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The Role of Information and Communication Technology (ICT) in Space Science and Technology Development

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ABSTRACT
This study was aimed at examining the role of information and communication technology (ICT) in space science and technology development. The study employed the review research approach using recent and verifiable journal publications from reputable sources such as IEEE, ISPRS, Telecommunications Policy, and Frontiers. From the results of the review, it was observed that some roles of ICT in space science and technology development are design and simulation, launch, tracking and control, data collection, satellite communication, data processing and analytics, weather forecasting, and climate studies. The analysis also indicated that ICT enables reliable communication through systems such as Starlink and VSAT, supports onboard processing of satellite data, improves Earth observation analysis through artificial intelligence, and enhances autonomous spacecraft operations and monitoring. From the results, it was concluded that ICT plays several crucial roles in space science and technology development, given that ICT has transformed space activities by improving efficiency, reducing operational delays, and increasing the availability of accurate scientific information and will continue to play a critical role in future space exploration, communication, environmental monitoring, and global digital connectivity.

KEYWORDS: *Artificial intelligence, Data Processing & Analytics, ICT, Satellite communication, Space Science and Technology.*

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1. INTRODUCTION
Space science and technology "deal with the study of the upper atmosphere (space) and the body in outer space or celestial body other than the earth, as well as how the engineering and scientific disciplines will be able to explore and use outer space to the benefit of humanity" (Mohammed and Ayegba, 2016). Information and Communication Technology (ICT) refers to the combination of computer systems, software applications, telecommunications networks, and digital devices used for collecting, processing, storing, retrieving, and transmitting information. It involves an extensive range of technologies that facilitate data storage, retrieval, manipulation, transmission, and reception in various forms, including audio, visual, textual, and digital content. Information and Communication Technology (ICT) is an umbrella term that includes all technologies used to handle telecommunications, broadcast media, intelligent building management systems, audiovisual processing, and transmission systems, as well as network-based control and monitoring functions. It combines both information technology (IT) and communication technology (CT), encompassing devices like computers, the internet, mobile phones, digital televisions, and software applications.

According to Sadiku et al. (2024), Information and Communication Technology (ICT) refers to the collection of technologies used for the acquisition, processing, storage, retrieval, transmission, and exchange of information. The authors further explained that ICT encompasses computer systems, telecommunications, software applications, networking technologies, and digital communication tools that support activities across sectors such as education, healthcare, business, government, agriculture, and scientific research. With the development of the Internet and the increase of digital multimedia communication services, satellite communication is developing rapidly (Rame et al., 2024). The findings suggested that the combination of Earth observation and machine learning was successfully applied in several different fields across the world. Additionally, it was observed that all machine learning categories could be used to analyse Earth observation data or to improve acquisition processes (Ferreira, 2022). According to Beauchamp and Baran (2024)**,** communication is fundamental to human interaction and has enabled societies to develop and exchange knowledge over time. They further explained that the Internet and other digital communication technologies have transformed the way people communicate, allowing individuals to remain connected regardless of geographical distance while promoting global interaction. This work focuses on how ICT has played, and is still playing, important roles in the general development of space science and technology.

1.1. KEY COMPONENTS OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT)

Information and Communication Technology (ICT) is composed of several components that collectively support the creation, processing, storage, transmission, and management of data or information. These components include hardware, software, networks, data management systems, telecommunications, the Internet of Things (IoT), people, and operational procedures.

1.1.1. Hardware: Hardware refers to the physical devices and equipment used in ICT systems. It constitutes the tangible infrastructure that enables data processing, storage, input, output, and communication. Examples are

A. Computers such as desktop systems, laptops, and servers serve as the primary processing devices within ICT environments.

B. Mobile devices such as smartphones, tablets, and wearable technologies provide portable computing capabilities and facilitate communication and data access regardless of location.

C. Networking equipment such as routers, switches, modems, and firewalls enable interconnection among devices and support the transfer of data within local and wide-area networks. Routers direct traffic between networks, switches connect devices within the same network, and firewalls provide security through traffic monitoring and filtering.

D. Peripheral devices such as printers, scanners, and external storage drives extend the functionality of computing systems and support activities, including document processing, data backup, and information sharing.

1.1.2. Software

Software comprises the programs, applications, and operating systems that instruct hardware on how to perform specific tasks. Software enables users to process information, manage resources, and communicate effectively.

Operating systems, including Windows, macOS, Linux, Android, and iOS, manage hardware resources and provide the platform upon which other applications operate. They coordinate processes, memory allocation, file management, and device control, thereby forming the core of computing operations.

1.1.3. Networks

Networks are systems of interconnected devices that facilitate communication and information exchange. They are essential for connecting computers, mobile devices, and other digital systems across different geographical locations.

The Internet represents the largest global network and connects billions of devices worldwide. It supports communication, information sharing, e-commerce, remote work, and access to online services irrespective of geographic boundaries.

1.1.4. Data Management Systems

Data management systems are technologies designed to store, organize, process, retrieve, and analyze information. Cloud storage services, including Google Drive, Dropbox, and Amazon Web Services (AWS), allow data to be stored remotely and accessed through the Internet, thereby supporting backup, disaster recovery, collaboration, and scalable data management.

1.1.5. Telecommunications

Telecommunications refers to the transmission of voice, video, and data over distances through electronic communication systems or over long distances. It forms a central element of ICT infrastructure.

Voice and video communication technologies, including Voice over Internet Protocol (VoIP) platforms such as Zoom, Skype, and Microsoft Teams, enable real-time audio and video interaction. Broadcasting technologies, including radio, television, and digital streaming services, provide one-way communication to large audiences for purposes such as news dissemination, entertainment, and public information.

1.1.6. Internet of Things (IoT)

The Internet of Things (IoT) is a network of physical devices connected to the Internet that can collect, transmit, and exchange data. IoT technologies are widely applied in sectors such as healthcare, transportation, agriculture, manufacturing, and smart city development to improve monitoring, automation, and decision-making.

1.1.7. People

People constitute a fundamental component of ICT because they design, develop, manage, maintain, and utilise technological systems. Users employ ICT tools for communication, education, research, work, and entertainment, while IT professionals such as software developers, network engineers, system administrators, and data analysts are responsible for the implementation, maintenance, and security of ICT infrastructure.

1.1.8. Operational Procedures

Operational procedures are the established guidelines and processes used to manage and maintain ICT systems. These procedures include software updates, hardware maintenance, data backup, security management, troubleshooting, and system monitoring. This approach is needed in any organization in order to achieve reliable, secure, and efficient ICT operations.

2. METHODOLOGY

This study adopted a review research method to examine the role of information and communication technology (ICT) in space science and technology development. The method was considered appropriate because the study focused on synthesizing existing knowledge and findings from published scholarly works rather than collecting primary experimental data. Relevant literature was obtained from reputable academic databases, including IEEE Xplore, ISPRS Journal of Photogrammetry and Remote Sensing, Telecommunications Policy, Frontiers in Communications and Networks, and other peer-reviewed sources. Information extracted from the selected publications was organized according to major thematic areas. Each study was critically examined to identify how ICT contributes to the operation, management, and advancement of space science and technology systems. The use of the review method allowed the study to compare different scholarly perspectives, identify common trends, and highlight the growing importance of ICT in supporting communication, data management, environmental monitoring, and autonomous spacecraft operations.

3. RESULTS AND DISCUSSION

The major roles of Information and Communication Technology (ICT) in space science and technology development include the following:

3.1. Design and Simulation

Information and Communication Technology (ICT) plays a major role in the design and simulation of space systems. Before a rocket, satellite, or spacecraft is physically built, engineers use computer-based tools to create detailed three-dimensional models of every component. Through the computer or ICT software, they can test whether parts fit together properly and whether the structure will withstand the harsh conditions of space. ICT also enables powerful simulations that predict how a spacecraft will behave during launch, orbit, and re-entry into the atmosphere. Higher computing analysis can analyze heat, vibration, radiation, and fuel consumption of the spacecraft without the need for expensive physical testing. Mohan et al. (2024) reported that advanced computer-aided design and simulation platforms enable engineers to model spacecraft structures, thermal conditions, and launch dynamics before physical construction begins. Their study revealed that digital simulation significantly reduces design errors and improves mission reliability by allowing thousands of virtual tests to be conducted. Modeling and simulation are powerful methods to evaluate the design of a space system, as simulation models represent valuable knowledge. In spacecraft design, for instance, control engineers model the attitude and orbit control system (AOCS) of a spacecraft and use a continuous or discrete simulation to validate orbit maneuvers and attitude control performance (Schaus, et al., 2013).

3.2. Launch, Tracking, and Control

ICT is important during the launch and operation of a spacecraft in space. Once a rocket leaves the ground, a large number of sensors continuously send information back to Earth through a process called telemetry, which includes the rocket's speed, altitude, temperature, fuel level, and position. This information or telemetry is received by the ground stations, which are facilities equipped with antennas and communication networks in real time and allow engineers or scientists to monitor the mission from Earth. Through ICT systems, operators or engineers can also send commands back to the spacecraft to adjust its orbit, activate instruments on the spacecraft like cameras and transponders, or correct faults. ICT also supports the navigation systems, and this will enable it to calculate precise orbital positions and ensure that satellites remain on their intended paths or orbital altitudes. Without these ICT technologies, mission controllers would have little ability to track or manage spacecraft after launch. A practical example is the communication between the satellite ground station in the National Space Research and Development Agency (NASRDA), Abuja, and Nigerian satellites, where ICT is used to maintain contact, monitor performance, and control satellite operations from Earth. According to Rame et al. (2024), most of the existing automatic tracking schemes drive the tracking system based on the beacon signal or forwarded pilot signal transmitted by the received satellite. The automatic antenna positioning system primarily functions to identify the source of the signal, since the system can detect signals of various types, recognizing specific signals and adjusting the antenna's position to optimize signal strength reception. This can be achieved through the ICT, using computer mode or fully automated mode by interfacing with Orbitron software. As reported by Horace and Harry (1999), today's flight software systems can be scripted to perform sophisticated closed-loop tracking and navigation, autonomous attitude control, and onboard processing of science data, and can greatly reduce the burden on ground operations in monitoring and exercising control over the spacecraft.

Plate 1. NASRDA Ground station, NASRDA, Abuja

3.3. Data Collection

Earth-observation satellites capture images used for various functions such as weather forecasting, agriculture, environmental monitoring, disaster management, and security operations. Satellites in space send large volumes of scientific data back to Earth for analysis, and ICT systems, including cloud computing and big-data platforms, make it possible to store these datasets and process them efficiently. Weather forecasting agencies rely heavily on satellite data processed through ICT systems to provide timely weather information and early warnings for floods and other environmental hazards. Therefore, ICT transforms raw space data into useful knowledge that supports scientific research, economic activities, and public safety. Software, a foundational component of ICT, is very key in autonomous satellite operation. As highlighted by Lutz (2011), the software onboard spacecraft acquires scientific data from sensors, cameras, and instruments and then transmits the information back to Earth for further analysis. It also processes and analyses part of the data onboard to reduce transmission demands and improve efficiency. ICT tools help scientists visualise, interpret, and manage the large volumes of data generated by satellites. The study further notes that advanced software supports autonomous decision-making, allowing satellites to identify important observations and prioritise data downlink. According to Horace and Harry (1999), flight software controls science instruments, acquires sensor and telemetry data, and manages the transmission of information to ground stations. The authors note that modern spacecraft perform onboard processing of science data, including data editing, image processing, and advanced data compression before downlinking. Software also supports autonomous navigation, tracking, and attitude control, reducing dependence on ground operators. In addition, multitasking operating systems and high-performance processors enable real-time handling of multiple data streams from different instruments.

3.4. Communication

ICT has made space one of the most important communication platforms in the world. Through communication satellites, people can access internet services, television broadcasts, radio programmes, and mobile communication even in areas where normal network infrastructure is poor. For example, satellite internet services such as Starlink and VSAT can provide connectivity to rural communities that may not have fibre-optic cables or strong mobile network coverage. ICT also supports communication with spacecraft that are far from Earth. Deep-space networks use advanced communication systems to exchange messages and scientific data with missions travelling to the Moon, Mars, and beyond. In simple terms, ICT allows satellites in space to become communication bridges that connect people, organisations, and even other planets. According to Feltrin et al. (2021), recent advances in satellite-based

Information and Communications Technology (ICT) have significantly enhanced the potential of Non-Terrestrial Networks (NTN) for broadband services. The authors emphasise that the adoption of 5G massive MIMO techniques—such as advanced beamforming, improved channel measurements, and delay/Doppler compensation—on low earth orbit (LEO) satellites has substantially improved latency, achievable data rates, and overall system capacity compared to previous generations of ICT from space. According to Kassem and Marinoni (2022), ICT is the foundation of Starlink's satellite internet system. The authors explained that Starlink uses software-controlled networking, digital signal processing, phased-array antennas, and beam-steering technologies to provide broadband internet through a constellation of low-Earth-orbit satellites. ICT enables real-time routeing of data between user terminals, satellites, and ground gateways, ensuring continuous connectivity even as satellites move across the sky. The study further noted that the use of advanced networking software and onboard communication management significantly reduces latency compared with traditional geostationary satellite systems. In essence, ICT transforms Starlink satellites into intelligent communication platforms capable of delivering high-speed internet and digital services to remote and underserved communities. According to Chiha et al. (2020), ICT plays a critical role in the operation of VSAT systems. The authors explained that VSAT terminals use ICT-based modulation, error correction, bandwidth allocation, and remote network management to connect local networks to communication satellites. These satellites relay voice, video, internet, and data traffic to central gateways that are linked to national communication infrastructures. The study emphasised that integrating VSAT with mobile and broadband networks improves connectivity in rural and hard-to-reach areas where fibre-optic infrastructure is unavailable.

3.5. Data Processing and Analytics

ICT facilitates the transmission, preprocessing, enhancement, and classification of massive volumes of raw satellite imagery. Information and Communication Technology (ICT) plays an important role in the processing and analysis of satellite imagery by enabling the efficient handling of large amounts of data generated by satellites. After images are captured, ICT systems facilitate their transmission to ground stations and provide the computing resources needed for analysis. The raw images are first preprocessed to remove noise, correct distortions, and improve accuracy. ICT-based software is then used for image enhancement, where features such as contrast and brightness are adjusted to make important details easier to identify. ICT also supports the classification of satellite images using techniques such as machine learning and artificial intelligence. These methods automatically identify features like vegetation, water bodies, urban areas, and disaster-affected regions, reducing the need for extensive manual interpretation. According to Parra Garcia et al. (2024), ICT is used onboard satellites to process synthetic aperture radar (SAR) data in real time. The authors explained that onboard computing performs data processing and compression before transmission to Earth. ICT helps reduce the volume of raw radar data that must be downlinked, thereby optimizing limited satellite bandwidth. The study also showed that onboard analytics improves the speed of delivering final data products for time-sensitive applications. Furthermore, ICT enables faster image generation, lower transmission delays, and more efficient use of communication resources. According to Barretta et al. (2026), ICT enables satellites to process and analyze Earth observation data directly onboard using artificial intelligence and advanced computing systems. The authors explained that onboard AI reduces the need to transmit large volumes of raw data to ground stations. ICT supports autonomous image processing, feature extraction, anomaly detection, and real-time decision-making. The study further noted that onboard analytics reduces latency and improves the speed of disaster monitoring, environmental surveillance, and climate assessment. By shifting computation from the ground to the satellite, ICT allows faster generation of useful information products.

3.6. Weather Forecasting and Climate Studies

ICT processes meteorological satellite data to improve weather prediction, climate monitoring, and early warning systems. Weather forecasting and climate studies represent a major application of information and communication technology (ICT) in space science and technology. Meteorological satellites continuously observe the Earth's atmosphere, oceans, clouds, and land surfaces, generating enormous amounts of data every day. ICT systems are used to receive, process, store, and analyze this satellite data in real time. Through advanced computer networks, databases, and forecasting software, scientists can identify weather patterns, monitor atmospheric changes, and predict future weather conditions with greater accuracy. In weather forecasting, ICT enables the rapid processing of satellite images and sensor measurements to detect phenomena such as storms, rainfall, hurricanes, droughts, and temperature variations. The processed information is integrated into numerical weather prediction models, which help meteorologists forecast short-term and long-term weather conditions. This improves the accuracy of daily weather reports and supports sectors such as agriculture, aviation, transportation, and disaster management.

For climate studies, ICT plays a crucial role in analyzing long-term environmental trends. By comparing satellite data collected over many years, researchers can monitor climate change indicators such as rising temperatures, melting ice, sea-level changes, and shifts in rainfall patterns. ICT also supports early warning systems by enabling the timely dissemination of alerts to governments, emergency agencies, and the public when severe weather events are detected. In the work by Kumar et al. (2023), which investigated the use of meteorological satellite data combined with machine-learning algorithms for short-term weather forecasting, it was reported that the integration of ICT-based data processing with machine-learning models improved rainfall prediction accuracy compared with traditional forecasting methods. Similarly, Ramachandran et al. (2022) state that ICT plays a fundamental role in processing and managing satellite observations for climate monitoring and Earth system research. The authors explained that Earth observation satellites generate enormous volumes of environmental data that require advanced computing, cloud technologies, and data analytics for efficient storage and analysis. ICT enables the integration of satellite observations with climate models to monitor long-term changes in temperature, precipitation, vegetation, and land use. The study further noted that modern ICT platforms improve data accessibility, visualization, and decision-making for researchers and policymakers. The authors concluded that ICT has become indispensable for transforming satellite observations into reliable climate information that supports environmental management and sustainable development.

3.7. Remote Sensing and Earth Observation

ICT facilitates the interpretation of satellite imagery for applications such as agriculture, environmental monitoring, disaster management, and urban planning. Remote sensing and Earth observation are important applications of information and communication technology (ICT) in space science and technology. Remote sensing satellites capture images and measurements of the Earth's surface, atmosphere, and oceans using sensors that operate in different parts of the electromagnetic spectrum. ICT systems are then used to receive, process, store, and interpret this large volume of satellite data. Through advanced computer software, image-processing techniques, and communication networks, raw satellite imagery is transformed into useful information for decision-making. In agriculture, ICT-assisted remote sensing helps monitor crop health, soil moisture, vegetation growth, and irrigation requirements. Farmers and agricultural agencies can identify areas affected by drought, pests, or nutrient deficiencies and take appropriate actions to improve productivity. For environmental monitoring, satellite imagery is used to track deforestation, land degradation, water pollution, and changes in ecosystems over time. ICT enables researchers to analyze these environmental changes quickly and accurately. Xu et al. (2022) investigated the application of deep-learning techniques to satellite imagery for crop monitoring. Using multispectral Earth observation data, the authors developed a convolutional neural network model to classify crop types and assess vegetation health. Their results demonstrated improved classification accuracy compared with conventional image-processing methods. The study concluded that ICT-enabled remote sensing can support precision agriculture by providing timely information on crop conditions and resource management. According to Ma et al. (2019), ICT has significantly improved remote sensing and Earth observation through the use of deep learning and advanced image-processing techniques. The authors explained that satellite imagery can be automatically analyzed for land-cover classification, environmental monitoring, agriculture, and urban planning. ICT enables the processing of large volumes of remote-sensing data using artificial intelligence and cloud-based computing systems. The study further noted that automated feature extraction improves the accuracy and speed of interpreting satellite images. In addition, ICT supports the integration of multispectral and hyperspectral data for more detailed Earth observation analysis. According to Li et al. (2016), ICT plays a central role in the handling and analysis of large geospatial datasets generated by Earth observation satellites. The authors explained that modern remote-sensing systems produce massive amounts of spatial data that require advanced computing, storage, and processing technologies. ICT enables real-time data management, distributed processing, and cloud-based analytics for satellite observations. The study also highlighted the use of geospatial databases and visualization tools to support environmental monitoring, disaster management, and climate studies.

4. Conclusion

The focus of this study was to examine the role of information and communication technology (ICT) in the development of space science and technology.

Through the reviewed literature, it was observed that ICT supports satellite communication, spacecraft control and monitoring, remote sensing, Earth observation, weather forecasting, and onboard data processing. Technologies such as Starlink, VSAT, artificial intelligence, cloud computing, and telemetry systems have improved the efficiency, accuracy, and reliability of space operations. ICT has also enabled real-time data analysis, autonomous spacecraft functions, and the delivery of communication services to remote and underserved areas. The findings demonstrate that modern space systems depend heavily on ICT for the collection, processing, transmission, and management of information. The results of this research will be important to relevant stakeholders in the space industry, including policymakers, engineers, researchers, and agencies such as NASRDA. This study is very important as it will enhance understanding of the critical integration of ICT in space systems, support future innovations in space exploration, environmental monitoring, scientific research, and global communication networks, as well as contribute to the advancement of space science and technology in Nigeria and beyond.

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