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Formulation of Satellite-UAVs Integration System for Earth Remote Sensing in the Republic of the Union of Myanmar

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Conflicts of interest

The authors declare that there is no conflict of interest.

Abstract. The article develops the concept of a Hybrid Earth Remote Sensing System (HERS) for Myanmar, integrating Low-Earth Orbit (LEO) satellites and Unmanned Aerial Vehicles (UAVs) to obtain near real-time, high-resolution geospatial data for environmental monitoring and disaster risk management tasks. Analysis of the existing Earth remote sensing infrastructure and implemented projects revealed several limitations: high latency of satellite systems, cloud-cover interference, restricted data availability, and institutional barriers, including weak interagency coordination, a shortage of trained personnel, and insufficient funding. As a result of the study, the HERS architecture is formulated, including integration of satellites and UAVs, the use of multifrequency and laser communication channels, and energy-efficient UAVs with modular payloads (SAR, hyperspectral, and infrared sensors), providing compatible processing and rapid data transmission to the national GIS infrastructure. It is shown that the proposed system improves the spatiotemporal resolution of observations, reduces the impact of cloud cover, lowers operational costs compared with predominantly satellite-based solutions, and expands the range of practical tasks; from monitoring agriculture, forests, and water resources to near real-time response to floods and cyclones. The practical significance of the work lies in the fact that implementation of HERS, together with the development of a national GIS platform and specialist training programs, increases Myanmar's resilience to natural and anthropogenic threats and provides more evidence-based support for decision-making.

Keywords: Remote sensing of the Earth, hybrid remote sensing system, satellite imaging, UAV-based monitoring, agriculture monitoring

Authors' contribution

Starkov A.V. — research concept, selection of literature; *Zin M.L.* — analyzing the received data, writing; *Samusenko O.E.* — summarizing the results obtained, editing the text, visualization; *Thant A.M.* — writing; *Nay H.L.* — writing. All authors read and approved the final version of the article.

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Разработка системы интеграции спутников и беспилотных летательных аппаратов для дистанционного зондирования Земли в Республике Союз Мьянма

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Авторы заявляют об отсутствии конфликта интересов.

Аннотация. Разработана концепция гибридной системы дистанционного зондирования Земли (ГСДЗЗ) для Мьянмы, интегрирующей низкоорбитальные спутники (LEO) и беспилотные летательные аппараты (БПЛА) для оперативного получения детализированных пространственных данных в задачах мониторинга окружающей среды и управления рисками стихийных бедствий. Анализ существующей инфраструктуры ДЗЗ и реализованных проектов выявил ограничения: высокую латентность спутниковых систем, помехи от облачности, ограниченную доступность данных, а также институциональные барьеры, включая слабую межведомственную координацию, дефицит подготовленных кадров и недостаточное финансирование. В результате исследования сформулирована архитектура ГСДЗЗ, включающая интеграцию спутника и БПЛА, использование многочастотных и лазерных каналов связи и энергоэффективных БПЛА с модульной полезной нагрузкой (SAR, гиперспектральные и инфракрасные сенсоры), обеспечивающих совместимую обработку и оперативную передачу данных в национальную ГИС-инфраструктуру. Показано, что предложенная система повышает пространственно-временное разрешение наблюдений, снижает влияние облачности, уменьшает эксплуатационные затраты по сравнению с преимущественно спутниковыми решениями и расширяет спектр прикладных задач; от мониторинга сельского хозяйства, лесов и водных ресурсов до оперативного реагирования на наводнения и циклоны в режиме, близком к реальному времени. Практическая значимость работы заключается в том, что внедрение ГСДЗЗ совместно с развитием национальной ГИС-платформы и программ подготовки специалистов повышает устойчивость Мьянмы к природным и антропогенным угрозам и обеспечивает более обоснованную поддержку управленческих решений.

Ключевые слова: гибридная система, спутниковые снимки, мониторинг с помощью беспилотных летательных аппаратов, мониторинг сельского хозяйства

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Старков А.В. — концепция исследования, подбор литературы; *Зин М.Л.* — анализ полученных данных, написание текста; *Самусенко О.Е.* — обобщение полученных результатов, редактирование текста, визуализация; *Аунг М.Т.*— написание текста; *Най Х.Л.* — написание текста. Все авторы ознакомлены с окончательной версией статьи и одобрили ее.

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Introduction

Introduction of UAV-Satellite Hybrid Remote Sensing System

Existing satellite-based remote sensing systems often lack real-time data transmission and suffer from high latency and cloud-cover interference. However, UAV-based monitoring, although flexible and precise, struggles with range limitations and energy constraints. The lack of an integrated approach hinders efficient decision making, particularly in disaster response, agriculture monitoring, and climate change adaptation. This study aimed to develop a Hybrid Remote Sensing System (HRSS) that combines the wide-area coverage of Low-Earth Orbit (LEO) satellites with the real-time precision of UAV-based monitoring to create a cost-effective, scalable, and adaptive solution for Myanmar. Traditional remote sensing systems often rely on either LEO satellites or Unmanned Aerial Vehicles (UAVs) independently. Although satellites provide global coverage and long-term data collection, they have limitations, such as low temporal resolution, high operational costs, and cloud interference. On the other hand, UAVs offer high-resolution, real-time monitoring with operational flexibility, but they are limited in endurance and range. To overcome these challenges, an HRSS integrating LEO satellites and UAVs was proposed for Myanmar's environmental and resource management needs. Remote sensing and Geographic Information Systems (GIS) have become integral tools for environmental monitoring, disaster risk management, and resource planning [1; 2]. This study provides an in-depth analysis of the advancements, applications, and challenges associated with remote sensing technologies in Myanmar. This study explores the historical development of satellite data utilisation, the role of key institutions, ongoing research initiatives, and future perspectives. Particular emphasis is placed on the Myanmar-India Friendship Centre for Remote Sensing, postgraduate education programs, and collaborative efforts with international agencies. This study highlights the importance of capacity building, technological advancements, and policy integration to optimise the potential of remote sensing for sustainable development.

The proposed HRSS offers a synergistic solution by integrating satellite-based remote sensing with UAV-based aerial surveillance. First, LEO satellites provide wide-area continuous coverage, making them ideal for large-scale environmental and climate monitoring. However, their fixed orbital paths and data-acquisition delays can hinder real-time disaster response. Second, UAVs offer on-demand high-resolution imaging, allowing for detailed local monitoring, rapid deployment, and flexibility in data collection. They can supplement satellite limitations by capturing imagery in critical regions affected by cloud cover, enabling continuous monitoring, regardless of weather conditions. Finally, the combination of these technologies enhances the overall efficiency, ensuring a high temporal resolution from UAVs and extensive spatial coverage from satellites. This hybrid system will provide accurate, real-time, and multispectral data, essential for precision agriculture, forestry management, urban planning, and disaster response.[1]

Introduction of the Remote Sensing in Myanmar

The First Myanmar-India Friendship Centre for Remote Sensing and Data Processing was established on 15 February 2001 as a result of a collaborative initiative between the Ministry of Science and Technology (MOST) of Myanmar and the Indian Space Research Organization (ISRO) of India. This centre marked a significant milestone in the advancement of remote sensing technology and its practical applications in Myanmar, laying the foundation for the integration of geospatial technologies into the country's development agenda[2] [3]. The establishment of the centre was a testa-

[1] Remote Sensing for REDD+MRV for Myanmar Officials. Available from: https://www.icimod.org/remote-sensing-for-redd-mrv-for-myanmar-officials (accessed: 14.03.2025); *Learning from the experiences of 13 developing countries. Global Comparative Study on REDD+(GCS REDD+).*

[2] Floodlist, UN Report — Floods in Myanmar Had Devastating Impact on Agriculture, 2015. Available from: https://floodlist.com/asia/un-myanmar-floods-food-security (accessed: 14.03.2025); *Learning from the experiences of 13 developing countries. Global Comparative Study on REDD+(GCS REDD+).*

ment to the growing recognition of the im-portance of remote sensing and GIS in addressing critical challenges in agriculture, urban planning, environmental management, and disaster risk reduction. Since its inception, the centre has played a pivotal role in building local capacity, fostering innovation, and promoting sustainable development through the effective use of space-based technologies.

One of the centre's primary achievements has been the comprehensive training of its staff members in the applications of remote sensing technology. This training, facilitated by Indian scientists and experts, has equipped Myanmar's professionals with the technical skills and knowledge necessary to harness the power of geospatial data. The training programs have covered a wide range of topics, including data acquisition, image processing, spatial analysis, and the integration of remote sensing with GIS for decision-making. In addition to theoretical knowledge, the centre has emphasised hands-on learning through the execution of several mini-projects. These projects have not only enhanced the technical expertise of the participants, but also demonstrated the practical utility of remote sensing in addressing real-world challenges[3] [4].

Among the notable projects undertaken by the centre are **Crop Area Estimation and Condition Monitoring** for the Bago Division, which has provided valuable insights into agricultural productivity and resource management; **Coastal Land Use Analysis** in Rakhine State, which has supported sustainable coastal development and conservation efforts; and **Urban Land Use Mapping and Planning** for a section of the Mandalay Region, which has contributed to the efficient management of urban growth and infrastructure development. Other significant projects include **Land Use and Land Cover Mapping** for Myanmar, which has provided a comprehensive overview of the country's land resources; **Forest Type Mapping** in Pyinmana, which has aided in biodiversity conservation and forest management; and **Wasteland Development** in the Sagging Division, which has promoted the rehabilitation of degraded lands for agricultural and ecological purposes. These projects have not only addressed specific sectoral needs but have also highlighted the versatility and transformative potential of remote sensing technology[4].

In addition to its project-based initiatives, the centre has successfully implemented a research-oriented program for postgraduate studies affiliated with the United Nations Centre for Space Science and Technology Education in Asia and the Pacific (CSSTEAP). Since its launch in 2002, this program has aimed to enhance the academic and professional capabilities of students in the field of remote sensing and data processing. By offering advanced training and research opportunities, the program has nurtured a new generation of experts who are equipped to tackle complex challenges using geospatial technologies. The program's emphasis on interdisciplinary learning and international collaboration has further enriched its curriculum, enabling students to gain exposure to global best practices and innovative approaches [1; 5].

The establishment and ongoing activities of the First Myanmar-India Friendship Centre for Remote Sensing and Data Processing underscore the importance of international collaboration in advancing scientific research and technological applications for sustainable development. By leveraging the expertise and resources of ISRO and otherinternational partners, the centre has been able to accelerate the adoption of remote sensing and GIS technologies in Myanmar. Its contributions have not only strengthened the country's technical capacity but have also fostered a culture of innovation and knowledge-sharing. As Myanmar continues to face challenges related to climate change, urbanisation, and resource management, the centre's work remains critical in providing data-driven solutions and supporting evidence-based decision-making. Through its commitment to excellence and collaboration, the centre serves as a model for how international partnerships can drive technological progress and sustainable development in the region.

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[3] *Union of Myanmar. Ministry of Forestry. National Action Programme of Myanmar to Combat Desertification in the context of United Nations Convention to Combat Desertification (UNCCD).* Yangon: Ministry of Forestry; 2005

[4] *Learning from the experiences of 13 developing countries. Global Comparative Study on REDD+(GCS REDD+).*

1. Materials and Methods

1.2. Advanced Professional Certification in Geospatial Technologies and Applications

In 2007–2008, the first Post Graduate Diploma Course on Remote Sensing and GIS was successfully launched, enrolling 13 trainees. This course aimed to enhance the technical expertise and practical skills of the participants in the application of remote sensing and GIS technologies across various fields. The training program covered diverse areas, including **Agriculture and Soil Science**, **Geoscience Applications**, **Marine Science Applications**, and **Urban Planning**[5] [1].

These projects and courses have contributed significantly to the development of expertise in remote sensing and GIS applications, fostering advancements in environmental monitoring, resource management, and urban development.

In 2007, the Myanmar-India Friendship Centre for Remote Sensing and Data Processing (RSDPC) was reorganised and renamed as the Remote Sensing Department. This department was placed under the auspices of Mandalay Technological University (MTU) and the Ministry of Science and Technology (MOST). This reorganisation marked a new chapter in the department's mission to advance research and education in remote sensing and GIS technologies, further solidifying its role in national and regional development initiatives[6] [5].

1.2. Historical Applications and Case Studies in Remote Sensing and GIS

The Remote Sensing Department has a rich history of conducting impactful research and projects that leverage remote sensing and GIS technologies. These initiatives have addressed various critical areas including disaster risk management, environmental studies, and agricultural planning. Key projects and studies include the following.

1. *Disaster Risk Management in Myanmar:* This project focused on utilising remote sensing and GIS to assess and mitigate the risks associated with natural disasters, enhancing the country's preparedness and response strategies.

2. *Groundwater Potential Zone of the Kyaukse Area*: A comprehensive analysis was conducted to identify and map groundwater potential zones in the Kyaukse area to support sustainable water resource management.

3. *Geomorphological Studies on Ayeyarwaddy Deltaic Shelf*: This study involved detailed geomorphological mapping and analysis of the Ayeyarwaddy Deltaic Shelf and contribute to a better understanding of the region's physical landscape and its changes over time.

4. *Crop Pattern Change Analysis of Mandalay Area*: Remote sensing techniques were employed to monitor and analyse changes in crop patterns in the Mandalay area, aiding in agricultural planning and policy-making.

5. *Land Use/Land Cover Change Analysis of Mandalay City:* This project focused on mapping and analysing land use and land cover changes in Mandalay City to provide valuable insights for urban planning and development.

6. *Irrigation Management System for Paddy Field in Mandalay Region:* An advanced irrigation management system was developed using remote sensing and GIS technologies to optimise water use and improve paddy field productivity in the Mandalay Region.

These projects underscore the department's commitment to applying cutting-edge technologies to address real-world challenges, contributing to sustainable development and resource management in Myanmar[7].

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[5] Reliefweb, Myanmar: Floods — Final Report, 2017. Available from: https://reliefweb.int/report/myanmar/myanmar-floods-final report-mdrmm006 (accessed: 14.03.2025); *United Nations Platform for Space-Based Information for Disaster Management and Emergency Response (UN-SPIDER), Flood 2022*, 2022. Available from: https://www.un-spider.org/flood (accessed: 14.03.2025).

[6] *Remote Sensing for REDD+MRV for Myanmar Officials*. Available from: https://www.icimod.org/remote-sensing-for-redd-mrv-for-myanmar-officials (accessed: 14.03.2025); Learning from the experiences of 13 developing countries. Global Comparative Study on REDD+(GCS REDD+)

[7] *Learning from the experiences of 13 developing countries. Global Comparative Study on REDD+(GCS REDD+); Reliefweb, Myanmar: Floods — Final Report*, 2017. Available from: https://reliefweb.int/report/myanmar/myanmar-floods-final report-mdrmm006 (accessed: 14.03.2025); *Union of Myanmar. Ministry of Forestry. National Action Programme of*

1.3. Current Initiatives and Innovations in Remote Sensing and GIS Applications

The Remote Sensing Department is currently engaged in several significant projects and initiatives that highlight the continued application of remote sensing and GIS technologies [1; 6]. These activities span a range of critical areas from environmental monitoring to cultural heritage preservation and urban safety. Key ongoing activities include the following.

1. *Delineation of Outer Limits of Continental Shelf beyond 200 Nautical Miles*: This project involves the precise mapping and delineation of Myanmar's continental shelf extending beyond 200 nautical miles, contributing to the nation's maritime boundary claims and resource management.

2. *Creating Database of Myanmar Ancient Cities to Include in the List of World Cultural Heritage:* Efforts are underway to develop a comprehensive database of Myanmar's ancient cities. This initiative aims to support the inclusion of these sites in the UNESCO World Cultural Heritage List, promoting cultural preservation and tourism.

3. *ASEAN-INDIA Cooperation Project (Extent of Transfer of Alien Invasive Organisms in South/Southeast Asia Region by Shipping):* This collaborative project focuses on assessing the transfer of alien invasive organisms through shipping activities in the South and Southeast Asia regions. This project aims to mitigate ecological risks and protect biodiversity.

4. *Urban Fire Analysis in Mandalay using Remote Sensing & GIS Techniques:* Remote sensing and GIS technologies are being utilised to analyse and map urban fire risks in Mandalay. This project supports urban planning and emergency response strategies to enhance public safety.

5. *Teaching Remote Sensing and GIS Subjects for Ph.D. Civil Engineering Students*: The department is actively involved in the education and training of Ph.D. students in Civil Engineering, offering specialised courses in remote sensing and GIS. This initiative aims to build an advanced technical expertise among future researchers and professionals.

These ongoing activities demonstrate the department's commitment to leveraging remote sensing and GIS technologies for diverse applications, thereby contributing to national development, environmental sustainability, and academic advancement.

1.4. Utilization of Space-based Technologies for Disaster Risk Management

The initiative entitled "Utilization of Space-based Technologies for Disaster Risk Management" was organised by the Asian Disaster Reduction Center (ADRC) in collaboration with the Asian Institute of Technology (AIT). This program aimed to enhance regional capabilities in disaster risk management through the application of advanced geospatial technologies. The initiative included a series of training workshops supported by Tokyo University, Japan to build technical expertise and foster knowledge exchange. Two key workshops were conducted as part of this initiative: **Basic Geospatial Technologies Workshop**: Held in February 2011, which provided foundational training in geospatial technologies, equipping participants with essential skills for disaster risk assessment and management. **Advanced Geospatial Technologies Workshop**: Conducted in November 2011, this workshop focused on advanced applications of geospatial technologies, enabling participants to leverage sophisticated tools and methodologies for more effective disaster risk management.

1.5. Collaborative Partnerships

In addition to the training workshops, the project established significant collaboration to further its objectives:

Myanmar to Combat Desertification in the context of United Nations Convention to Combat Desertification (UNCCD). Yangon: Ministry of Forestry; 2005. Remote Sensing for REDD+MRV for Myanmar Officials. Available from: https://www.icimod.org/remote-sensing-for-redd-mrv-for-myanmar-officials (accessed: 14.03.2025); Floodlist, UN Report — Floods in Myanmar Had Devastating Impact on Agriculture, 2015. Available from: https://floodlist.com/asia/un-myanmar-floods-food-security (accessed: 14.03.2025); *United Nations Platform for Space-Based Information for Disaster Management and Emergency Response (UN-SPIDER), Flood 2022*, 2022. Available from: https://www.un-spider.org/flood (accessed: 14.03.2025).

■ **China Centre of Resources Satellite Data and Applications (CRESDA)**: A partnership was formed with CRESDA to enhance the utilisation of satellite data in disaster risk management.

■ **China Myanmar Satellite Data Sharing Service Platform Program**: Launched in March 2014, which aimed to create a platform for sharing satellite data between China and Myanmar. This initiative sought to improve the application of space-based technologies in disaster risk management, fostering regional cooperation and capacity building [5; 7; 8].

These efforts underscore the importance of international collaboration and advanced technological applications for enhancing disaster risk management capabilities. The partnerships and training programs have contributed significantly to building regional expertise and promoting the effective use of geospatial technologies for disaster preparedness and response (Figure 1).

Figure 1. Flood after Cyclone Nargis at 2008 in Myanmar

Source: by Hurricanes & Society*
Available from: https://www.hurricanescience.org/history/storms/2000s/cyclonenargis/ (accessed: 14.03.2025).

2. Results and Discussion

2.1. Leveraging Remote Sensing Technology for Enhanced Meteorological and Hydrological Services in Myanmar

The Department of Meteorology and Hydrology (DMH) in Myanmar serves as a critical institution for monitoring and managing meteorological, hydrological, and seismological activities. Over the decades, the DMH has developed a range of services and achieved notable milestones, significantly contributing to both national and international initiatives in environmental monitoring and disaster risk reduction.[9]

[9] Floodlist, UN Report — Floods in Myanmar Had Devastating Impact on Agriculture, 2015. Available from: https://floodlist.com/asia/un-myanmar-floods-food-security (accessed: 14.03.2025). Learning from the experiences of 13 developing countries. Global Comparative Study on REDD+(GCS REDD+)

Establishment of Services

1. *Meteorological Services:* Initiated in 1937, these services provide crucial weather forecasts and climate information, supporting diverse sectors, such as agriculture, aviation, and public safety.

2. *Agro-meteorological Services:* Established in 1970, these services deliver specialised meteorological data and forecasts to aid agricultural planning and management, thereby enhancing crop productivity and food security.

3. *Hydrological Services:* Launched in 1964, these services oversee the monitoring of water resources, including rivers, lakes, and groundwater, thereby facilitating sustainable water management and accurate flood forecasting.

4. *Seismological and Earthquake Activities:* Since their inception in 1961, these activities have involved the systematic observation and analysis of seismic events, improving earthquake preparedness and response strategies.

International Memberships

- *International Meteorological Organization (IMO):* The DMH's membership in the IMO underscores its commitment to global meteorological collaboration and exchange of scientific knowledge.
- *Acid Deposition Monitoring:* Introduced in 2003, this program focuses on tracking acid rain and its environmental consequences, contributing to the understanding of atmospheric pollution.
- *Acid Deposition Monitoring Network in Asia (EANET):* Joining in 2006, the DMH has reinforced regional efforts to monitor and mitigate the effects of acid deposition across Asia.

The DMH's core functions encompass the issuance of timely information, forecasts, and warnings, which are disseminated to decision makers, policymakers, various departments, and the public [2; 9]. The primary responsibility of the DMH is the operation of the Early Warning System, which plays a vital role in disaster risk reduction by providing advance notice of potential hazards. Information, Forecasts, and Warnings: The DMH is responsible for issuing accurate and timely meteorological and hydrological information, forecasts, and warnings to support decision making and public safety. Data Dissemination: Critical data is disseminated to decision makers, policy makers, various departments, and the public to inform and guide actions related to weather, water resources, and disaster preparedness. Early Warning System: Managing the Early Warning System is a primary responsibility of the DMH, particularly in the context of Disaster Risk Reduction (DRR). This system plays a crucial role in mitigating the impacts of natural disasters by providing early alerts and facilitating timely responses [2; 9].

Various satellite data applications are utilised by the Department of Meteorology and Hydrology (DMH). These applications are categorised into warnings, bulletins, forecasts, and news, which are essential for public safety and informed decision making. They include: Warnings: Cyclone Warning, Storm Surge, Warning Flood Warning, Untimely Rainfall Warning, Fog Warning, Heavy Rain Warning, Aviation Weather Warning, Tsunami Warning, Port Warning, Forecasts: Daily Weather/Water Level Forecast, 10 Days Weather/Flood Forecast, Monthly Weather/Flood Forecast, Seasonal Weather/River Flood Forecast, Aviation Weather Forecast, Marine Weather Forecast, Low Flow Water Level Forecast, Special Forecast, Bulletins and News: Rainfall/Temperature Records, Bay Bulletin, Cyclone News, Flood Bulletin, Special Weather Bulletin, Earthquake News [4; 9; 10].

A historical overview of the application of satellite data and remote sensing technologies by the Department of Forest. Aerial photographs were utilized in the 1920s to assess the vegetative cover of the Ayeyarwady Delta Mangroves. Satellite imagery was first introduced to the Forest Department in 1980 under the FAO/UNEP Tropical Resources Assessment Project. This initiative aimed to conduct a comprehensive forest cover assessment across the entire country. In early 1996, the Forest Department established a Remote Sensing and GIS Section. A digital image processing system was installed during this period, facilitated by financial assistance from the "Watershed Manage-ment for Three Critical Areas Project" (MYA/93/005) [11–15].

The image details the remote sensing data sources and software utilised for forest cover assessment and conservation efforts. Here are some Remote Sensing Data Sources: Landsat TM and ETM+: Imagery with a resolution of 30m x 30m was used for previous forest cover assessments of the entire country in 1990, 2000, and 2005. IRS LISS III: Imagery with a resolution of 23.5m was used for the 2010 forest cover assessment of the entire country. High-Resolution Satellite Imageries: Quickbird, IKONOS, ALOS, Rapideye, and Aster were used for specific conservation priority areas, including: Tanimtharyi Nature Reserve, Ayeyarwady Delta, Naypyitaw Region, Rakhine State, Shan State[10] [10].

Several challenges are faced in the implementation and utilisation of Remote Sensing (RS) and GIS technologies. These challenges can be categorised as technical, institutional, and resource-related issues, and there is a pressing need for technical training in RS and GIS for local staff to enhance their proficiency and operational capabilities. Interconnectivity between ministries and agencies is limited, necessitating stronger partnership activities to foster collaboration. The relationship between government ministries and related departments is weak, which hampers coordinated efforts. Information exchange mechanisms are inadequate, leading to inefficient data sharing and utilisation. Public Awareness and Community Engagement: There is a significant lack of public awareness and local knowledge regarding the benefits and applications of RS and GIS technologies [2]. The capacity of community response and operation is limited, which affects the effective implementation of these technologies at the grassroots level. The absence of a National GIS-based system is a major impediment to the centralised and efficient management of geospatial data (Figure 2).

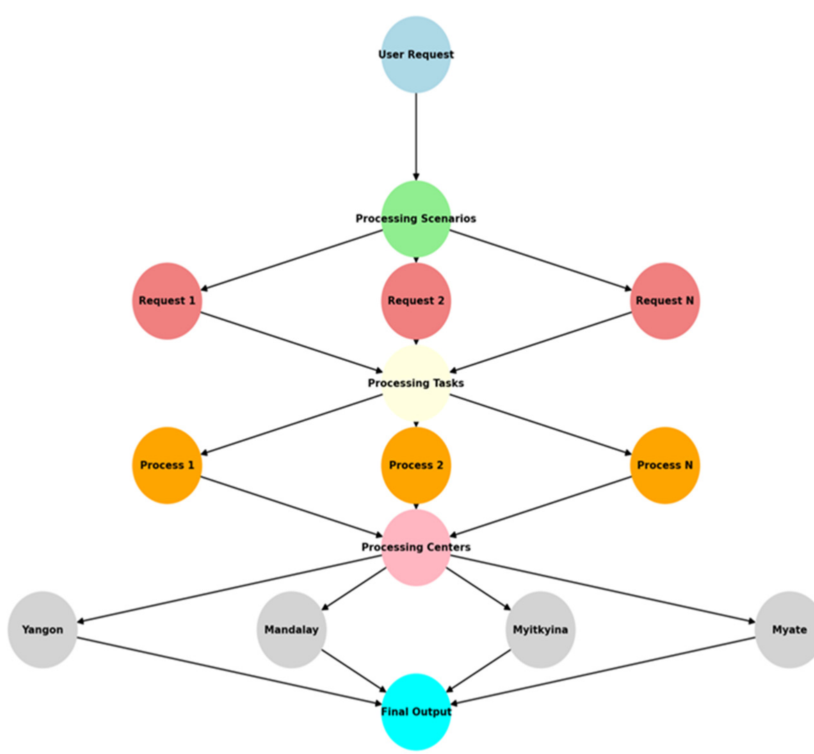

Figure 2. Workflow Efficiency in Application Processing Systems
S o u r c e: by A.V. Starkov, O.E. Samusenko, Aung Myo Thant

[10] Remote Sensing for REDD+MRV for Myanmar Officials. Available from: https://www.icimod.org/remote-sensing-for-redd-mrv-for-myanmar-officials (accessed: 14.03.2025); *United Nations Platform for Space-Based Information for Disaster Management and Emergency Response (UN-SPIDER), Flood 2022*, 2022. Available from: https://www.un-spider.org/flood (accessed: 14.03.2025).

Funding limitations restrict the acquisition of necessary tools, technologies, and training programs. There is a shortage of human resources with the requisite skills and expertise to fully leverage RS and GIS technologies.

GIS has been identified as a crucial tool for providing up-to-date information, enabling timely and appropriate actions in various sectors. There is a need for comprehensive capacity-building programs, including seminars, workshops, and hands-on training, to facilitate the sharing of knowledge and experiences among stakeholders [4; 10]. Access to near-real-time satellite data is essential for effective decision making and response strategies. Technical training should be provided to personnel in related ministries and departments to enhance their proficiency in using GIS and remote sensing technologies. Interdepartmental and interministerial coordination and planning are necessary to ensure cohesive and integrated efforts. Strengthening the collaboration and cooperation of the remote sensing and space-based technology task force through training and project initiatives is vital. Promoting collaborative activities and projects focused on space technology and its applications will help to leverage these technologies for broader societal benefits.[11]

2.2. Challenges and Future Perspectives

Despite advancements in remote sensing and GIS applications, several challenges remain:

Technical limitations: The need for continuous training and skill enhancement remains a pressing issue.

Data-sharing constraints: Limited interconnectivity between government agencies hampers the effective utilisation of GIS technologies.

Funding and resource constraints: Budget limitations affect the procurement of high-resolution satellite imagery and analytical tools.

Public awareness: There is a need to enhance community engagement and awareness regarding the benefits of remote sensing applications.

Future advancements in remote sensing technologies in Myanmar should focus on the following:

- Strengthening international collaborations for data access and knowledge exchange.
- Implementing real-time satellite monitoring systems for enhanced disaster response.
- Developing a centralised National GIS framework to facilitate integrated resource management.
- Enhancing technical training programs to build a skilled workforce proficient in the latest remote sensing and GIS technologies.
- Encouraging government-private sector partnerships to invest in high-resolution satellite imagery and geospatial infrastructure.
- Expanding public engagement initiatives to raise awareness of the importance of geospatial technologies in daily life and decision-making.

These conclusions emphasise the importance of GIS and remote sensing in informed decision making and highlight the need for capacity building, technical training, and enhanced collaboration to maximise the potential of these technologies in Myanmar. The adoption of remote sensing and GIS technologies in Myanmar has contributed significantly to various sectors, from agriculture and disaster management to cultural heritage preservation. While progress has been made, further investment in capacity building, infrastructure, and policy integration is necessary to maximise the benefits of these technologies. Strengthened collaboration between government institutions, academia, and international agencies will be crucial in ensuring the sustainable development of geospatial technologies in Myanmar. Implementing robust technical training programs, fostering public-private partnerships, and increasing public

[11] Reliefweb, Myanmar: Floods — Final Report, 2017. Available from: https://reliefweb.int/report/myanmar/myanmar-floods-final report-mdrmm006 (accessed: 14.03.2025); *Union of Myanmar. Ministry of Forestry. National Action Programme of Myanmar to Combat Desertification in the context of United Nations Convention to Combat Desertification (UNCCD*). Yangon: Ministry of Forestry; 2005; *United Nations Platform for Space-Based Information for Disaster Management and Emergency Response (UN-SPIDER), Flood 2022*, 2022. Available from: https://www.un-spider.org/flood (accessed: 14.03.2025).

awareness can significantly enhance the efficiency and effectiveness of remote sensing applications in Myanmar.[12]

2.3. UAV-Satellite Integration for Earth Remote Sensing

Unmanned Aerial Vehicles (UAVs) and Low Earth Orbit (LEO) satellites have become critical technologies for Earth remote sensing. Their integration provides enhanced spatial and temporal resolution, real-time data collection, and improved environmental monitoring capabilities. This thesis explores the challenges and methodologies associated with UAV-Satellite integration for remote sensing applications. The key areas of focus include optimising data transmission, improving energy efficiency, overcoming environmental constraints, ensuring seamless system integration, and addressing cybersecurity risks. This study aims to establish a framework for the effective use of UAV-Satellite networks to enhance Earth observation and disaster management. Remote sensing has transformed the monitoring of the Earth's surface, climate, and ecosystems. Traditionally, satellitebased remote sensing has been the primary tool for largescale environmental monitoring. However, satellite imagery often suffers from temporal delays, cloud-cover interference, and limited revisit times. UAVs, owing to their ability to capture high-resolution imagery in real time, offer a complementary solution (Figure 3).

The integration of UAVs with LEO satellites allows for more frequent and precise Earth observation, benefiting various applications, such as disaster response, agriculture, climate change studies, and urban development. This thesis examines the technical aspects of UAV-LEO satellite integration and explores practical solutions to overcome these challenges [16; 17].

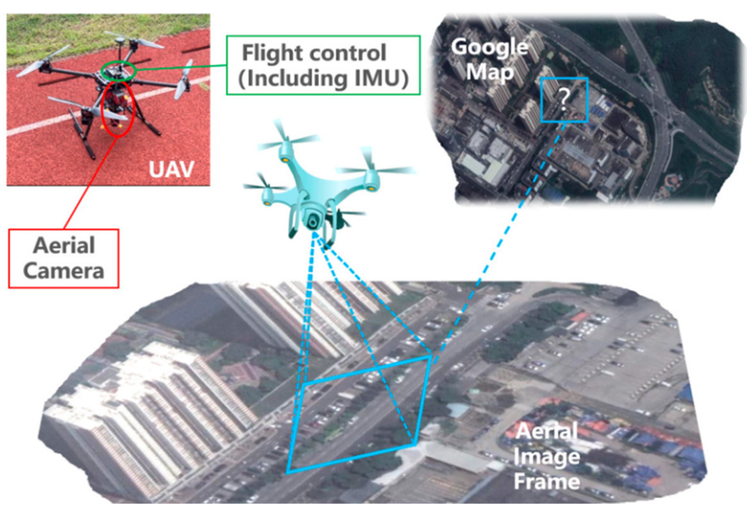

Figure 3. UAVs supports systems for Arieal Image with separated Area
S o u r c e: by A.V. Starkov, O.E. Samusenko, Aung Myo Thant

2.4. Advantages of UAV-Satellite Integration

Satellites provide global coverage with periodic updates, but their spatial resolution is limited by altitude and sensor constraints. UAVs offer ultra-high-resolution imagery at low altitudes, filling the gap in satellite imaging by capturing finer details. By integrating both the platforms, the system can achieve comprehensive coverage with real-time updates in high-priority areas.

[12] *Floodlist, UN Report — Floods in Myanmar Had Devastating Impact on Agriculture*, 2015. Available from: https://floodlist.com/asia/un-myanmar-floods-food-security (accessed: 14.03.2025); *Learning from the experiences of 13 developing countries. Global Comparative Study on REDD+(GCS REDD+).*

UAVs can relay real-time data to satellites, which then transmit infor-mation to ground stations for immediate analysis. This capability is essential for time-sensitive appli-cations such as disaster response, where rapid decision-making is re-quired. UAVs equipped with onboard processing units can preprocess data, reducing the burden on satellites and improving data transmission efficiency [16; 18–20].

Optical satellites are affected by cloud cover, which can obstruct imaging capabilities. UAVs equipped with Synthetic Aperture Radar (SAR) can operate under all weather conditions, providing uninterrupted imaging. The fusion of optical satellite imagery with UAV SAR data enhances the accuracy of remote-sensing applications.

Satellites are constrained to fixed orbits, there by limiting their capacity to focus on specific locations at will. UAVs can be deployed in targeted regions by adjusting their flight paths based on real-time events and mission requirements. This flexibility allows for rapid response to emerging environmental changes, natural disasters, and other critical situations (Figure 4). The deployment of LEO satellites requires significant investment, and their revisit frequency may not meet all the operational require-ments. UAVs provide a cost-effective solution for continuous monitoring of specific regions, reducing the need for frequent satellite launches. The hybrid approach minimises operational costs while maximising data coverage and frequency.

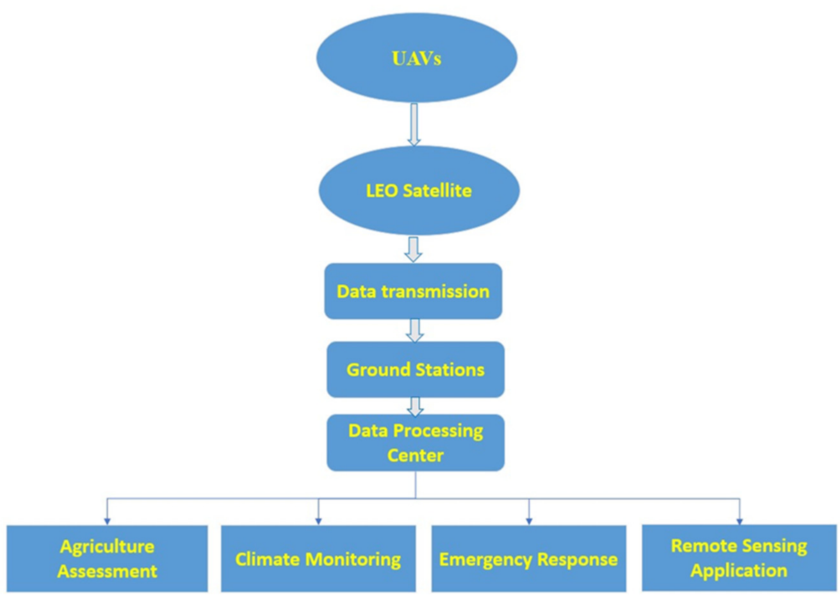

Figure 4. Application of UAV-Satellite Hybrid Systems to Users
S o u r c e: by A.V. Starkov, O.E. Samusenko, Aung Myo Thant

UAVs can be deployed rapidly in disaster-affected areas to assess damage, locate survivors, and provide first responders with real-time data. LEO satellites provide a broader overview of affected regions, helping authorities coordinate large-scale emergency response efforts. The combination of UAV and satellite data improves situational awareness and enhances relief operations. LEO satellites carry a variety of sensors, including optical, infrared, and hyperspectral imaging. UAVs can be equipped with complementary sensors such as LiDAR, thermal imaging, and high-resolution video cameras. This multi-sensor integration enhances the ability to monitor environmental changes, detect anomalies, and improve data accuracy. UAVs can act as relay nodes, ensuring continuous data transmission even in areas with limited satellite connectivity. Secure communication channels, including quantum encryption and frequency-hopping techniques, enhance data protection. Redundant transmission methods ensure data integrity, preventing losses during critical remote-sensing operations.

2.5. Proposed Methodologies

To optimise data relay efficiency, hybrid data transmission networks leverage laser communication between UAVs and LEO satellites, ensuring high-speed and low-latency connectivity [16; 21]. By implementing multichannel frequency-hopping techniques, these networks minimise the risk of signal interference, enhancing communication reliability in dynamic environments. Additionally, high-speed downlink stations play a crucial role in processing and distributing UAV-LEO data, thereby reducing reliance on terrestrial infrastructure. Starlink's optical inter-satellite communication system significantly decreases the dependency on ground stations, enabling more efficient and direct data transmission across space-based networks. Energy-Efficient UAV Design. To enhance the endurance and efficiency of remote-sensing missions, **solar-powered UAVs** are being developed, allowing for prolonged operation without frequent recharging. Additionally, integrating **fuel cell technologies** provides a supplementary power source, enabling UAVs to handle high-energy applications, such as advanced sensor payloads and long-range data transmission. Furthermore, the use of **lightweight composite materials** improves aerodynamics, reducing the overall power consumption and increasing flight efficiency. Airbus Zephyr's solar-powered UAV has demonstrated continuous flight beyond **30 days**, showcasing the potential for long-endurance, energy-efficient aerial operations [16; 20–22].

To enhance UAV-based remote sensing capabilities, Synthetic Aperture Radar (SAR) is integrated for cloud-penetrating imaging, enabling data acquisition under all weather conditions. Additionally, hyperspectral and infrared sensors provide advanced environmental monitoring by detecting subtle changes in vegetation, pollution levels, and temperature variations. The development of modular UAV payload systems further enhances flexibility, allowing UAVs to be adapted for diverse remote sensing applications from disaster response to agricultural assessment. NASA employs SAR-equipped UAVs to monitor Arctic ice sheets and analyse climate patterns, thereby providing critical insights into environmental changes. Ensuring seamless communication between UAVs and LEO satellites requires the establishment of interoperability protocols that facilitate efficient data exchange. Frequency coordination strategies are implemented to mitigate signal interference, optimising communication stability across multiple channels. Additionally, secure telemetry transmission safeguards data integrity, preventing potential corruption or cyber threats during transmission. The European Space Agency's Sentinel satellite program utilizes standardized data-sharing protocols to streamline Earth observation data integration across multiple platforms [17; 23].

Reducing the financial burden of UAV-Satellite integration involves leveraging CubeSats for low-cost LEO satellite launches, enhancing the affordability of UAV network expansion [18]. The development of modular UAV platforms with replaceable components ensures cost-effective maintenance, extending the operational lifespan while minimising expenses. Furthermore, high-altitude UAVs serve as viable alternatives to expensive geostationary satellites, offering regional monitoring capabilities at a fraction of the cost. SpaceX's cost-effective satellite launch solutions have significantly reduced deployment expenses, making remotesensing missions more accessible and scalable (Figure 5).

As UAV-LEO satellite communication systems have become more advanced, ensuring data security is a critical priority. Quantum encryption is employed to secure communication channels and prevent cyber threats such as eavesdropping and data interception. To enhance resilience against GPS spoofing and jamming attacks, alternative navigation methods, such as Inertial Navigation Systems (INS), are integrated to enable UAVs to operate autonomously without reliance on satellite-based positioning. Additionally, electromagnetic shielding is deployed to protect UAV electronics from external interference, ensuring stable operation even in environments with high electromagnetic activity. China's quantum communication satellite system significantly enhances data security for space-based operations, setting a new standard for encrypted satellite-UAV communications (Figure 6).

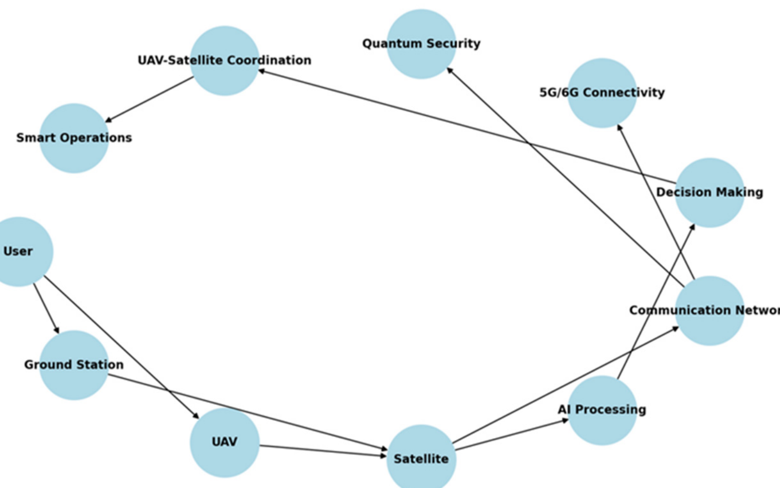

Figure 5. Flow chart UAVs-Satellite integration Cost-Effective Deployment Strategies

S o u r c e: by A.V. Starkov, O.E. Samusenko, Aung Myo Thant

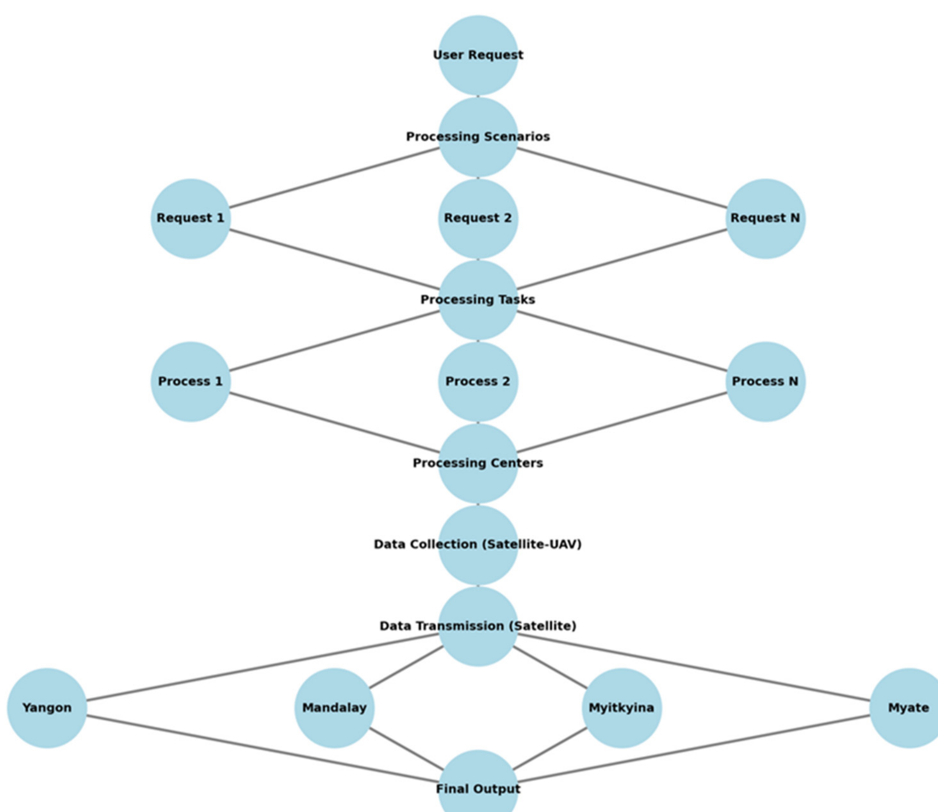

Figure 6. Flow chart UAVs-Satellite integration

S o u r c e: by A.V. Starkov, O.E. Samusenko, Aung Myo Thant

The integration of UAVs with satellites presents a promising advancement in Earth remote sensing, offering improved spatial resolution, real-time monitoring, and expanded coverage. Addressing technical challenges such as communication reliability, energy efficiency, environmental adaptability, and cybersecurity will enable sustainable UAV-satellite operations. By leveraging laser communication, solar-powered UAVs, SAR imaging, and standardised networking protocols, this study provides a framework for future UAV-assisted satellite remote sensing missions. Future developments will focus on refining UAV endurance, optimizing power consumption, and expanding UAV applications in climate change monitoring, agricultural assessment, and disaster management[13] [15; 20; 23; 24]

Conclusion

Satellite-UAV hybrid systems significantly enhance capabilities across various applications owing to their complementary strengths. Satellites excel at covering vast, often remote, regions, providing reliable and consistent large-scale monitoring. By contrast, UAVs, commonly known as drones, specialise in localised operations, capturing high-resolution imagery and precise data close to the ground. When these technologies are integrated, they offer an unmatched combination of wide-area coverage and detailed local insights, creating an ideal solution for comprehensive data gathering. The accuracy and resolution of data were significantly improved in these hybrid systems. While satellites typically offer broad-scale data that might lack fine details, UAVs can provide high-quality, detailed information about targeted areas. Thus, the hybrid approach ensures precise, accurate, and actionable information, which is critical for informed decision making in emergency response scenarios or detailed environmental analyses.

Real-time responsiveness is another vital advantage of Satellite-UAV hybrid systems. Satellites alone often experience latency between revisits to a particular location, potentially causing delays in urgent scenarios. UAVs complement this by swiftly responding to and delivering immediate data when rapid assessments are crucial, such as during natural disasters, humanitarian crises, or security operations. Reliable communication was further strengthened by using the hybrid approach. Satellites maintain robust communication channels that are essential in isolated regions lacking terrestrial infrastructure. Meanwhile, UAVs can act as temporary communication relays, especially valuable in situations where local ground communication networks are damaged or compromised[14].

These hybrid systems are characterised by flexibility and adaptability. Satellites provide consistent, predictable data collection due to their fixed orbital paths, while UAVs can quickly adapt to changing mission requirements, modifying their paths or targets in real time. This dual capability allows the hybrid system to manage evolving scenarios effectively. Cost effectiveness and system resilience are additional key factors. Satellites require significant initial investments, but offer affordable, continuous coverage over long periods. On the other hand, UAVs are cost-effective for rapid deployment and targeted short-term operations. Integrating both allows cost optimisation by leveraging satellite efficiency for long-term monitoring and UAV agility for immediate focused missions. Furthermore, the redundancy provided by both satellites and UAVs increases the overall reliability, ensuring continuous operation even if one component experiences disruption. Finally, the diverse application potential of Satellite-UAV hybrid systems is extensive.

They effectively support disaster management, environmental monitoring, agricultural and forestry

[13] European Parliament and of the Council of 27 April 2016, Regulation (EU) 2016/679 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation). Available from: http://data.europa.eu/eli/reg/2016/679/oj, 2016 (accessed: 14.03.2025).

[14] Union of Myanmar. Ministry of Forestry. National Action Programme of Myanmar to Combat Desertification in the context of United Nations Convention to Combat Desertification (UNCCD). Yangon: Ministry of Forestry; 2005. Remote Sensing for REDD+MRV for Myanmar Officials. Available from: https://www.icimod.org/remote-sensing-for-redd-mrv-for-myanmar-officials (accessed: 14.03.2025). *United Nations Platform for Space-Based Information for Disaster Management and Emergency Response (UN-SPIDER), Flood 2022*, 2022. Available from: https://www.un-spider.org/flood (accessed: 14.03.2025).

management, military and security surveillance, communication reinforcement in remote regions, and precise infrastructure inspection tasks. This breadth of applications demonstrates the significant value and broad appeal of adopting integrated Satellite-UAV solutions [25].

Implementing a **Satellite-UAV hybrid system** is highly advantageous for Myanmar, given the country's geographical diversity, frequent natural disasters, and limited infrastructure in remote regions. Satellites can provide extensive coverage across Myanmar's challenging terrain, enabling the reliable and comprehensive monitoring of environmental conditions, disaster risks, and resource management. Simultaneously, UAVs (drones) offer precise, high-resolution data collection, which is crucial for immediate local responses to disasters, such as cyclones, floods, or earthquakes. The integration of these technologies has the potential to enhance emergency responsiveness, strengthen communication connectivity in isolated regions, and facilitate effective management of agricultural, environmental, and infrastructural developments. This, in turn, is expected to support the nation's resilience and sustainable growth.

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