSAT™
Satellite Mass	50 kg	~190 kg
Platform	35 kg	~150 kg
Payload	15 kg	42 kg
Dimension	690 x 360 x 360 mm (Height x Width x Depth)	1200 x 1200 mm (Diameter x Height)
Communication	Data rates from 9.6kbps to 76.8kbps at VHF/UHF frequency	- 9.6 kbit/s / 1.2 kbit/s S-band TT&C uplink - 38.4 kbit/s / 9.6 kbit/s / 1.2 kbit/s S-band TT&C downlink
Command & Data Handling	Primary on-board computer uses 386 processors, and the secondary uses 186 processors with controller area network (CAN) data bus	- Two on-board computers - Analog telemetry channels: up to 90 - Digital telemetry channels: up to 120
Attitude Determination & Control	Earth pointing $\leq 3^{o}$ using 6m boom gravity gradient stabilisation with a 3-axis magnetometer and 2-dimensional sun sensors	- 3-axis stabilisation based on 4 (reaction wheels) - Pointing Accuracy: $< 0.2^{o}$ (2σ) - Pointing Knowledge: 1 arcmin (2σ) - Attitude sensing: Course Sun Sensor, Fine Sun Sensor, Magnetometer, Star Sensors, Gyroscope
Electrical Power Supply	35W GaAs solar arrays to provide 50W peak and 20W orbit-average power, stored using 7Ah NiCd batteries.	- GaAs/Ge solar array - NiCd batteries (18 Ah) - Peak Power Tracking (PPT) & constant current control - Solar Power : >300 W @ EOL

TiungSAT-1 carried two Earth imaging cameras for remote sensing missions, namely Multi-spectral Earth Imaging System (MSEIS) and Meteorological Earth Imaging System (MEIS). Both systems used the same area array Charged-Coupled Device (CCD) at the camera focal plane, but the optical lens and filter system differed. MSEIS employs narrow-angle lenses capable of capturing ground details on the Earth at 78m ground resolution and a swath width of 78km in three green, red and near-infrared (NIR) multi-spectral bands. On the contrary, MEIS used a wide-angle lens to provide a ground resolution of 900 m with a swath width of 900 km at a single near-infrared band. The main specifications of the MSEIS and MEIS camera systems are summarised in Table 2.

Table 2. Main Specifications of TiungSAT-1 and RazakSAT™ imaging systems (Source: Hamzah et al., 2001 and ATSB, 2006).

	TiungSAT-1		RazakSAT™
	MSEIS	**MEIS**	**MAC**
Ground sampling distance	78 m	900 m	2.5 m (PAN) 5 m (MS)
Swath Width	78 km	900 km	20 km
Spectral Band	Green (0.50-0.59μm) Red (0.61-0.69μm) NIR (0.81-0.89μm)	NIR (0.81-0.89μm)	PAN (0.51-0.73μm) Blue (0.45-0.52μm) Green (0.52-0.60μm) Red (0.63-0.69μm) NIR (0.76-0.89μm)
Radiometric Resolution	8 bits	8 bits	8 bits
Data storage	150 compressed images	450 compressed images	32Gbit (~ 32 uncompressed images)
Field of view	7^{o}	71^{o}	1.675^{o}

The TiungSAT-1 imaging systems captured 130 images after about one year of its operation in orbit (Khan, 2001). In addition to the Earth imaging cameras, TiungSAT-1 carried a payload on digital store-and-forward communications and Cosmic Energy Deposition Experiment (CEDEX) for application in communication and measurement of space radiation environment, respectively.

Shortly after the successful launch of TiungSAT-1 in 2000, ATSB initiated an international collaborative programme with SaTReC*i* Initiative Co Ltd. of Daejeon from South Korea to jointly develop a high-resolution small Earth observation satellite for Malaysia in 2001. Originally named Medium-sized Aperture Camera Satellite (MACSAT), the satellite was renamed to RazakSAT™ to honour the late Tun Abdul Razak Dato' Hussain, Malaysia's second Prime Minister. RazakSAT™, as depicted in Figure 1(b), was a mini-class hexagonal-shape satellite weighing about 200 kg, fully developed in August 2005 by an integrated team of engineers from ATSB and SaTReC*i*. The main aim of the RazakSAT™ programme was to develop and validate technologies for a Near Equatorial Orbit (NEqO) remote sensing satellite system (Chun et al., 2006). Instead of placing RazakSAT™ in the usual sun-synchronous orbit, launching the satellite into NEqO provides far greater imaging opportunities over Malaysia territory. The potential imaging chances were increased from 2 times up to 7 times a day due to Malaysia's geographical location in the tropics. After several delays due to the launch vehicle readiness, RazakSAT™ was successfully launched into a 9° inclined Low Earth Orbit at 685km altitude on 14 July 2009. The launch marked Malaysia as the first country in the world to put a remote-sensing satellite into NEqO. The main specifications of the RazakSAT™ platform are listed in Table 1.

A medium-sized Aperture Camera (MAC) was the only mission payload carried on-board RazakSAT™. The MAC system is an electro-optical pushbroom linear camera system that captures high-resolution images in one panchromatic band (PAN) and four multi-spectral bands (MS). The ground sampling distance for MAC at a nominal altitude of 685km is 2.5m for the PAN band and 5m for MS bands with a 20 km swath width. The main specifications of the MAC system are summarised in Table 2 (Chun et al., 2006). Although RazakSAT™ was designed for three years mission lifetime, the satellite never fulfilled its intended lifetime, and the operation of RazakSAT™ ceased completely after about a year in operation due to radiation-induced on-board computer failure. There are about 1300 images captured during this operation period. The images captured by both TingSAT-1 and RazakSAT have been used by researchers from higher learning institutions in Malaysia to test their ability to solve various environmental problems. The following section reports the applications of the data.

5. Application of TingSAT and RazakSAT Data

Two books (non-SCOPUS cited) were published by a private company Astronautic Technology Sdn. Bhd (ATSB). These books report on the inception to the inauguration of the satellite (Othman and Arshad, 2001) and its various applications (Arshad and Hashim, 2003). A total of ten chapters in the book discuss the applications of Tiungsat-1 data in multiple fields covering environmental assessment, sea surface current tracking (Marghany et al., 2008), water quality and chlorophyll mapping (Matjafri et al., 2017) and vegetation and land cover mapping (Kanniah and Teh, 2003; Lim and Komoo, 2001). The potential of TiungSAT-1 data to separate information related to vegetation from other features was shown by computing Tasselled Cap Transformation coefficients and running supervised classification (Kanniah and Teh, 2003). Lim and Komoo (2001) demonstrated the capability of TiungSAT data for land use and landcover delineation (forest, vegetation, urban and bare land), lineaments and faults identification, and bathymetry mapping in the northern states of Penang, Kedah and Perak. The limited number of spectral bands and coarse spatial resolution of 78 m could classify only four land cover classes. However, the study discussed the potential of the data for earth resource evaluation and planning in Malaysia. The data could have been used for environmental monitoring purposes if it had been in operation for several years/decades.

As far as the RazakSAT™ satellite is concerned, only four publications reported on the application of the dataset. This could be due to the very short lifetime of the satellite. Nevertheless, it is important to understand their usages to understand better their potential applications, especially in disaster prevention and environmental planning.

Although RazakSAT™ images have the potential to be used in various applications covering cartography, land use/cover mapping, agriculture, forestry, oceanography and maritime industries due to their high spatial resolution and frequent revisit period of up to 14 times a day, not many studies, have been focussed on these applications. A subset of the RazakSAT™ image covering an area on the west coast of Peninsular Malaysia (Melaka) was used by Hashim et al. (2013) for updating planimetric and topographic features and for classifying land use/land cover in the study area. However, the data were first geometrically and radiometrically corrected to reduce the noise level in both the panchromatic and multi-spectral MAC images. The high-resolution data (2.5 m) enabled the authors to extract road networks within an area of 10 km x 10 km for updating the existing topographic map at 1:25,000 scale and a local plan at 1:5000 scale. The authors also fused panchromatic and multi-spectral images and classified them to obtain detailed (Level-3) land-use and land-cover maps. Although the data was noisy and the sharpness of the image was only moderately good, analysis of the data proved the potential application of the data in terrain mapping.

Other studies include that of Pohl and Hashim (2013, 2014), that investigated the effect of different image fusion techniques on panchromatic and multi-spectral data of RazakSAT™ on the land cover classification of Melaka city. An overall accuracy of 95% was achieved using the Fuzego Spectral fusion technique and the Support Vector Machine classification technique. These techniques produced eight land cover classes. Nevertheless, the authors concluded that selecting a suitable fusion technique depends on many factors, such as the input image, field data, pre-processing techniques of remote sensing images, modification of fusion technique parameters etc. (Pohl and Hashim, 2013). However, when the multi-spectral bands of the RazakSAT™ data were used for land cover classification, it was found to perform poorly compared to the Landsat data, probably due to their limited spectral properties of only four spectral bands compared to 6 spectral bands of Landsat data that are used in the classification scheme (Ahmad, 2013).

The rest of the publications found from the SCOPUS database discuss mainly various technical issues, such as the attitude position of Earth-centered inertia (Hasan et al., 2015; Cherd et al., 2015; Hamzah et al., 2015; Hamzah et al., 2016; Hazadura et al., 2021), ground communication system during the satellite tracking operation and maintenance works (Theng and Salim, 2014), anomalies due to the space radiation environment which led to the malfunction of RazakSAT™ (Theng and Salim, 2014; Suparta and Zulkeple, 2018) rain attenuation of reflectivity (Badron et al., 2016; Badron et al., 2015), free space path attenuation (Yaccop et al., 2016), geometric and radiometric properties of the sensor (Hashim et a., 2013; Dibs et al., 2015;) and processing for feature extraction from the data (Dibbs et al., 2022). This is understandable as the satellite had various technical problems that warrant particular attention for future design and launch of RazakSAT 2.

All the existing studies on the application of RazakSAT™ data show that the high spatial resolution data are proven helpful in land use and utility planning in cities. Unfortunately, no studies have used the multi-temporal data of RazakSAT™ to study environmental disasters, such as floods or landslides in cities that are highly dynamic both in terms of spatial and temporal. Although RazakSAT™ was anticipated to overcome the issue of cloud cover (with its 14 overpasses in a day) in the tropical region, this is only part of the solution (Pohl and Hashim, 2013). Moreover, RazakSAT™ images have only four spectral bands that may not be suitable for land cover classification and vegetation studies.

6. Future Direction and Summary

The government of Malaysia ensures the previous development of TiungSAT-1 and RazakSAT™ satellite programmes is continued by initiating a new satellite development programme. The programme is planned to continue developing the nation's capacity in optical remote sensing satellites, including human capital and space-related infrastructure. One of the programmes scheduled earlier was the continuation of RazakSAT™. RazakSAT-2 satellite was expected to be a small-sized satellite with higher spatial resolution and image quality than the previous RazakSAT™ satellite to acquire satellite imagery for high-precision fine-scale mapping. The satellite was scheduled to be launched into a sun-synchronous orbit. Spatial resolution for panchromatic and multi-spectral data of the RazakSAT-2 satellite was planned to be 1m and 4m, respectively, and expected to be widely used by the local remote sensing community for applications in infrastructure development, town planning and agriculture (Subari and Hassan, 2014). However, until the writing of this manuscript, the satellite has not been launched yet. There has not been any significant progress made in terms of Malaysia's space programme since the launch of RazakSAT in 2009. The slackened progress could be due to the absence of a National Space Policy and a consequent failure to obtain funding for developing satellites or any major space projects (Othman, 2019).

The Malaysian Space Agency is seeking a public-private partnership in developing the next Malaysian remote sensing satellite and planning to tender out such large-scale government projects to the private sector (personal communication with the director of MySA). This effort is expected to solve any financial constraints the government faces to venture into major space projects. Recently, Angkasa-X Innovation Sdn Bhd, a local space technology company, has been collaborating with a local public university to develop an Earth station and a space technology centre concurrently in the northern state of Penang. The collaboration is expected to launch the first Malaysian-made 24 remote sensing satellites between 2024 and 2026. The Earth station constructed in Universiti Sains Malaysia will be able to receive signals from all the satellites, and data obtained from the satellites will be very useful in disaster management and other environmental applications. The Earth station and the space technology centre are anticipated to encourage more private sectors to invest in space technology in Malaysia. Furthermore, they will accommodate research, development, and education by offering professional courses for Asia countries (Malaymail, 2023). The space, particularly the remote sensing sector, appears to have an optimistic future in Malaysia with the privatisation and/or public-private partnership.

Malaysia could also look beyond the optical satellite for next-generation remote sensing satellite programmes, e.g., synthetic aperture radar (SAR) satellites. Geographically, Malaysia is a tropical country with a very high occurrence of cloud obstruction for optical imagery acquisition. SAR satellites' all-weather and all-day capability is particularly well suited for this country's optimum remote sensing data collection. This study provides a brief review of the applications of Tiungsat-1 and RazakSAT™ data in the context of Malaysia and the need for future works. Future microsatellites of Malaysia are highly expected to provide continuous remote sensing images to enrich the environmental data flow in Malaysia.

Acknowledgements

The authors would like to thank the Malaysian Space Agency for providing Figure 1, which has been included in this manuscript.

References

Ahmad, A., 2013. "*Classification simulation of RazakSAT satellite*". Procedia Engineering, *53*, pp.472-482.

Arshad, A. B., and Hashim, M. 2003. *"Astronautic Technology (M) Sdn Bhd., TiungSAT-1: Data Applications"* Bukit Jalil, Kuala Lumpur, pp. 89. ISBN 983- 41363-0-7.

Arshad, A.S and Yusoff, A. 2014. "*Remote Sensing as part of the Knowledge Economy for a Developed Malaysia"*. https://pintu.instun.gov.my/artikel/download/remote-sensing-as-part-of-the-knowledge-eco-for-developed-malaysia (Accessed 13 March 2023).

Astronautic Technology (M) Sdn Bhd. & Surrey Satellite Technology Limited (ATSB), 2001. *"TiungSAT-1 Microsatellite Mission Design. In: TiungSAT-1: From Inception to Inauguration"*. Edited by Othman M. and Arshad A.S., Astronautic Technology (M) Sdn Bhd, Kuala Lumpur, pp. 29-46.

Astronautic Technology (M) Sdn Bhd, 2006. *"RazakSAT™ User Handbook"*.

Badron, K., Ismail, A.F. and Ismail, M., 2015. *"Estimating tropical rain attenuation on the Earth-satellite path using radar data"*. International Journal of Remote Sensing, 36(24), pp.6101-6115.

Badron, K., Ismail, A.F., Ismail, M., Salim, H. and Mustapha, H., 2016. *"Derivation of Z-γ (Reflectivity-Specific Attenuation) Relation for Satellite Link in Tropical Region"*. Advanced Science Letters, 22(10), pp.2750-2753.

Cherd, T.V., Abu Bakar, S., Yaacob, S. and Hamzah, N.H., 2015. *"Flexible Dynamic Model of Attitude Maneuvering of RazakSAT (R) Satellite"*. Jurnal Teknologi, 76(12), pp.1-7.

Chun, H.J., Kim B. J., Chang H. S., Kim E. E., Park W. K., Park S. D., and Ashard A. S., 2006. *"RazakSAT - A High-Performance Satellite Waiting for Its Mission in Space"*. Proceedings of the 20th Annual AIAA/USU Conference on Small Satellites, pp.1-9.

Cracknell, A.P., Hashim, M., Ibrahim, A.L., Sandau, R (Eds), 2013, Earth Observation Small Satellites for Remote Sensing Applications: Extended and refereed papers from the workshop (Kuala Lumpur, Malaysia 20-23 November 2007), 320 pp, ISBN 9780415548816

Dibs, H., Mansor, S., Ahmad, N. and Pradhan, B., 2015. *"Band-to-band registration model for near-equatorial Earth observation satellite images with the use of automatic control point extraction"*. International Journal of Remote Sensing, 36(8), pp.2184-2200.

Dibs, H., Hasab, H.A., Jaber, H.S. and Al-Ansari, N., 2022. *"Automatic feature extraction and matching modelling for highly noise near-equatorial satellite images*". Innovative Infrastructure Solutions, 7(1), p.2.

Hamzah, N., Arshad A.S., and Hidayat M.R., 2001. *"TiungSAT-1: Earth Imaging System. In: TiungSAT-1: From Inception To Inauguration",* edited by Othman M. and Arshad A.S., Astronautic Technology (M) Sdn Bhd, Kuala Lumpur, pp. 47-56.

Hamzah, N.H., Yaacob, S., Muthusamy, H. and Hamzah, N., 2015. *"Updated model of RazakSAT's attitude during sun tracking mode using time series"*. In AIP Conference Proceedings, AIP Publishing, Vol. 1660, No. 1, pp. 070121.

Hamzah, N.H., Yaacob, S., Muthusamy, H., Hamzah, N. and Hasan, M.Z., 2016. *"Unmodeled disturbances torque exerted on RazakSAT's attitude during sun tracking mode"*. In AIP Conference Proceedings, AIP Publishing, Vol. 1775, pp. 030081.

Hasan, M.Z., Yaacob, S., Ahmed, A., Hamzah, N.H., Yaakob, S.B., Idris,M.H., and Md Said,M.A., 2015. *"Analysis on Attitude Position of Earth Centered Inertial (ECI) Based on RazakSAT Data"*. Jurnal Teknologi, 76:12, pp. 97-103.

Hashim, M., El-Mahallawy, M.S., Reba, M.N.M., Abas, A.A., Ahmad, S., Yap, X.Q., Marghany, M. and Arshad, A.S., 2013. *"Geometric and radiometric evaluation of RazakSAT medium-sized aperture camera data"*. International journal of remote sensing, 34(11), pp.3947-3967.

Hazadura, H.N., Kadri, J.A., Zamri, H.M. and Vilcherd, T., 2021, July. *"Verification of nonlinear state observer system for RazakSAT using extended Kalman filter"*. In AIP Conference Proceedings (Vol. 2347, No. 1, p. 020038). AIP Publishing LLC.

Kanniah, K.D., Hashim, M. and Mohd, M.I.S., 2000. *"A systematic approach in remote sensing education and training in Malaysia with special reference to Universiti Teknologi Malaysia"*. In *14th ISPRS Congress Amsterdam, The Netherlands* (pp. 153-163).

Kanniah, Kasturi Devi and Teh, Poey Lee (2003) *Generation of Tasseled Cap Transformation Coefficients for the Use of TiungSAT-1 Multi Spectral Earth Imaging System (MSEIS) Data*. In: TiungSAT-1: Data Applications. Astronautic Technology (M) Sdn. Bhd., Bukit Jalil, Kuala Lumpur, pp. 61-80. ISBN 983-41363.

Kramer, H.J. and Cracknell, A.P., 2008. *"An overview of small satellites in remote sensing"*. International journal of remote Sensing, 29(15), pp.4285-4337.

Khan, N.G., 2001. *"TiungSAT-1 Mission Control Station. In: TiungSAT-1: From Inception To Inauguration"*, edited by Othman M. and Arshad A.S., Astronautic Technology (M) Sdn Bhd, Kuala Lumpur, pp. 141-149.

Mainura, T.I., 2019, *"Review of Space Law and Policy in Malaysia"*, ASM Science Journal, 12, Special Issue 2, ISSN 1823-6782.

Malaymail, 2022, *"Angkasa-X and USM to build RM30m earth station and space technology centre in Penang*", Retrieved from: https://www.malaymail.com/news/malaysia/2022/05/19/angkasa-x-and-usm-to-build-rm30m-earth-station-and-space-technology-centre-in-penang/7628 (Accessed on March 27, 2023).

Marghany, M., Hashim, M. and Cracknell, A.P., 2008. *"Hopfield neural network for sea surface current tracking from Tiungsat-1 data"*. In Computational Science and Its Applications–ICCSA 2008: International Conference, Perugia, Italy, June 30–July 3, 2008, Proceedings, Part II 8 (pp. 950-958). Springer Berlin Heidelberg.

Matjafri, M.Z., Abdullah, K. and Lim, H.S., 2017. *"Malaysian Tiungsat-1 Imagery for Water Quality Mapping"*, Retrieved from: https://www.geospatialworld.net/article/malaysian-tiungsat-1-imagery-for-water-quality-mapping/ (Accessed on March 27, 2023)

Othman, M., 2019, *"Editorial: Malaysia in space"*, ASM Science Journal, 12, Special Issue 2, ISSN 1823-6782.

Othman, M., and Arshad, A.S., 2001, "TiungSAT 1: from inception to inauguration", Astronautic Technology, 9838671932, 9789838671934, pp 242.

Pohl, C. and Hashim, M., 2013. *"Using Advanced Image Fusion Techniques To Increase The Usability of RazakSAT Data For Map Updating In The Tropics"*. In Proceedings of the 34th ACRS (Asian Conference on Remote Sensing), Bali, Indonesia.

Pohl, C. and Hashim, M., 2014. *"Increasing the Potential of RazakSAT Images for Map-Updating in the Tropics"*. In IOP Conference Series: Earth and Environmental Science, IOP Publishing, Vol. 18, No. 1, pp. 012029.

Subari, M.D. and Hassan, A., 2014, June. *"Building EOS capability for Malaysia–the options"*. In IOP Conference Series: Earth and Environmental Science (Vol. 20, No. 1, p. 012034). IOP Publishing.

Suparta, W. and Zulkeple, S.K., 2018. *"Investigating space radiation environment effects on communication of Razaksat-1"*. Journal of Aerospace Technology and Management, 10.

Sweeting, M., Sun, W., and Othman, M., 2001. *"TiungSAT-1: Malaysia's Microsatellite Programme. In: TiungSAT-1: From Inception To Inauguration",* edited by Othman M. and Arshad A.S., Astronautic Technology (M) Sdn Bhd, Kuala Lumpur, pp. 13-25.

Theng, O.S. and Salim, H., 2014, November. *"Recommendations for enhancement on ground communication system at ANGKASA, Malaysia for space missions"*.

In Telecommunication Technologies (ISTT), 2014 IEEE 2nd International Symposium, pp. 226-229.

Xue, Y., Li, Y., Guang, J., Zhang, X. and Guo, J., 2008. "*Small satellite remote sensing and applications–history, current and future''*. International Journal of Remote Sensing, 29 (15), pp.4339-4372.

Yaccop, A.A.H., Yao, Y.D., Ismail, A.F., Nordin, M.A.W.N. and Badron, K., 2016. *''Preliminary Analyses on Measured Received Signals of Orbiting RazakSAT Satellite''*. Advanced Science Letters, 22(10), pp.2790-2793.