Abdullah, Q., Abdullah, N., Balfaqih, M., Shah, N. S. M., Anuar, S., Almohammedi, A. A., Salh, A., Farah, N., & Shepelev, V. (2020). Maximising system throughput in wireless powered sub-6 GHz and millimetre-wave 5G heterogeneous networks. Telkomnika, 18(3), 1185–1194. <https://doi.org/10.12928/TELKOMNIKA.v18i3.15049>

The current study explores the performance of dense small cells operating in the millimetre-wave (mm-Wave) band and sub-6 GHz frequencies to achieve high throughput with low transmission power in 5G networks. The study analyzes propagation path loss and wireless powered transfer for a 5G wireless cellular system, considering macro cells and femtocells in both sub-6 GHz and mm-Wave tiers. The paper proposes a novel distributed power algorithm to mitigate inter-beam interference and achieve high throughput under game theory-based power constraints across the sub-6 GHz and mm-Wave interfaces. The research emphasizes the importance of massive MIMO systems and beamforming gain in combating path loss in millimetre wave transmission for high throughput in 5G networks.

The findings in the paper have several implications for the future development of 5G networks:

**High Throughput with Low Transmission Power:** The study highlights the potential to achieve high throughput in 5G networks while using low transmission power. This efficiency can lead to improved network performance and reduced energy consumption in future 5G deployments.

**Utilization of Millimetre-Wave Technology:** By focusing on the performance of dense small cells operating in the millimetre-wave band, the paper underscores the importance of leveraging millimetre-wave technology for high-speed data transmission in 5G networks. This suggests that future 5G networks may heavily rely on millimetre-wave frequencies to meet increasing data demands.

**Interference Mitigation Strategies:** The proposed distributed power algorithm for mitigating inter-beam interference can guide the development of advanced interference management techniques in 5G networks. Future network designs may incorporate similar strategies to optimize throughput and enhance overall network performance.

**Integration of Massive MIMO Systems:** The emphasis on massive MIMO systems as a critical component for millimetre wave technology in 5G networks indicates that future developments may prioritize the integration of massive MIMO for improved coverage, capacity, and spectral efficiency.

**Game Theory-Based Power Constraints:** The use of game theory-based power constraints in the study suggests that future 5G network designs may benefit from incorporating advanced optimization techniques to manage power allocation efficiently and enhance network performance.

Overall, the findings in this paper provide valuable insights into optimizing system throughput in 5G networks, which can influence the future development of 5G technologies by emphasizing efficiency, interference mitigation, utilization of millimetre-wave frequencies, and integration of advanced network optimization strategies.

Hong, W., Jiang, Z. H., Yu, C., Hou, D., Wang, H., Guo, C., Hu, Y., Kuai, L., Yu, Y., Jiang, Z., Chen, Z., Chen, J., Yu, Z., Zhai, J., Zhang, N., Tian, L., Wu, F., Yang, G., Hao, Z., & Zhou, J. Y. (2021). The Role of Millimeter-Wave Technologies in 5G/6G Wireless Communications. IEEE Journal of Microwaves, 1(1), 101–122. <https://doi.org/10.1109/JMW.2020.3035541>

The paper discusses several key findings and insights regarding millimeter-wave technologies in the context of 5G and future 6G wireless communications. Some of the key points highlighted in the paper include:

**Importance of Millimeter-Wave Spectrum**: The paper emphasizes the significance of utilizing the millimeter-wave spectrum for the first time in mobile communication infrastructures to achieve ultra-fast data rates, low latency, and improved spectral efficiency in 5G networks.

**Role in Future 6G Networks**: As the demand for data-intensive applications grows beyond 5G capabilities, the paper suggests that millimeter-wave technologies will continue to play a crucial role in enabling the envisioned network performance and communication tasks in future 6G networks.

**Enabling Technologies**: The paper reviews recent developments in millimeter-wave enabling technologies, including advancements in system architectures of active beamforming arrays, beamforming integrated circuits, antennas for base stations and user terminals, system measurement and calibration, and channel characterization.

**System Requirements**: The authors briefly discuss the requirements of various components such as antennas, beamforming systems, and RF integrated circuits for future 6G communications, highlighting the need for continued innovation in these areas to meet the evolving demands of wireless networks.

**Coverage and Connectivity**: The paper envisions that 6G networks will cover almost the entire surface of the earth and extend into near outer space, indicating the need for advanced technologies like millimeter-wave to ensure seamless connectivity and communication across vast geographical areas.

These findings underscore the critical role of millimeter-wave technologies in shaping the evolution of wireless communications from 5G to future 6G networks, paving the way for enhanced performance, connectivity, and user experiences in the era of next-generation wireless technologies.

The authors of "The Role of Millimeter-Wave Technologies in 5G/6G Wireless Communications" propose leveraging millimeter-wave technologies to enhance the performance and capabilities of future wireless networks through several key strategies and advancements. Here are some of the ways in which the authors suggest utilizing millimeter-wave technologies for this purpose:

**Ultra-Fast Data Rates**: By exploiting the millimeter-wave spectrum, future wireless networks can achieve ultra-fast data rates, enabling high-speed data transmission and supporting bandwidth-intensive applications such as virtual reality, augmented reality, and high-definition video streaming.

**Low Latency**: Millimeter-wave technologies can help reduce latency in wireless communications, enabling real-time interactions and applications that require instantaneous responsiveness, such as autonomous vehicles, remote surgery, and industrial automation.

**Improved Spectral Efficiency**: The use of millimeter-wave frequencies allows for improved spectral efficiency, enabling more data to be transmitted over the airwaves simultaneously. This increased efficiency can support the growing demand for data-intensive services and applications in future wireless networks.

**Massive MIMO and Beamforming**: The authors advocate for the implementation of massive multiple-input multiple-output (MIMO) systems and beamforming techniques at millimeter-wave frequencies to enhance coverage, capacity, and reliability in wireless networks. These technologies help focus the radiated energy into targeted directions, overcoming the challenges of high free-space path loss at millimeter-wave frequencies.

**Advanced Antenna Technologies**: The paper discusses advancements in millimeter-wave antennas for base stations and user terminals, highlighting the importance of deploying sophisticated antenna systems to improve signal quality, coverage, and network performance in future wireless networks.

By incorporating these strategies and technologies, the authors believe that millimeter-wave technologies can significantly enhance the performance, capacity, and capabilities of future wireless networks, paving the way for a new era of high-speed, low-latency, and efficient wireless communications in the 6G era and beyond.

Barb, G., Danuti, F., Ouamri, M. A., & Otesteanu, M. (2022, November). Analysis of vegetation and penetration losses in 5G mmwave communication systems. 2022 International Symposium on Electronics and Telecommunications (ISETC) Electronics and Telecommunications (ISETC), 2022 International Symposium on. :1-5 Nov, 2022. <https://doi.org/10.1109/ISETC56213.2022.10009963>

The authors provides a comprehensive analysis of the propagation channel characteristics in 5G systems, specifically focusing on vegetation and penetration losses in mmWave communication. The study aims to understand the impact of vegetation and penetration on signal propagation in order to optimize the design and deployment of 5G networks. Here is a summary of the literature review presented in the document:

**5G Technology Overview**: The paper introduces the concept of 5G networks as the fifth generation of mobile telephony standards, validated by the ITU and 3GPP. It highlights the importance of high-frequency spectrum bands above 6 GHz, such as millimeter waves (mmWave), for delivering large bandwidth and enabling seamless communications.

**Propagation Channel Characteristics**: The study emphasizes the significance of understanding the propagation effects in mmWave bands due to their sensitivity to obstructions in real-life environments. Challenges such as body shadowing, building penetration, and foliage attenuation are discussed, underscoring the need for a thorough analysis of these effects for optimal network design and base station placement.

**Research on mmWave Technology**: Previous research on mmWave technology is referenced, including studies on optimizing 5G cellular systems, channel estimation schemes, beamforming effects, and throughput estimates for mmWave networks. Technical challenges associated with mmWave frequencies are acknowledged, necessitating a detailed analysis of propagation effects.

**Literature References**: The document cites relevant literature on mmWave propagation channels, including studies on microwave vs. millimeter-wave propagation channels, scattering suppression in base station antenna arrays, NLOS coverage using specular building reflections, and MIMO relays for building penetration communications 5.

**Future Research Directions**: The paper outlines future research directions, indicating a plan to investigate penetration losses for normal window glass and glazed glass to determine their suitability for future network development.

**Simulation Parameters and Results**: The study presents simulation parameters used for the analysis, conducted using Nokia's internal simulator with MATLAB. The environment replicates outdoor propagation, with specific antenna heights and widths considered for the simulations.

Overall, the document provides a comprehensive overview of the challenges and opportunities in optimizing the propagation channel for 5G mmWave communication systems, highlighting the importance of understanding vegetation and penetration losses for efficient network deployment.

The main issues associated with using millimeter-wave (mmWave) bands for 5G networks include:

**Propagation Losses**: Millimeter waves have higher propagation losses compared to lower frequency bands. These losses are influenced by atmospheric absorption, scattering, and penetration through obstacles such as buildings and vegetation.

**Limited Range**: Millimeter waves have a shorter range compared to lower frequency bands, requiring more base stations for coverage. The higher frequencies result in shorter wavelengths, making them more susceptible to blockages and signal attenuation.

**Obstruction Sensitivity**: Millimeter waves are highly sensitive to obstructions such as buildings, trees, and even human bodies. This sensitivity can lead to signal blockages, shadowing, and reduced coverage in urban environments with dense infrastructure.

**Fading and Reflections**: Millimeter waves are prone to fading due to multipath reflections and scattering. The reflections off surfaces can cause signal degradation and interference, impacting the overall network performance.

**Equipment and Infrastructure**: Deploying mmWave networks requires specialized equipment and infrastructure due to the unique characteristics of these high-frequency bands. This includes antenna design, beamforming technology, and network planning to mitigate propagation challenges.

**Regulatory Considerations**: Utilizing mmWave spectrum for 5G networks requires adherence to regulatory guidelines and standards. Coordinating spectrum allocation and ensuring compliance with regulations can be complex and time-consuming.

Addressing these challenges through advanced technologies such as beamforming, massive MIMO, and adaptive antenna systems, as well as conducting thorough propagation studies and network planning, are essential for successful deployment and optimization of mmWave-based 5G networks.

Some of the key benefits of adopting new frequency bands, such as millimeter-wave (mmWave), for 5G networks compared to traditional frequency bands below 6 GHz include:

**Increased Bandwidth**: Millimeter-wave bands offer significantly larger bandwidth compared to lower frequency bands, enabling higher data rates and supporting the growing demand for data-intensive applications and services in 5G networks.

**Enhanced Capacity**: The use of mmWave frequencies allows for increased network capacity, enabling more devices to connect simultaneously and providing better support for applications requiring high throughput and low latency.

**Low Latency**: Millimeter-wave technology can help reduce latency in 5G networks, enabling faster response times for real-time applications such as virtual reality, augmented reality, autonomous vehicles, and industrial automation.

**Support for Massive Connectivity**: MmWave bands can support massive connectivity by accommodating a large number of devices within a small geographical area, making them suitable for IoT applications and dense urban environments.

**Improved Spectrum Efficiency**: Utilizing mmWave frequencies allows for more efficient spectrum utilization, enabling operators to maximize the use of available spectrum resources and optimize network performance.

**Future-Proofing Networks**: By adopting new frequency bands like mmWave, 5G networks can be future-proofed to meet the evolving demands of users and applications, ensuring scalability and readiness for emerging technologies.

**Innovative Use Cases**: The unique characteristics of mmWave technology open up opportunities for innovative use cases and services, such as ultra-high-definition video streaming, immersive gaming, and advanced industrial applications that require high-speed, low-latency connectivity.

In summary, the adoption of new frequency bands like mmWave in 5G networks offers significant advantages in terms of bandwidth, capacity, latency, spectrum efficiency, and support for emerging technologies, paving the way for a more connected and technologically advanced future.

Bose, T., Chatur, N., Mukherjee, M., Verma, S., & Adhya, A. (2024). Traffic-Aware Optimal Multi-Beam Resource Allocation in 5G Networks Impaired by Rain and Foliage. IEEE Communications Letters, 1. <https://doi.org/10.1109/LCOMM.2024.3357174>

The authors discusses a novel approach for optimizing resource allocation in 5G networks affected by rain and foliage attenuation. It introduces a graphical methodology to compute the optimal coverage radius of the gNB, utilizes the k-means clustering algorithm to determine the optimal gNB location, and proposes a non-linear programming (NLP) framework for multi-beam resource allocation. The study demonstrates improved performance in terms of the number of users served compared to genetic algorithms and surrogate optimization methods. Additionally, the document highlights simulation results, network deployment details, and future research directions, emphasizing the significance of efficient resource allocation in 5G and upcoming 6G networks.

In the study, foliage attenuation is considered as one of the impairments affecting the performance of 5G networks. To account for foliage attenuation, the study incorporates the foliage depth as a parameter in the optimization process. By varying the foliage depth (1m, 2m, 5m), the impact of foliage attenuation on the network deployment and resource allocation is analyzed.

The study does not estimate the foliage directly. Instead, it considers foliage attenuation as an environmental factor that impacts the performance of 5G networks. The foliage depth is used as a parameter to represent the level of foliage attenuation in the optimization process. By varying the foliage depth (1m, 2m, 5m), the study evaluates how different levels of foliage attenuation affect the optimal location of the gNB and the coverage radius. The focus is on optimizing resource allocation strategies to mitigate the effects of foliage attenuation and ensure efficient network performance in the presence of foliage obstacles. The study does not involve direct estimation or measurement of foliage but incorporates foliage depth as a parameter to model the attenuation caused by foliage in the network environment.

Khan, N. A., & Schmid, S. (2024). AI-RAN in 6G Networks: State-of-the-Art and Challenges. IEEE Open Journal of the Communications Society, 5, 294–311. <https://doi.org/10.1109/OJCOMS.2023.3343069>

The article "AI-RAN in 6G Networks: State-of-the-Art and Challenges" by Khan and Schmid explores the advancements and challenges in deploying AI-driven Radio Access Networks (RAN) in 6G networks. It discusses the integration of mmWave and T-Hz technologies, Intelligent Reflecting Surfaces (IRS) cells, adaptive modulation/coding, and beamforming to enhance network performance. The article highlights complex use cases like URLLC, smart cities, autonomous transportation, remote healthcare, and AR/VR applications enabled by AI-RAN. It emphasizes the importance of advanced technologies such as AI, machine learning, edge computing, and blockchain in optimizing network resources and addressing challenges in network optimization, security, and spectrum utilization. Overall, the article provides insights into leveraging AI technologies to revolutionize network capacity, coverage, and user experience in the future of wireless communication networks.

Pradeep, T., Shukla, N. K., Animesh, T., & Shiv, P. (2021). Investigating the Effect of Rain, Foliage, Atmospheric Gases, and Diffraction on Millimeter (mm) Wave Propagation for 5G Cellular Networks. <https://doi.org/10.1007/978-981-16-3346-1_42>

Technologies for wireless networking are rising increasingly to satisfy increasing usage requirements. The burden on current wireless systems has increased exponentially due to numerous mobile devices, multimedia applications with a high data rate, audio and video streaming in high definition (HD) and the number of users of wireless communication systems continues to increase. At the same time, the usage of data per user has increased. This manifests in the steady growth of wireless network systems to keep momentum with the growing demand for data rate. Because of the growth in the number of customers, congestion in the conventional cellular bands is also rising, so the use of EHF bands in communications is gaining increasing interest. Millimeter-Wave (mm-Wave) bands are capable of delivering broad bandwidth applications with multi-Gigabit rate, therefore, attracted significant attention. The mm-Wave bands face few challenging issues. Walls can be breached by low-frequency signals and protect very far ranges and, however, fly short distances with mm-Waves and cannot pierce buildings and other things. This paper investigates the propagation properties of millimeter waves and the effects of external influences, such as rain, foliage, and diffraction of atmospheric gases. The main focus would be to analyze the impact of these variables on the propagation of mm-Wave frequency. Further, it also measures the damage due to gases in the atmosphere, rain, and foliage at frequencies that are unlikely to be used in 5G cellular networks. Besides this, we suggest a data-driven computational intelligence generic framework to optimize quality of service (QoS) parameters such as bandwidth and path loss.

Zhang, Y., Anderson, C. R., Michelusi, N., Love, D. J., Baker, K. R., & Krogmeier, J. V. (2019). Propagation Modeling Through Foliage in a Coniferous Forest at 28 GHz. *IEEE Wireless Communications Letters*, *8*(3), 901–904. <https://doi.org/10.1109/LWC.2019.2899299>

The article highlights that foliage in coniferous forests can significantly impact the deployment of 28-GHz millimeter wave communication systems. Traditional foliage analysis models designed for lower-frequency wireless communications were found to be inadequate for accurately predicting path loss in forest environments at millimeter wave frequencies. This inadequacy can lead to challenges in deploying and optimizing communication systems in such settings.

To address this issue, the researchers developed novel site-specific models that showed substantial improvements in path loss predictions through vegetation blockages. By considering the unique characteristics of coniferous forests and incorporating detailed foliage analysis, the proposed models offer a more accurate representation of signal propagation in these environments. This improved understanding of foliage effects at 28 GHz can help optimize deployment strategies, mitigate signal attenuation, and enhance the performance of communication systems operating in forested areas.

Traditional foliage analysis models for lower-frequency wireless communications were found to inconsistently output correct path loss predictions in forest environments. The proposed site-specific models yielded an overall improvement of 0.9 dB and up to 20 dB regional improvement in root mean square errors, showcasing significant enhancements in prediction accuracy through shallow to deep vegetation blockages. The site-specific models are fully automated, easy to implement, and feasible for application in machine learning frameworks, offering consistent performance throughout the dataset. These findings highlight the importance of tailored models for accurate propagation modeling through foliage in forest environments at millimeter wave frequencies.

Lai, C., Senic, D., Gentile, C., Senic, J., & Golmie, N. (2023). Raytracing Digital Foliage at Millimeter-Wave: A Case Study on Calibration Against 60-GHz Channel Measurements on Summer and Winter Trees. *IEEE Access*, *11*, 145931–145943. <https://doi.org/10.1109/ACCESS.2023.3345248>

The study's findings on raytracing digital foliage at millimeter-wave frequencies and its calibration against 60-GHz channel measurements on summer and winter trees have significant implications for the design and optimization of wireless networks in various environments. By digitally representing foliage as a mesh of faceted leaves and branches, the study enhances the precision of foliage modeling, enabling more accurate predictions of foliage loss in wireless communication systems. The calibrated raytracing models provide a reliable framework for understanding and mitigating the impact of foliage on wireless propagation, allowing network designers to account for foliage blockage effects in their planning processes. The tree-specific predictions derived from the calibrated models can be integrated into entire outdoor environments, facilitating tailored network design based on surrounding foliage characteristics. This scalability and generalizability support optimized network deployment in urban, suburban, and rural areas with diverse vegetation profiles, improving coverage, capacity, and reliability in wireless communication systems. Overall, the study's findings advance the design and optimization of wireless networks by offering nuanced insights into foliage effects at millimeter-wave frequencies and providing calibrated models for accurate channel propagation predictions in varied environmental settings.

Chen, Q., Gao, T., Zhu, J., Wu, F., Li, X., Lu, D., & Yu, F. (2022). Individual Tree Segmentation and Tree Height Estimation Using Leaf-Off and Leaf-On UAV-LiDAR Data in Dense Deciduous Forests. *Remote Sensing*, *14*(12), 2787. <https://doi.org/10.3390/rs14122787>

The article "Individual Tree Segmentation and Tree Height Estimation Using Leaf-Off and Leaf-On UAV-LiDAR Data in Dense Deciduous Forests" by Chen et al. (2022) presents a comprehensive study on the segmentation of individual trees and the estimation of tree height in dense deciduous forests using UAV-LiDAR data. The research focuses on the innovative use of leaf-off and leaf-on UAV-LiDAR data to improve the accuracy of tree height estimation in challenging forest environments.

The study area encompassed four distinct stand types, including mixed broadleaved forest, mixed broadleaf-conifer forest, Mongolian oak forest, and larch plantation forest. Field data collection involved the establishment of multiple rectangular plots for each stand type, with ground reference data collected for 25 plots in May 2019. Tree diameter at breast height (DBH), tree height, crown class, tree species, stem density, and tree positions were among the key parameters measured during field data collection.

The research leveraged advanced technologies such as UAV-LiDAR data to segment individual trees and estimate tree height accurately. The study's findings highlight the significance of utilizing both leaf-off and leaf-on UAV-LiDAR data for improved tree height estimation in dense deciduous forests. The integration of these data sets allowed for a more comprehensive analysis of forest structure and enabled the researchers to overcome the challenges posed by dense vegetation cover.

The article contributes to the existing body of literature on forest inventory and management by demonstrating the effectiveness of UAV-LiDAR data in enhancing the precision of tree height estimation. By employing cutting-edge technologies and methodologies, the study provides valuable insights for forest researchers, managers, and conservationists seeking to optimize forest monitoring and assessment practices.

Overall, the research conducted by Chen et al. (2022) underscores the importance of incorporating UAV-LiDAR data, particularly leaf-off and leaf-on data, in individual tree segmentation and tree height estimation in dense deciduous forests. The findings of this study have implications for improving forest management strategies, enhancing biodiversity conservation efforts, and advancing the field of remote sensing applications in forestry.

Deng, X., Tang, G., & Wang, Q. (2022). A novel fast classification filtering algorithm for LiDAR point clouds based on small grid density clustering. *Geodesy and Geodynamics*, *13*(1), 38–49. <https://doi.org/10.1016/j.geog.2021.10.002>

The article presents a novel fast classification filtering algorithm for LiDAR point clouds based on small grid density clustering. This algorithm addresses the challenges of point cloud classification in discontinuous terrain by clustering point clouds based on elevations and selecting plane point clouds. By reducing the number of samples and feature dimensions, the algorithm improves classification accuracy. The proposed method does not require human intervention once appropriate parameter ranges are determined. Through validation with 15 sample sets and comparison with eight classical filtering algorithms, the algorithm demonstrates effectiveness in rural and urban areas, removing vegetation, bridges, and buildings while retaining topographic relief. The algorithm relies on the "density connection" of ground point clouds, allowing for accurate classification even in areas with large elevation differences and slope changes.

The limitations of LiDAR and point cloud data highlighted in the article include challenges related to the large volume of data, leading to processing complexity and memory requirements. Additionally, traditional clustering algorithms face difficulties in handling high-dimensional data, necessitating improvements for enhanced efficiency. Filtering errors, especially in discontinuous terrain, and edge limitations in classification accuracy are also noted as challenges that need to be addressed for improved point cloud data processing.

Mazzacca, G., Grilli, E., Cirigliano, G. P., Remondino, F., & Campana, S. (2022). Seeing among foliage with lidar and machine learning: Towards a transferable archaeological pipeline. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLVI-2-W1-2022*, 365–372. <https://doi.org/10.5194/isprs-archives-XLVI-2-W1-2022-365-2022>

The article discusses the use of Airborne Laser Scanning (ALS) and Light Detection And Ranging (LiDAR) technologies in archaeological research, focusing on the challenges of identifying and mapping archaeological evidence hidden among dense vegetation. The study proposes a novel pipeline based on artificial intelligence algorithms for filtering out vegetation and detecting archaeological structures directly from LiDAR point clouds. The methodology involves multi-level multi-resolution point cloud semantic segmentation, bare-ground Digital Terrain Model (DTM) generation, and visualisation techniques for anomaly detection. The research emphasizes the importance of accurate DTM generation from LiDAR data and highlights the complexities involved in archaeological prospection under vegetation cover. Various machine learning and deep learning strategies are discussed in the context of archaeological evidence detection, with a focus on enhancing the visibility of terrain characteristics to identify buried structures. The article also addresses the challenges of ground point filtering in ALS datasets and the significance of preserving archaeological information during data processing. Overall, the study provides valuable insights into the integration of LiDAR, machine learning, and artificial intelligence for archaeological research in challenging environments.

Machine learning algorithms provide significant advantages for filtering vegetation in ALS datasets. They offer fast processing of large LiDAR datasets, saving time compared to manual methods. These algorithms ensure accurate vegetation filtering in complex environments, enhancing the identification of underlying archaeological structures. Machine learning techniques enable the detection and mapping of above-ground structures directly from 3D point clouds, improving visibility of archaeological features. Additionally, they facilitate the generation of high-resolution Digital Terrain Models (DTMs) for detecting anomalies and shallow structures of archaeological interest. The output from machine learning-based vegetation filtering can be easily transferred to a Geographic Information System (GIS) environment for further analysis. Overall, machine learning algorithms enhance efficiency, accuracy, and scalability in archaeological research, particularly in challenging terrains with dense vegetation cover.

The limitations highlighted in the article include challenges related to the large dimensions of ALS datasets, encompassing vast areas with billions of points. The presence of steep slopes in the investigated territories adds complexity to terrain filtering and recognition tasks. The diverse and dense vegetation cover in archaeological areas complicates the identification of hidden archaeological evidence. While the machine learning approach offers significant advantages, there are critical issues that need to be addressed. These limitations emphasize the complexities of processing large LiDAR datasets and the challenges of archaeological prospection under vegetation cover in varied environmental settings.

Rogers, S. R., Manning, I., & Livingstone, W. (2020). Comparing the Spatial Accuracy of Digital Surface Models from Four Unoccupied Aerial Systems: Photogrammetry Versus LiDAR. *Remote Sens.*, *12*(17). <https://doi.org/10.3390/rs12172806>

The study compared the spatial accuracy of Digital Surface Models (DSMs) generated by four popular Unoccupied Aerial Systems (UAS) using photogrammetry and high-precision Ground Control Points (GCPs). The UAS platforms tested were DJI Inspire 1, DJI Phantom 4 Pro, DJI Mavic Pro, and DJI Matrice 210. The research site in Nova Scotia featured mixed land cover types, enabling flights on a single battery. Results showed that the DJI Phantom 4 Pro performed best overall, with the lowest error values compared to checkpoints. LiDAR DSMs were found to be superior to vegetated terrain, highlighting the strengths and limitations of UAS LiDAR technology. The study emphasized the importance of GCPs for accurate DSM production and provided insights into spatial errors across different UAS platforms and land cover types. Overall, the research contributes valuable information on the comparative spatial accuracy of DSMs from various UAS platforms, offering insights for future remote sensing applications.

Unoccupied Aerial Systems (UAS) equipped with photogrammetric sensors offer a cost-efficient alternative to traditional airborne LiDAR for local-scale investigations. The integration of LiDAR sensors on UAS can be more cost-effective than using airborne LiDAR for certain applications, such as in ecology, forestry, and precision agriculture. The advancements in UAS technology, sensors, and processing techniques have enabled data collection at lower altitudes, higher resolutions, and user-defined spatial and temporal scales, making UAS a viable and affordable option for collecting geographic data. While UAS DSMs may not be as accurate as those produced from airborne LiDAR, they provide a sufficient low-cost solution for surveying forest stands and other applications. The study emphasizes the practical applications of UAS technology and highlights the cost efficiency of using UAS-LiDAR systems for high-quality data collection in various fields.

Gaspari, F., Ioli, F., Barbieri, F., Belcore, E., & Pinto, L. (2022). INTEGRATION OF UAV-LIDAR AND UAV-PHOTOGRAMMETRY FOR INFRASTRUCTURE MONITORING AND BRIDGE ASSESSMENT. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*, (B2), 995–1002. <https://doi.org/10.5194/isprs-archives-XLIII-B2-2022-995-2022>

The article discusses the integration of UAV-LiDAR and UAV-photogrammetry for bridge inspection, comparing traditional topographic techniques with innovative UAV-based methods. UAV technologies offer cost-effective, non-invasive, and flexible solutions for monitoring infrastructure, enhancing safety and accessibility while enabling rapid data acquisition. The study highlights the potential of UAVs in infrastructure monitoring, emphasizing their ability to capture high-resolution data and integrate with other technologies for comprehensive assessments. By combining UAV data with traditional surveying techniques, GIS, and BIM, the article presents a framework for creating dynamic 3D models for infrastructure management systems. Overall, the research showcases the benefits of UAV-based monitoring for assessing the health and condition of critical infrastructure like bridges in a more efficient and effective manner.

Attaran, M., & Celik, B. G. (2023). Digital Twin: Benefits, use cases, challenges, and opportunities. *Decision Analytics Journal*, *6*, 100165. <https://doi.org/10.1016/j.dajour.2023.100165>

The article "Digital Twin: Benefits, use cases, challenges, and opportunities" explores the rapid growth and transformative impact of Digital Twin technology across various industries. It defines Digital Twins as a seamless integration of data between physical and virtual entities, tracing its origins to NASA's space missions. The literature review emphasizes the technology's application in manufacturing, Industry 4.0, production planning, and supply chain management. Use cases in construction involve enhancing project monitoring and reducing errors. In healthcare, Digital Twins aid in disease detection, treatment experimentation, and surgical preparation through accurate human body modeling. The article highlights the significant attention Digital Twins have garnered in academia and industry, showcasing their potential for intelligent automation. Challenges such as high infrastructure costs and complexity may hinder widespread adoption. Overall, Digital Twins are seen as a fast-growing IT solution with expanding applications and promising opportunities for enhancing operational efficiency and innovation across sectors.

Shahat, E., Hyun, C. T., & Yeom, C. (2021). City Digital Twin Potentials: A Review and Research Agenda. *Sustainability*, *13*(6). <https://doi.org/10.3390/su13063386>

The study "Shahat\_City Digital Twin Potentials" delves into the potentials of City Digital Twins for smart cities. It discusses the shift from 3D models to digital twins, presents examples of digital twin city development, and explores the benefits that smart cities can bring to urban areas. The review classifies the potentials of city digital twins thematically and addresses challenges in their full utilization. The research agenda proposes future directions for exploring digital twin technology in urban settings. The dataset analyzed in the study includes articles from various countries, with a notable contribution from the USA, the UK, and Germany. The work was supported by funding from the Ministry of Education of the Republic of Korea and the National Research Foundation, among others. The authors declare no conflicts of interest, and the paper concludes with implications for further research in this field.

Deng, T., Zhang, K., & Shen, Z.-J., (Max). (2021). A systematic review of a digital twin city: A new pattern of urban governance toward smart cities. *Journal of Management Science and Engineering*, *6*(2), 125–134. <https://doi.org/10.1016/j.jmse.2021.03.003>

The article "A systematic review of a digital twin city: A new pattern of urban governance toward smart cities" explores the concept of a digital twin city (DTC) and its role in transforming urban governance in smart cities. It discusses the key technologies involved in creating a DTC, such as IoT, blockchain, and artificial intelligence, and highlights the potential application scenarios for DTCs in addressing challenges like global warming, population growth, and resource depletion in urban areas. The paper emphasizes the importance of digital transformation in urban governance and the significant impact of DTCs on improving efficiency, sustainability, and quality of life in smart cities.

Gabriele, M., Cazzani, A., Zerbi, C. M., & Brumana, R. (2023). DIGITAL TWIN TO MONITOR, UNDERSTAND AND PRESERVE THE COMPLEXITY OF MULTI-SCALE NATURAL, AGRICULTURAL, DESIGNED LANDSCAPES AND ARCHITECTURE: BIODIVERSITY CONSERVATION, TRANSFORMATION AND DECLINE AT VILLA ARCONATI SITE AT CASTELLAZZO OF BOLLATE (MI). *International Archives of Photogrammetry, Remote Sensing & Spatial Information Sciences*, *48*(M/2), 613–620. <https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-613-2023>

The article discusses the application of Digital Twin technology to monitor and preserve the complexity of landscapes, focusing on the case study of Villa Arconati in Castellazzo of Bollate, Milan. The research emphasizes the importance of utilizing a multi-sensor, multi-temporal approach to digitize complex sites for assessing environmental sustainability, biodiversity conservation, and transformation. By integrating Earth Observation data with local information, researchers can monitor natural systems and human activities in real-time. The study involves a detailed analysis at two scales: an environmental-scale study using historical maps and NDVI analysis to monitor biodiversity transformations, and a local-scale survey employing experimental equipment like spherical cameras to extract 3D vegetation models for conservation criteria. The research aims to raise awareness about the significance of preserving historical, architectural, and biodiversity values at the site, amidst urbanization pressures and land use changes. The findings highlight the role of cultural heritage sites in promoting biodiversity preservation and sustainable management practices.

Khan, L. U., saad, W., Niyato, D., Han, Z., & Hong, C. S. (2022). Digital-Twin-Enabled 6G: Vision, Architectural Trends, and Future Directions. *IEEE Communications Magazine*, *60*(1), 74–80. <https://doi.org/10.1109/MCOM.001.21143>

The article discusses the importance of digital twins in enabling Internet of Everything (IoE) applications over sixth-generation (6G) wireless systems. It highlights the diverse requirements of IoE applications in terms of latency, reliability, data rate, and user-defined performance metrics. To address these requirements, a new framework based on digital twins is proposed to manage, operate, and optimize 6G wireless systems and IoE services. Key points covered in the article include:

Introduction to the evolving wireless research landscape to support emerging IoE applications.

* Key properties of 6G wireless systems such as self-sustaining capabilities and proactive online learning.
* The concept of digital twins as a means to efficiently enable the properties of 6G wireless systems.
* Comparison of different types of twins, including edge-based twins, cloud-based twins, and edge-cloud-based twins.
* Design requirements for digital-twin-enabled 6G systems, including decoupling, scalable intelligent analytics, and blockchain-based data management.
* Proposed architecture for digital-twin-enabled 6G systems and future research directions in the field.

Overall, the article emphasizes the significance of digital twins in optimizing 6G wireless systems for IoE applications and provides insights into the architectural trends and design requirements for achieving this goal.

Kuruvatti, N. P., Habibi, M. A., Partani, S., Han, B., Fellan, A., & Schotten, H. D. (2022). Empowering 6G communication systems with digital twin technology: A comprehensive survey. *IEEE Access*, *10*, 112158–112186. <https://doi.org/10.1109/ACCESS.2022.3215493>

The article "Empowering 6G Communication Systems With Digital Twin Technology: A Comprehensive Survey" by Nandish P. Kuruvatti and team addresses the gap in the literature regarding the deployment of digital twin (DT) technology in the telecommunications sector, specifically in the context of 6G communication systems. The key contributions of the article include:

* Recognition of the importance of DT technology for the research and development of 6G communication systems.
* State-of-the-art survey of major papers on DT technology, focusing on its applications in mobile communication systems and narrowing down to DT in 6G communication systems.
* Review of DT applications in mobile communication systems, highlighting different domains and solution areas where DT technology has been applied.
* Historical background on the application of DT technology in the telecom industry and its implications on the development of 6G communication systems, emphasizing the integration of intelligence and automation into DT technology for 6G networks.

The article also delves into the interaction between Digital Twin Networks (DTN) and 6G communication systems, emphasizing the need for trusted APIs and standardized architectural frameworks for seamless communication. Furthermore, it provides insights into the ongoing standardization activities related to DT technology by various Standards Development Organizations (SDOs) and discusses the state-of-the-art literature on DT technology in 6G communication systems.

Overall, the article offers a comprehensive overview of the potential of digital twin technology in advancing 6G communication systems, highlighting its significance in enhancing network performance, automation, and intelligence.

Farooq, U., & Lokam, A. (2023). Performance analysis of mmWave/sub-terahertz communication link for 5G and B5G mobile networks. *Frequenz*, *77*(11/12), 599–606. <https://doi.org/10.1515/freq-2023-0024>

Millimeter (mmWave) and sub-terahertz communication is a key technology to support high data rate requirements of 5G and B5G mobile networks. However this field is still in its initial development stage because of the various technical difficulties in its practical implementation due to inherently distinct propagation properties of mmWave/sub-terahertz frequencies. A thorough investigation of mmWave/sub-terahertz communication link is required in order to successfully deploy these frequency bands in 5G and B5G mobile networks. This paper investigates the effect of atmospheric conditions like dry air, humidity, rain, snow, fog and foliage on the performance of the mmWave/sub-terahertz link. The work also presents a mathematical analysis of the coverage of mmWave/sub-terahertz communication link and investigates the effect of various parameters like frequency, bandwidth, transceiver antenna gain, path loss coefficient (LOS, NLOS case) and system noise on its performance.

Anzum, R. (2021). Factors that affect LoRa Propagation in Foliage Medium. *Procedia Computer Science*, *194*, 149–155. <https://doi.org/10.1016/j.procs.2021.10.068>

The article "Factors that affect LoRa Propagation in Foliage Medium" by Rabeya Anzum delves into the impact of different factors on LoRa propagation in vegetation-rich environments. The study highlights the significance of considering various factors that affect the performance of LoRa technology in foliage mediums, crucial for applications in smart cities and smart agriculture. An experimental investigation was conducted using a line of five date palm trees to analyze LoRa physical layer performance with different spreading factors (SF7-SF12). The study measured Received Signal Strength Indication (RSSI) values for propagation through the tree line and compared them with expected values. Surprisingly, the measured RSSI values were higher than expected, indicating potential implications for LoRa propagation channel modeling in foliage mediums in future studies.

The study on LoRa propagation in foliage medium highlighted the impact of foliage on the performance of LoRa technology. Foliage significantly affects the Received Signal Strength Indication (RSSI) values in LoRa propagation through vegetation-rich environments. Factors such as the presence of trees, leaves, and other vegetation can cause signal degradation, leading to variations in signal strength and quality. The foliage acts as an obstacle that attenuates the radio signals, resulting in higher measured RSSI values than expected. This interference from foliage can impact the reliability and range of LoRa communication, making it essential to consider foliage effects when designing and deploying LoRa networks in such environments.

Chikhale, D., Munde, M., & Deosarkar, S. (2022). Atmospheric effects and behavior of electromagnetic signals in the millimeter wave range wireless communication. *International Journal of Microwave & Optical Technology*, *17*(2), 115–125.

The article "Atmospheric Effects and Behaviour of Electromagnetic Signals in the Millimeter Wave Range Wireless Communication" explores the impact of atmospheric conditions on wireless communication in the millimeter wave range. It discusses phenomena like absorption and emission of electromagnetic waves when photons interact with particle molecules. The International Telecommunication Union (ITU) standard is referenced for dividing the globe into temperate and tropical regions, with India and African countries falling into the latter category. Site measurements and meteorological data are used to calculate losses in wireless communication systems.

The document also delves into transmission loss calculations, including basic transmission loss, system loss, and environmental losses such as absorption, reflection, scattering, diffraction, and precipitation losses. It emphasizes the importance of fade reduction techniques for propagation at millimeter wave frequencies.

Furthermore, the study highlights the significance of considering foliage loss in wireless communication systems, especially in tropical regions where vegetation can significantly impact signal degradation. The research conducted by Devidas Chikhale, Mahesh Munde, and Shankar Deosarkar provides valuable insights for the design and optimization of millimeter wave wireless communication systems, particularly in the context of 5G technology development in 2022.

Hematang, F., Murdjoko, A., Hendri, H., & Tokede, M. (2022). Application of Unmanned Aerial Vehicle (UAV) For Estimation of Tree Height in Heterogeneous Forest. *Biosaintifika: Journal of Biology & Biology Education*, *14*(2), 168–179. <https://doi.org/10.15294/biosaintifika.v14i2.35637>

The article "Application of Unmanned Aerial Vehicle (UAV) For Estimation of Tree Height in Heterogeneous Forest" by Francine Hematang et al. explores the use of UAV technology to estimate tree height in heterogeneous forests. Tree height is a crucial indicator in forest management, but traditional field data collection methods can be costly and time-consuming. The study aims to test the effectiveness of low-cost UAVs in estimating tree height and analyzing the distribution of tree height classes on Mansinam island in West Papua, Indonesia.

The research findings highlight the efficiency and cost-effectiveness of using UAVs for tree height estimation compared to traditional field surveys. The study demonstrates that UAVs can quickly and accurately measure tree height over a wide area, providing valuable data for forest management. The use of UAV technology, combined with Structure from Motion (SFM) techniques, offers a new approach to collecting biophysical data in forests, leading to more effective natural resource management plans.

Overall, the study emphasizes the potential of UAVs in revolutionizing forest monitoring and management practices by providing a faster, cheaper, and more accurate way to estimate tree height in heterogeneous forest environments.

Shen, Y., Huang, R., Hua, B., Pan, Y., Mei, Y., & Dong, M. (2023). Automatic Tree Height Measurement Based on Three-Dimensional Reconstruction Using Smartphone. *Sensors 2023*, *23*(16), 7248. [https://doi.org/10.3390/ s23167248](https://doi.org/10.3390/%20s23167248)

The article "Automatic Tree Height Measurement Based on Three-Dimensional Reconstruction Using Smartphone" by Shen et al. presents a novel method for measuring tree height using smartphone technology. The study introduces the Depth-Attention-UNet model, which incorporates depth maps as an additional input to improve tree image segmentation. By leveraging depth information to differentiate between trees and non-tree objects, the model enhances the accuracy of image segmentation compared to traditional methods like Attention-UNet.

The research demonstrates the effectiveness of the Depth-Attention-UNet model through training and testing on a dataset, showcasing improved performance in accurately identifying tree boundaries and distinguishing between different trees. The study highlights the potential of smartphone-based three-dimensional reconstruction for non-destructive and cost-effective tree height measurement, offering valuable insights for forestry management and conservation practices.

Overall, the article provides a comprehensive overview of the proposed methodology, its implementation, and the benefits it offers for forest inventory and ecological studies.

Suhaizad, L. S., Khalid, N., & Abu Sari, M. Y. (2023). Tree Height and Crown Extraction From UAV-Based Multispectral Imagery. *International Journal of Geoinformatics*, *19*(5), 61–68. <https://doi.org/10.52939/ijg.v19i5.2661>

The article "Tree Height and Crown Extraction From UAV-Based Multispectral Imagery" published in the International Journal of Geoinformatics discusses the importance of trees in urban landscapes and the benefits they provide to society. It emphasizes the role of trees in improving human health, enhancing the visual appeal of neighborhoods, and reducing environmental impacts such as stormwater runoff and cooling costs.

The study focuses on using UAV-based multispectral imagery and advanced digital image processing techniques to extract tree height and crown diameter accurately and efficiently. By utilizing technologies like the DJI P4 Multispectral sensor and software such as Agisoft and ArcMap, the researchers were able to collect high-resolution images, generate orthomosaics, and derive digital surface models for analysis.

The research methodology involved four main phases: preliminary study, data collection, data processing, and analysis. The study area in Shah Alam was carefully selected for its residential and greenery characteristics, making it suitable for drone flights and data collection. The UAV imagery processing involved classification processes to identify ground points and produce digital elevation and surface models.

Overall, the study demonstrates the potential of UAV-based multispectral imagery and digital processing techniques in accurately extracting tree parameters, such as height and crown diameter, for urban planning, tree management, and environmental monitoring purposes. The integration of geospatial technologies and machine learning algorithms like Support Vector Machine (SVM) classifiers enhances the efficiency and accuracy of tree extraction processes, offering valuable insights for sustainable urban development and vegetation analysis.

Sun, Z., Xue, B., Zhang, M., & Schindler, J. (2023). *An Improved Mask R-CNN for Instance Segmentation of Tree Crowns in Aerial Imagery*. 2023 38th International Conference on Image and Vision Computing New Zealand (IVCNZ), Image and Vision Computing New Zealand (IVCNZ). <https://doi.org/10.1109/IVCNZ61134.2023.10343827>

The article "An Improved Mask R-CNN for Instance Segmentation of Tree Crowns in Aerial Imagery" presents a novel method for accurately identifying and segmenting individual tree crowns in aerial imagery. The proposed method utilizes an improved Mask R-CNN framework with a focus on enhancing the backbone structure and introducing a new mask branch. By leveraging ConvNeXt as the backbone network and optimizing the mask branch, the method achieves superior performance compared to traditional backbone structures like ResNet and ResNeXt. The study demonstrates the effectiveness of the proposed method through both qualitative and quantitative results, showcasing improved canopy detection and boundary delineation. The research aims to address the instance segmentation task of tree crowns in aerial images and highlights the importance of accurate canopy identification for various applications such as forest management and urban planning. Additionally, the study suggests future work on designing lightweight architectures to reduce computational costs.

Zhao, Y., Cheng, D., Shen, S., Cai, D., & Lyu, X. (2023). *Improved Mask R-CNN for Disturbed Area Extraction in Construction Projects from High-Resolution Satellite Imagery*. 2023 6th International Conference on Artificial Intelligence and Big Data (ICAIBD), Artificial Intelligence and Big Data (ICAIBD). <https://doi.org/10.1109/ICAIBD57115.2023.10206407>

The article presents an improved Mask R-CNN model for automatically extracting disturbed areas in construction projects from high-resolution satellite imagery. The model optimizes feature extraction and loss function to enhance object recognition and segmentation accuracy. By integrating the SENet channel attention mechanism, the model improves its capacity to detect target objects effectively. The study demonstrates the effectiveness of the proposed method using high-resolution satellite data from GF-1 in Liuyang City, Hunan Province, China. Experimental results show significant improvements in accuracy compared to traditional Mask R-CNN and other classical models, highlighting the potential for more effective soil and water conservation monitoring in construction projects.

Mask R-CNN offers several benefits for extracting disturbed areas in construction projects from high-resolution satellite imagery. Firstly, it provides a compact and versatile framework for object instance segmentation, allowing for the identification and segmentation of targets within images with high precision. Secondly, by incorporating a Fully Convolutional Network (FCN) branch, Mask R-CNN achieves pixel-level segmentation of target objects, enabling detailed extraction of disturbed areas. Additionally, the model's integration of the SENet channel attention mechanism enhances its ability to detect target objects effectively by preserving crucial channel features and suppressing irrelevant information. Overall, Mask R-CNN improves object recognition and segmentation accuracy, leading to more precise identification and extraction of disturbed areas in construction projects, which can aid soil and water conservation authorities in monitoring tasks efficiently and effectively.

Nguyen, H. X., Trestian, R., To, D., & Tatipamula, M. (2021). Digital Twin for 5G and beyond. *IEEE Communications Magazine*, *59*(2), 10–15. <https://doi.org/10.1109/MCOM.001.2000343>

The article discusses the emerging concept of digital twin (DT) technology and its potential to revolutionize the development and deployment of 5G networks and beyond. With advancements in technologies such as the Industrial Internet of Things (IIoT), wireless sensor networks, deep learning algorithms, and cloud-based platforms, DTs have gained significant attention. DTs serve as high-fidelity digital replicas of physical entities, evolving synchronously with their physical counterparts throughout their lifecycle.

The integration of artificial intelligence tools within the DT architecture is crucial for understanding the complex data patterns of 5G networks. Machine learning algorithms can create models for 5G traffic and network behavior using historical and real-time IoT data, enabling the detection of anomalies and prediction of potential bottlenecks in network performance. The article emphasizes the importance of AI algorithms in updating the operational model of DTs, which integrate surrogate models representing various aspects of the actual 5G network.

Furthermore, the article highlights the potential of DTs in various industries beyond smart manufacturing, such as oil and gas, construction, bio-engineering, and automotive. By leveraging DT technology, industries can enhance preventive maintenance programs, pioneer new business models, improve product development, and maximize sustainability and efficiency. The article also touches upon the challenges and opportunities in the development of 5G networks, emphasizing the need for innovative solutions to enable disruptive 5G use cases for future society.

Overall, the article underscores the transformative power of DT technology in advancing 5G networks and beyond, offering a glimpse into how AI-driven digital twins can shape the future of complex network environments.

Qi, Q., & Tao, F. (2018). Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison. *IEEE Access*, *6*, 3593. <https://doi.org/10.1109/ACCESS.2018.2793265>

The article "Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison" discusses the significance of big data and digital twin technologies in the realm of smart manufacturing and Industry 4.0. It delves into the concepts of big data and its applications in manufacturing, emphasizing the increasing reliance on data-driven decision-making. The paper also explores the digital twin technology and its role in replicating physical assets digitally to optimize performance and maintenance.

Furthermore, the article presents a comparison between digital twin and big data in the manufacturing sector, highlighting their respective contributions and functionalities. It discusses the fusion of these technologies in manufacturing processes to enhance efficiency, productivity, and predictive maintenance. The paper concludes by drawing insights on the synergies between digital twin and big data, underscoring their combined potential in revolutionizing the manufacturing industry towards smarter and more efficient operations.

Thuvander, L., Somanath, S., & Hollberg, A. (2022). PROCEDURAL DIGITAL TWIN GENERATION FOR CO-CREATING IN VR FOCUSING ON VEGETATION. *International Archives of Photogrammetry, Remote Sensing & Spatial Information Sciences*, *48*(4/W5), 189–196. <https://doi.org/10.5194/isprs-archives-XLVIII-4-W5-2022-189-2022>

The article "Procedural Digital Twin Generation for Co-Creating in VR" explores the use of automated procedural workflows to generate high-quality Digital Twin models for Virtual Reality (VR) visualization, focusing on existing green structures in urban development projects. The study emphasizes the importance of engaging citizens in the planning process through immersive VR experiences, allowing for better understanding, communication, and participation in decision-making. Key findings from user tests with the VR prototype include positive feedback on interactivity, engagement, and learning outcomes. The integration of existing green structures in VR applications enhances civic engagement by providing a realistic and interactive platform for stakeholders to visualize and contribute to urban development projects. Architects are identified as a potential user group who can benefit from using VR for design communication and decision-making processes. Overall, the article highlights the potential of procedural workflows in creating DT models for VR to facilitate co-creation and participatory approaches in urban planning and design.

Zhao, D., Li, X., Wang, X., Shen, X., & Gao, W. (2022). Applying Digital Twins to Research the Relationship Between Urban Expansion and Vegetation Coverage: A Case Study of Natural Preserve. *Frontiers in Plant Science*, *13*, 840471. <https://doi.org/10.3389/fpls.2022.840471>

The research article titled "Applying Digital Twins to Research the Relationship Between Urban Expansion and Vegetation Coverage: A Case Study of Natural Preserve" by Zhao et al. explores the impact of urban expansion on vegetation coverage using Digital Twins technology. The study focuses on a natural preserve in a coastal city and utilizes field investigation data along with Convolutional Neural Network (CNN) modeling to analyze spatial-temporal characteristics and identify plant types from multispectral images collected by UAVs.

Key contributions of the study include:

* Development of a high-accuracy CNN model for plant identification, comparing its performance with traditional index methods.
* Spatial-temporal analysis of the research area, highlighting land cover changes and current issues due to urbanization over the past 15 years.
* Integration of Digital Twins throughout the research process, from data collection to decision support, providing a valuable reference case for related studies.

The study also offers six suggestions for future urban expansion planning in the area. However, challenges such as low-resolution satellite images and limitations in historical data identification with the CNN model are acknowledged, indicating areas for improvement in data collection and modeling techniques.

Overall, this research provides valuable insights into the use of Digital Twins for studying the interaction between urban development and natural environments, offering a foundation for further research in this field.

Chen, J., Wang, G., Luo, L., Gong, W., & Cheng, Z. (2021). Building Area Estimation in Drone Aerial Images Based on Mask R-CNN. *IEEE Geoscience and Remote Sensing Letters*, *18*(5), 891–894. <https://doi.org/10.1109/LGRS.2020.2988326>

The article "Building Area Estimation in Drone Aerial Images Based on Mask R-CNN" presents a novel method for calculating building areas in rural areas using drone aerial images. The approach leverages Mask R-CNN, a segmentation algorithm that can distinguish adjacent objects and extract object outlines. By incorporating transfer learning, the model is trained efficiently with a small number of drone aerial images. The method involves pretraining with satellite images, fine-tuning with drone images, and testing with new images to calculate building areas based on the number of building pixels. Experimental results demonstrate the effectiveness of the proposed method in achieving accurate building area estimation, with performance metrics such as F1 score and intersection over union showing promising results. The approach offers advantages in terms of efficiency and accuracy compared to traditional manual methods or classic alternatives, making it a valuable tool for property assessment in disaster-prone areas.

He, K., Gkioxari, G., Dollár, P., & Girshick, R. (2018). Mask R-CNN. *arXiv.org*. <https://doi.org/10.48550/arXiv.1703.06870>

The article "Mask R-CNN" introduces a novel framework for object instance segmentation called Mask R-CNN. This framework builds upon the Faster R-CNN detector by adding a parallel mask prediction branch to generate binary masks for each region of interest (RoI). By decoupling mask and class prediction and using RoIAlign for more accurate mask generation, Mask R-CNN achieves significant improvements in mask accuracy, especially under stricter localization metrics. The method surpasses previous state-of-the-art results on the COCO instance segmentation task and also performs well on object detection. The authors emphasize the simplicity, flexibility, and generalizability of Mask R-CNN, making it a valuable tool for various computer vision tasks. The code for implementing Mask R-CNN has been released to facilitate further research and experimentation in the field.

Jiang, B., An, X., Xu, S., & Chen, Z. (2023). Intelligent Image Semantic Segmentation: A Review Through Deep Learning Techniques for Remote Sensing Image Analysis. *Journal of the Indian Society of Remote Sensing*, *51*(9), 1865–1878. <https://doi.org/10.1007/s12524-022-01496-w>

The article "Intelligent Image Semantic Segmentation: A Review Through Deep Learning Techniques for Remote Sensing Image Analysis" provides an in-depth review of semantic segmentation methods for remote sensing images, focusing on advancements in deep learning technologies. The paper covers the following key points:

**Introduction**: Image semantic segmentation is defined as the process of dividing an image into distinct sections without overlap.

**Deep Learning-Based Methods**: The study discusses various deep learning-based semantic segmentation algorithms for remote sensing images, highlighting their importance and applications in the field.

**Classification of Algorithms**: The paper classifies deep learning-based semantic segmentation algorithms into different categories, emphasizing their role in remote sensing image analysis.

**Datasets and Data Preparation**: Commonly used datasets and data preparation techniques, including pre-processing and augmentation methods, are introduced to provide a comprehensive understanding of the data used in remote sensing image analysis.

**Challenges and Future Directions**: The article analyzes the challenges faced in this domain and provides insights into future research directions, aiming to guide researchers interested in advancing the field of remote sensing image analysis.

Overall, the study aims to broaden knowledge in the field of remote sensing image analysis and serve as a valuable resource for researchers looking to explore and enhance semantic segmentation methods using deep learning techniques.

Savelonas, M. A., Veinidis, C. N., & Bartsokas, T. K. (2022). Computer Vision and Pattern Recognition for the Analysis of 2D/3D Remote Sensing Data in Geoscience: A Survey. *Remote Sensing*, *14*(23), 6017. <https://doi.org/10.3390/rs14236017>

The article "Computer Vision and Pattern Recognition for the Analysis of 2D/3D Remote Sensing Data in Geoscience" explores the application of computer vision and pattern recognition techniques in the field of geoscience, specifically focusing on the analysis of 2D/3D remote sensing data. The authors discuss various approaches and methodologies used in processing and interpreting geoscience-related imaging data, highlighting the challenges and opportunities in this domain.

Key points covered in the article include:

Introduction to computer vision and pattern recognition techniques in geoscience applications.

Discussion on the use of deep learning models, such as Generative Adversarial Networks (GANs) and Recurrent Neural Networks (RNNs), for tasks like pan-sharpening, cloud removal, and land cover mapping.

Overview of descriptors and feature extraction methods for point clouds and remote sensing images.

Comparison of traditional clustering and classification algorithms with advanced techniques like visual dictionaries and semantic segmentation.

Examination of the performance of Long Short-Term Memory (LSTM) networks in pixel-based and object-based classifications.

Summary of various research studies and methodologies presented in the article, showcasing the advancements and challenges in applying computer vision and pattern recognition in geoscience.

Overall, the article provides a comprehensive overview of the current trends, challenges, and applications of computer vision and pattern recognition techniques in analyzing 2D/3D remote sensing data for geoscience research.

De Beelde, B., Plets, D., & Joseph, W. (2023). Characterization of Vegetation Loss and Impact on Network Performance at V-Band Frequencies. *IEEE Antennas and Wireless Propagation Letters*, *22*(3), 596–600. <https://doi.org/10.1109/LAWP.2022.3219556>

The article focuses on the characterization of vegetation loss and its impact on network performance at V-band frequencies. It presents measurements of vegetation loss at V-band frequencies and compares them with existing vegetation loss models. The study introduces a novel model for estimating vegetation loss as a function of frequency, plant area index (PAI), and vegetation depth. The authors also analyze network performance using IEEE 802.11ad transceivers in the presence of vegetation. This research is significant as it covers the full V-band for the first time and compares network performance estimations based on vegetation models with actual measurements. The methodology involves angular vegetation loss measurements in different environments using a spectrum analyzer-based channel sounder and an IEEE 802.11ad platform. The study provides valuable insights into the impact of vegetation on wireless communication systems operating at V-band frequencies.

Blume, C., Blume, S., Thiede, S., & Herrmann, C. (2020). Data-Driven Digital Twins for Technical Building Services Operation in Factories: A Cooling Tower Case Study. *Journal of Manufacturing Materials Processing*, *4*(4), 97. <https://doi.org/10.3390/jmmp4040097>

The digital twins in the discussed article are built based on the CRISP-DM (Cross-Industry Standard Process for Data Mining) approach, which is a widely used methodology for data mining projects. The process involves several key phases that are adapted for creating data-driven digital twins for technical building services operation in manufacturing systems. Here is a summary of how digital twins are built based on the CRISP-DM approach:

Business Understanding:

Gain a general understanding of the technical building services system, including key performance indicators (KPIs) and system conditions.

Define KPIs to express system conditions and identify hotspots.

Data Understanding:

Analyze and understand the available data sets related to the technical building services system.

Select relevant variables and measured data for analysis.

Data Preparation:

Pre-process the data by filtering outliers and aggregating information to ensure data quality.

Transform variables into their final form, including calculating target KPIs like cooling capacity and electric power demand.

Modeling:

Apply data mining algorithms such as regression, decision trees, and ensemble methods to create predictive models.

Evaluate the models for accuracy in predicting operational KPIs.

Deployment:

Implement the data-driven digital twin in the operational environment to support decision-making and improve system performance.

Monitor the performance of the digital twin and update it as needed based on new data and insights.

By following the CRISP-DM approach, the process of building data-driven digital twins for technical building services operation is structured, iterative, and focused on understanding the business context, analyzing data, creating predictive models, and deploying the digital twin for practical use in manufacturing systems.

Hayat Suhendar, M. T., & Widyani, Y. (2023, September 7–8). *Machine Learning Application Development Guidelines Using CRISP-DM and Scrum Concept* [Conference session]. 2023 IEEE International Conference on Data and Software Engineering (ICoDSE), Toba, Indonesia, Indonesia. <https://doi.org/10.1109/ICoDSE59534.2023.10291438>

The article discusses the integration of Scrum concepts into the CRISP-DM model for Machine Learning (ML) application development. By combining these methodologies, developers can benefit from detailed task breakdowns, progress tracking, and enhanced productivity. The research includes an analysis of CRISP-DM and interviews with experienced ML developers to understand the development situation. A proposed guideline is evaluated through a case study and evidence map analysis, showing its effectiveness in facilitating ML software development. Future research suggestions include broader interviews, diverse data variations, and involving external parties in the evaluation process.

Dutta, A., & Zisserman, A. (2019). *The VIA Annotation Software for Images, Audio, and Video*. <https://doi.org/10.1145/3343031.3350535>

In this paper, we introduce a simple and standalone manual annotation tool for images, audio and video: the VGG Image Annotator (VIA). This is a light weight, standalone and offline software package that does not require any installation or setup and runs solely in a web browser. The VIA software allows human annotators to define and describe spatial regions in images or video frames, and temporal segments in audio or video. These manual annotations can be exported to plain text data formats such as JSON and CSV and therefore are amenable to further processing by other software tools. VIA also supports collaborative annotation of a large dataset by a group of human annotators. The BSD open source license of this software allows it to be used in any academic project or commercial application.

Rezatofighi, H., Tsoi, N., Gwak, J., Sadeghian, A., Reid, I., & Savarese, S. (2019). *Generalized Intersection over Union: A Metric and A Loss for Bounding Box Regression*. <http://arxiv.org/abs/1902.09630>

The article "Generalized Intersection over Union: A Metric and A Loss for Bounding Box Regression" introduces a new metric and loss function called Generalized Intersection over Union (GIoU) to address the limitations of traditional Intersection over Union (IoU) in bounding box regression tasks. The authors propose GIoU as a more representative evaluation metric for comparing arbitrary shapes in object detection. By incorporating GIoU as a loss function, the paper demonstrates improved localization accuracy in object detection models. Experimental results on benchmarks like PASCAL VOC and MS COCO show the effectiveness of GIoU in enhancing object detection performance compared to traditional IoU-based methods.

Li, Z., Wu, B., Li, Y., & Chen, Z. (2023). Fusion of aerial, MMS and backpack images and point clouds for optimized 3D mapping in urban areas. *ISPRS Journal of Photogrammetry & Remote Sensing*, *202*, 463–478. <https://doi.org/10.1016/j.isprsjprs.2023.07.010>

Photorealistic 3D models are important data sources for [digital twin](https://www.sciencedirect.com/topics/computer-science/digital-twin) cities and [smart city applications](https://www.sciencedirect.com/topics/computer-science/smart-city-application). These models are usually generated from [data collected](https://www.sciencedirect.com/topics/computer-science/collected-data) by aerial or ground-based platforms (e.g., [mobile mapping](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/mobile-mapping) systems (MMSs) and backpack systems) separately. Aerial and ground-based platforms capture data from overhead and ground surfaces, respectively, offering complementary information for better 3D mapping in urban areas. Particularly, backpack mapping systems have gained popularity for 3D mapping in urban areas in recent years, as they offer more flexibility to reach regions (e.g., narrow alleys and pedestrian routes) inaccessible by vehicle-based MMSs. However, integration of aerial and ground data for 3D mapping suffers from difficulties such as tie-point matching among images from different platforms with large differences in perspective, coverage, and scale. Optimal fusion of the results from different platforms is also challenging. Therefore, this paper presents a novel method for the fusion of aerial, MMS, and backpack images and point clouds for optimized 3D mapping in urban areas. A geometric-aware model for feature matching is developed based on the SuperGlue algorithm to obtain sufficient tie-points between aerial and ground images, which facilitates the integrated bundle adjustment of images to reduce their geometric inconsistencies and the subsequent dense image matching to generate 3D point clouds from different image sources. After that, a graph-based method considering both geometric and texture traits is developed for the optimal fusion of point clouds from different sources to generate 3D mesh models of better quality. Experiments conducted on a challenging dataset in Hong Kong demonstrated that the geometric-aware model could obtain sufficient accurately matched tie-points among the aerial, MMS, and backpack images, which enabled the integrated bundle adjustment of the three image datasets to generate properly aligned point clouds. Compared with the results obtained from state-of-the-art commercial software, the 3D mesh models generated from the proposed point cloud fusion method exhibited better quality in terms of completeness, consistency, and level of detail.

Song, S., & Qin, R. (2022). A NOVEL INTRINSIC IMAGE DECOMPOSITION METHOD TO RECOVER ALBEDO FOR AERIAL IMAGES IN PHOTOGRAMMETRY PROCESSING. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *V-2-2022*, 23–30. <https://doi.org/10.5194/isprs-annals-V-2-2022-23-2022>

The article presents a novel outdoor aerial image formation model and albedo recovering method based on the model. The method is demonstrated through various photogrammetry applications such as relighting, feature matching, and dense matching. The approach requires RAW images with a linear color space for accurate radiometric equations, making it unsuitable for existing JPEG datasets. Unlike other methods, this approach estimates lighting conditions from images without requiring additional user assistance or data collection. The method shows outstanding performance in albedo recovery compared to state-of-the-art data-driven methods and commercial software, improving geometric quality in feature and dense matching. The workflow involves solving camera parameters, reconstructing 3D points, propagating albedo through images using a conditional random field, estimating illumination parameters, and refining albedo based on cast shadows. The method addresses sharp and high-contrast shading of cast shadows in datasets using a photometric model involving sun and sky irradiance and surface normals.

Wilk, Ł., Mielczarek, D., Ostrowski, W., Dominik, W., & Krawczyk, J. (2022). SEMANTIC URBAN MESH SEGMENTATION BASED ON AERIAL OBLIQUE IMAGES AND POINT CLOUDS USING DEEP LEARNING. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*, (B2), 485–491. <https://doi.org/10.5194/isprs-archives-XLIII-B2-2022-485-2022>

The article "Semantic Urban Mesh Segmentation" discusses the application of deep learning methods for semantic classification of urban 3D mesh models using oblique aerial images and point clouds. The study compares two approaches focusing on classifying input data rather than segmenting the 3D mesh itself. Results from the SUM Benchmark dataset and the Bordeaux dataset demonstrate that both methods yield good results with appropriate training data. However, the study highlights the importance of a diverse training dataset for accurate image segmentation. The research also explores the potential of multi-modal information transfer between imagery, point clouds, and meshes for future work. Additionally, the article mentions the significance of the Cesium 3D Tiles Next format for streaming 3D meshes with semantic metadata. Overall, the study provides insights into the effectiveness of deep learning techniques in semantic urban mesh segmentation and its implications for geospatial applications.

Angin, P., Anisi, M. H., Göksel, F., Gürsoy, C., & Büyükgülcü, A. (2020). AgriLoRa: a digital twin framework for smart agriculture. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications (JoWUA)*, *11*(4), 77–96. <https://doi.org/10.22667/JOWUA.2020.12.31.077>

The article "AgriLoRa: A Digital Twin Framework for Smart Agriculture" proposes a low-cost farmland digital twin framework called AgriLoRa to address the hesitation of farmers in developing countries to adopt smart agriculture systems due to high hardware and maintenance costs. The framework aims to create digital replicas of farmlands, known as digital twins, which enable near real-time monitoring of field conditions through the intelligent processing of data gathered from wireless sensor networks (WSNs) and multispectral imaging. By providing remote access to up-to-date information about the farm field, the digital twin framework facilitates precision agriculture by detecting crop diseases, nutrient deficiencies, and optimizing irrigation and fertilization strategies. The digital twin framework plays a crucial role in enhancing decision-making processes for farmers by offering a comprehensive view of the farm field and recommending appropriate actions based on intelligent data analysis.

Azad, M. M., Carla, C. M., & Scott, D. L. (2019). Leveraging Digital Twin Technology in Model-Based Systems Engineering. *Systems*, *7*(1), 7. <https://doi.org/10.3390/systems7010007>

The article "Leveraging Digital Twin Technology in Model-Based Systems Engineering" discusses the increasing relevance of digital twin technology in systems engineering, particularly in the context of model-based system engineering (MBSE). Digital twin, a concept introduced in 2002, is highlighted as a valuable tool for enhancing MBSE processes by providing digital connectivity through the digital thread and trusted data and knowledge through the digital twin. The integration of digital twins with system simulation and IoT is explored as a means to accelerate the transformation of systems engineering processes in MBSE.

While digital twin technology holds great promise for MBSE, the article also addresses concerns that need to be resolved before widespread adoption can be achieved. These concerns include issues related to privacy, ownership, data sharing with suppliers and customers, intellectual property, legal considerations, and determining who owns and benefits from the data provided by the digital twin.

The article emphasizes the potential benefits of leveraging digital twin technology in MBSE but also acknowledges the need to address various challenges and considerations to ensure successful implementation and adoption in the field of systems engineering.

Cureton, P., & Hartley, E. (2023). City Information Models (CIMs) as precursors for Urban Digital Twins (UDTs): A case study of Lancaster. *Frontiers in Built Environment*, *9*. <https://doi.org/10.3389/fbuil.2023.1048510>

The article discusses the importance of geospatial data in the context of the Lancaster City Information Model (LCIM) project. Here are some key points related to geospatial data:

**Data Incorporation**: The LCIM project incorporated additional national GIS layers, including Ordnance Survey UPRNs, Historic England Heritage Status, and Environment Agency LiDAR data. This integration of diverse geospatial datasets enhanced the richness and accuracy of the city information model.

**Data Licensing and Accessibility**: The LCIM was designed as CC-by open data to facilitate interaction with commercial and public sector bodies, addressing geographic data access issues in digital planning. This open data approach aimed to promote collaboration and remove barriers to accessing geospatial information.

**Data Acquisition Strategies**: A spatial data acquisition program was developed in collaboration with Bluesky International Ltd., involving the acquisition of stereo aerial imagery at high resolution and the development of LOD 2.5 buildings and infrastructure features using computational tools like ArcGIS and ESRI CityEngine. These strategies ensured the availability of detailed geospatial data for modeling and analysis.

**Challenges and Limitations**: The article highlights challenges such as data licensing restrictions that prevented the use of high-quality Digital Surface Models (DSMs) and budgetary constraints that limited further aerial acquisitions and updates. These limitations underscore the complexities involved in acquiring and managing geospatial data for urban modeling projects.

Overall, the discussion on geospatial data in the article emphasizes the critical role of accurate, accessible, and high-quality data in developing City Information Models and advancing towards Urban Digital Twins.

Kapteyn, M. G., & Willcox, K. E. (2020). From physics-based models to predictive digital twins via interpretable machine learning. *arXiv preprint arXiv:2004.11356*. <https://doi.org/10.48550/arXiv.2004.11356>

The article discusses the creation of data-driven digital twins using a combination of physics-based models and interpretable machine learning. The methodology involves generating training data offline by simulating various asset states using the physics-based model library. This data is then used to train an interpretable data-driven classifier, specifically utilizing optimal trees as a scalable machine learning method.

The trained classifier maps observed data from the physical asset to estimate which model from the library best matches the data, thus updating the digital twin in real-time. This approach ensures that the digital twin reflects the most recent observations from the asset, allowing for dynamic adaptation to changing conditions. The use of interpretable machine learning techniques provides transparency into the decision-making process of the digital twin, making predictions more trustworthy and reliable.

Overall, the methodology outlined in the study enables the development of predictive digital twins that leverage machine learning models to rapidly estimate asset states, facilitate decision-making, and enhance operational efficiency.

Zhang, J., Cosma, G., & Watkins, J. (2021). Image Enhanced Mask R-CNN: A Deep Learning Pipeline with New Evaluation Measures for Wind Turbine Blade Defect Detection and Classification. *Journal of Imaging*, *7*(3). <https://doi.org/10.3390/jimaging7030046>

The article "Image Enhanced Mask R-CNN for Wind Turbine Blade Defect Detection and Classification" investigates the performance of deep learning algorithms, specifically YOLOv3, YOLOv4, and Mask R-CNN, for detecting and classifying defects on wind turbine blades. The study introduces new evaluation measures tailored for defect detection tasks, including Prediction Box Accuracy, Recognition Rate, and False Label Rate. Key points from the article:

The study presents an empirical comparison of DL algorithms for defect detection, focusing on wind turbine blade inspections.

* Traditional evaluation measures like Recall, Precision, and F1-score were contextualized and new measures were proposed for defect detection evaluation.
* Experiments were conducted using datasets with various image augmentation settings to determine the best-performing algorithm.
* Mask R-CNN outperformed YOLOv3 and YOLOv4 in detecting most defect types, except for void defects where YOLOv3 and YOLOv4 showed better performance due to the size characteristics of void defects.

The study suggests that Mask R-CNN is the most suitable detection model for defects due to its high and stable detection performance, despite being slower than YOLOv3 and YOLOv4 in terms of detection speed.

The research provides insights into the effectiveness of deep learning algorithms for wind turbine blade defect detection and proposes a new defect detection pipeline called Image Enhanced Mask R-CNN. The study's findings have implications for improving wind turbine maintenance practices in the wind power industry.

In the study, the performance of YOLOv3, YOLOv4, and Mask R-CNN was compared in terms of detecting and classifying defects on wind turbine blades. Here are the key findings:

**Mask R-CNN vs. YOLOv3**:

Mask R-CNN outperformed YOLOv3 in terms of Prediction Box Accuracy (PBA) performance for detecting most defect types, except for void defects.

YOLOv3 achieved higher PBA values for void defects compared to Mask R-CNN, possibly due to void defects being smaller in size.

Figure 3d in the study illustrates that Mask R-CNN is relatively weaker than YOLOv3 in recognizing small-sized defects, such as voids.

**Mask R-CNN vs. YOLOv4**:

Mask R-CNN also outperformed YOLOv4 in terms of PBA performance for detecting most defect types.

YOLOv4 achieved higher PBA values for void defects compared to Mask R-CNN, similar to YOLOv3.

YOLOv4 did not comprehensively cover large-sized defect areas, such as erosion defects, in some cases.

Overall, the study suggests that Mask R-CNN performed better than YOLOv3 and YOLOv4 in detecting and classifying defects on wind turbine blades, except for void defects where YOLOv3 and YOLOv4 showed better performance due to the size characteristics of void defects.

Luo, S., Liang, Y., Luo, Z., Liang, G., Wang, C., & Wu, X. (2023). Vision-Guided Object Recognition and 6D Pose Estimation System Based on Deep Neural Network for Unmanned Aerial Vehicles towards Intelligent Logistics. *Applied Sciences*, *13*(1). <https://doi.org/10.3390/app13010115>

The article "Vision-Guided Object Recognition and 6D Pose Estimation System" presents a comprehensive study on a sophisticated system developed for unmanned aerial vehicles (UAVs) to enhance their capabilities in intelligent logistics. The system integrates object detection, target tracking, semantic segmentation, object classification, and 6D object pose estimation using deep neural networks. The researchers highlight the importance of accurate and efficient vision systems for UAVs in logistics tasks. The article reviews related work, discusses the system's methodology, experimental setup, and comparative results to demonstrate its effectiveness and robustness. The study is supported by various funding sources and datasets, and the authors declare no conflicts of interest. The article concludes with author contributions and acknowledgments.

Song, J., Zhao, Y., Song, W., Zhou, H., Zhu, D., Huang, Q., Fan, Y., & Lu, C. (2022). Fisheye Image Detection of Trees Using Improved YOLOX for Tree Height Estimation. *Sensors*, *22*, 3636. <https://doi.org/10.3390/s22103636>

The article "Fisheye Image Detection of Trees Using Improved YOLOX for Tree Height Estimation" presents a novel method for accurately estimating tree height in forestry research. The study introduces Attention-YOLOX-tiny, an improved target detection network, and proposes a new approach for measuring tree height based on this technology. By utilizing a mobile phone and a fisheye lens, the measurement device aims to enhance accuracy and efficiency in tree height estimation. Key points from the article include:

The average relative error of the proposed method is 2.31% under level 5–6 wind conditions, demonstrating good accuracy even in challenging environments.

The study highlights the importance of tree height as a key indicator for measuring forest carbon storage.

The research was funded by "The Fundamental Research Funds for the Central Universities" and the "Heilongjiang Provincial Natural Science Foundation of China."

The authors emphasize the need for future research to focus on 3D reconstruction of trees from 2D images to enhance the understanding of tree structures.

The article also discusses the network structure of YOLOX, training parameters, data augmentation techniques like mosaic data enhancement, and the use of transfer learning to improve model performance. Overall, the study contributes to advancing tree height estimation in forestry research through innovative technology and methodology.

Alkhateeb, A., Jiang, S., & Charan, G. (2023). Real-time digital twins: Vision and research directions for 6G and beyond. *IEEE Communications Magazine*, *61*(11), 128–134. <https://doi.org/10.1109/MCOM.001.2200866>

The article presents a visionary concept of real-time digital twins for wireless communication systems, leveraging technologies such as 3D mapping, multi-modal sensing, and machine learning. These digital twins aim to create accurate real-time replicas of physical environments, enabling informed decision-making at various communication layers. Key features include the use of 3D maps and sensory data for modeling, real-time decision-making capabilities, continuous refinement for accuracy, global sharing among devices, and application across communication layers. The article discusses the potential impact of digital twins on communication tasks, highlights the importance of overcoming fundamental challenges, and outlines future research directions in this innovative field.

Fett, M., Wilking, F., Goetz, S., Kirchner, E., & Wartzack, S. (2023). A Literature Review on the Development and Creation of Digital Twins, Cyber-Physical Systems, and Product-Service Systems. *Sensors (Basel, Switzerland)*, *23*(24). <https://doi.org/10.3390/s23249786>

The article "A Literature Review on the Development and Creation of Digital Twins" focuses on the technical and technological aspects of creating Digital Twins, Cyber-Physical Systems (CPS), and Product-Service Systems (PSS). The review follows the PRISMA approach and analyzes trends in publications related to these topics. It highlights a significant increase in publications on Digital Twins since 2018, with a growing interest in CPS and a moderate level of publications on PSS. The study categorizes the literature into holistic approaches, architecture, and models, showing a steady increase in publications over the years. The article emphasizes the importance of focusing on the creation of Digital Twins and provides insights into the development and implementation of these systems in various industries.

The article highlights the key benefits of Digital Twins for companies as follows:

Real-time condition monitoring and predictive maintenance.

* Performance and usage analysis.
* Collection of information for product development.
* Calculation of remaining useful lifetime.
* Opening up new digital business fields.

To leverage Digital Twins effectively, companies can:

Implement systematic procedures, guidelines, and methods for creating Digital Twins. Utilize findings from related fields such as Cyber-Physical Systems and Product-Service Systems. Invest in know-how, experience, human resources, and financial resources for successful implementation. Use advanced analytics and machine learning algorithms to derive actionable insights. Foster collaboration between departments to maximize the benefits of Digital Twins across various functions. By incorporating these strategies, companies can harness the full potential of Digital Twins to enhance operational efficiency, drive innovation, and gain a competitive advantage in their respective industries.

Lehtola, V. V., Koeva, M., Elberink, S. O., Raposo, P., Virtanen, J.-P., Vahdatikhaki, F., & Borsci, S. (2022). Digital twin of a city: Review of technology serving city needs. *International Journal of Applied Earth Observation and Geoinformation*, *114*, 102915. <https://doi.org/10.1016/j.jag.2022.102915>

The article "Digital twin of a city: Review of technology serving city needs" explores the concept of digital twins in the context of urban environments. Authored by Ville V. Lehtola and colleagues, the study delves into the potential benefits of digital twins for city management and the efficient operation of urban ecosystems. Key points discussed in the article include:

**City Management Benefits**: The article highlights specific examples of digital twin applications in cities like Helsinki, Zurich, and Vienna, emphasizing the technical differences and diverse applications of these digital twins. It suggests that digital twins can address various city needs and enhance decision-making processes.

**Components of a Digital Twin of a City**: The article proposes that a digital twin of a city should consist of four essential parts:

**Addressing the specific needs of the city**

Supporting high-fidelity content, including Building Information Modeling (BIM) data

Continuous updating to reflect the dynamic nature of cities

Ensuring safe and usable systems for effective decision-making

**City Needs and Challenges**: The study discusses the evolving needs of cities, such as sustainable urban development, education planning, and addressing socio-economic issues. It emphasizes the importance of city planning and governance in creating good living environments for inhabitants.

**Economic Efficiency and Innovation**: The article touches upon the potential of cities to become innovation hubs and exporters of solutions, leading to economic benefits and improved quality of life for residents. It highlights the role of digital twins in enhancing city management, planning activities, and fostering innovation within urban ecosystems.

**Future Considerations**: The article raises important questions about the security and updateability of digital twins, particularly in relation to third-party involvement and data quality control. It also emphasizes the need for incentives to encourage data sharing and collaboration among various stakeholders in the city ecosystem.

Overall, the article provides a comprehensive overview of the technology and considerations involved in developing and utilizing digital twins to meet the complex needs of modern cities and enhance their efficiency and sustainability.

Li, H., Ye, C., Guo, Z., Wang, L., Wei, R., & Li, J. (2021). A Fast Progressive TIN Densification Filtering Algorithm for Airborne LiDAR Data Using Adjacent Surface Information. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *14*, 12492–12503. <https://doi.org/10.1109/JSTARS.2021.3131586>

The article discusses the labor-intensive nature of processing LiDAR data, particularly in filtering out ground and object points. Traditional methods often require manual intervention or extensive computational resources to separate these points accurately. The Fast Progressive TIN Densification (FPTD) algorithm presented in the article aims to streamline this process by automating the filtering process and improving efficiency.

The article presents a Fast Progressive TIN Densification (FPTD) filtering algorithm for airborne LiDAR data using adjacent surface information. Traditional methods, such as Progressive Triangulated Irregular Network (PTD) algorithms, face challenges in steeply sloped areas and time-consuming processing. The FPTD algorithm addresses these issues by enhancing the selection of initial ground seed points, refining iterative judgment criteria, and reducing processing time.

Key aspects of the FPTD algorithm include utilizing a sliding window to obtain evenly distributed initial ground seed points, segmenting datasets into blocks for efficient processing, and classifying datasets based on terrain complexity to optimize filtering thresholds. By incorporating adjacent surface information and multithreaded processing, the FPTD algorithm demonstrates improved speed and robustness compared to traditional PTD methods.

Experimental results show that the FPTD algorithm outperforms PTD in terms of processing time and filtering accuracy, with an average processing time 1/12 of PTD and a higher kappa coefficient. The algorithm's effectiveness lies in its ability to efficiently filter LiDAR point clouds while maintaining accuracy, making it a valuable tool for various LiDAR applications.

Mylonas, G., Kalogeras, A., Kalogeras, G., Anagnostopoulos, C., Alexakos, C., & Muñoz, L. (2021). Digital twins from smart manufacturing to smart cities: A survey. *IEEE Access*, *9*, 143222–143249. <https://doi.org/10.1109/ACCESS.2021.3120843>

The article "Digital Twins: From Smart Manufacturing to Smart Cities - A Survey" provides a comprehensive overview of the applications, challenges, and potential of digital twins in various sectors, focusing on smart manufacturing and smart cities. It discusses key areas where digital twins are utilized, such as asset integrity monitoring, project planning, and life cycle management. The authors highlight challenges like cyber security, lack of standardization, and scope uncertainty in implementing digital twins.

In the context of smart cities, the article emphasizes the importance of involving stakeholders and end-users in the design and implementation of city-scale digital twins. It also stresses the significance of visualization tools for maximizing the potential of urban digital twins. The research agenda and open challenges for city-scale digital twins are outlined, including the need to make data meaningful and accessible to city stakeholders.

The survey paper compares the development of digital twins in smart manufacturing and smart cities, noting that smart manufacturing has seen more concrete advancements compared to smart cities. The lack of a widely agreed-upon definition and taxonomy for digital twins, as well as the relative lack of standardization activities, are highlighted as ongoing challenges in the field.

Overall, the article provides insights into the current state of digital twins, their applications in different sectors, and the challenges and opportunities associated with their implementation in smart manufacturing and smart cities.

Capecchi, I., Borghini, T., & Bernetti, I. (2023). Automated urban tree survey using remote sensing data, Google Street View images, and plant species recognition apps. *European Journal of Remote Sensing*, *56*(1), 2162441. <https://doi.org/10.1080/22797254.2022.2162441>

The article "Automated urban tree survey using remote sensing data, Google street view images, and plant species recognition apps" explores the integration of various technologies to conduct automated urban tree surveys for effective city planning. The study focuses on the city of Prato in Italy and aims to extract images of urban trees from Google Street View using LiDAR and multispectral data. The research utilizes two plant species recognition apps, Pl@ntNet and Plant.Id, along with a Convolutional Neural Network (CNN) for tree species classification.

The authors highlight the importance of urban tree inventories for urban planning in the context of global climate change. Traditional single-tree inventories are costly and often lack detail, leading to outdated information. By combining remote sensing data, Google Street View images, and AI-based species recognition apps, the study aims to enable automatic censuses of urban greenery at the individual tree level.

Challenges such as limited access to certain areas for data collection are addressed by proposing solutions like using unmanned aircraft for spherical photos. The research evaluates the performance of the classification systems based on morphological characteristics of tree species and compares the efficiency of the plant species recognition apps with a CNN trained on the study area.

Overall, the study provides insights into the potential of automated techniques for urban tree surveys, highlighting the benefits and limitations of integrating LiDAR data, Google Street View images, and tree species classification apps. The findings contribute to advancing cost-effective and efficient methods for urban green inventory and city planning.

Diab, A., Kashef, R., & Shaker, A. (2022). Deep Learning for LiDAR Point Cloud Classification in Remote Sensing. *Sensors*, *22*(20), 7868.  <https://doi.org/10.3390/s22207868>

The article discusses the application of deep learning techniques for LiDAR point cloud classification in remote sensing. It highlights the advantages of LiDAR technology in providing precise spatial information about Earth's surface components, particularly in vegetation analysis. The use of deep learning models, such as PointNet-based architectures, has shown promising results in classifying point cloud data. The article also addresses challenges in LiDAR data processing, such as computational intensity and the need for standardized test datasets. Future directions include expanding deep learning methods in autonomous driving applications.

According to the article, the primary benefits of LiDAR in comprehending foliage or vegetation include its sensitivity to vertical vegetation structure variations, enabling effective analysis in natural resources and forest applications. Additionally, LiDAR offers precise spatial information on vegetation shape and components, facilitating detailed foliage characterization and accurate tree species classification.

Concerning the constraints of LiDAR data processing, while specific limitations related to foliage understanding are not explicitly mentioned, general challenges may involve the computational intensity of LiDAR data processing, the complexity of interpreting large LiDAR point cloud datasets in dense vegetation environments, and factors like sensor calibration and data noise affecting data quality and analysis accuracy.

Lu, D., & Jiang, X. (2024). A brief overview and perspective of using airborne Lidar data for forest biomass estimation. *International Journal of Image and Data Fusion*, *15*(1), 1–24.  <https://doi.org/10.1080/19479832.2024.2309615>

The limitations of LiDAR data mentioned in the article include the high data requirements, labor-intensive and time-consuming data collection process, and challenges in processing due to factors such as data volume, model complexity, and generalizability. The article highlights that the collection of reference data for biomass estimation can be one of the most labor-intensive and time-consuming components of a biomass mapping project. Additionally, the processing of LiDAR data can be complex due to considerations such as data volume, processing speed, model complexity, and generalizability, especially when using point cloud data directly as input. These challenges underscore the importance of carefully assessing the strengths and weaknesses of using LiDAR data for forest biomass estimation within specific contexts.

The key advantages of using airborne Lidar data for forest biomass estimation as highlighted in the article include:

* Ability to quickly and accurately estimate forest biomass in a large area.
* Capability to extract tree height, which is closely related to forest biomass/volume, addressing the common data saturation problem in optical sensor or SAR data.
* Recognition as the most important data source for forest biomass estimation at the local scale, with many studies conducted for mapping forest biomass/carbon stock distributions in different climate zones.
* Provision of wall-to-wall mapping of forest biomass without integration with other data sources, unlike spaceborne Lidar data.

These advantages demonstrate the significance of airborne Lidar data in enabling precise and efficient forest biomass estimation at the local scale.

Li, Z., Hodgson, M. E., & Li, W. (2018). A general-purpose framework for parallel processing of large-scale LiDAR data. *International Journal of Digital Earth*, *11*(1), 26–47.  <https://doi.org/10.1080/17538947.2016.1269842>

 The article presents a general-purpose framework for parallel processing of large-scale LiDAR data to address the challenges posed by the high processing complexity and massive data volumes associated with LiDAR datasets. The framework is designed to efficiently handle big LiDAR datasets by utilizing sophisticated data decomposition and parallelization strategies. Key components of the framework include a tile-based spatial index for managing LiDAR data in a scalable and fault-tolerant Hadoop distributed file system, spatial decomposition techniques for parallelizing different LiDAR processing tasks, and the integration of existing LiDAR processing tools with Hadoop for parallel processing in a distributed computing environment.

The authors highlight the increasing importance of LiDAR data in various fields such as Digital Earth research, natural disasters, environmental applications, and engineering. They emphasize the need for scalable processing architectures to handle the large volumes of LiDAR data efficiently. The article discusses the computational challenges posed by processing massive LiDAR datasets, including the time-consuming nature of traditional processing workflows and the need to optimize results by testing different parameter values across large study areas.

The processing complexity of LiDAR data is high due to the massive amount of 3D data points, complex geospatial algorithms, and diverse selection of parameters involved in tasks such as point classification, ground point extraction, and generating final products like Digital Elevation Models (DEMs) and 3D building models. This complexity is further exacerbated when dealing with large-scale LiDAR data sets that can reach tens of Terabytes in volume, stressing the storage and computational limits of a single computer.

Overall, the proposed framework offers a scalable and efficient solution for parallel processing of large-scale LiDAR data without the need for specialized hardware or customized software solutions. By leveraging existing software modules and widely used LiDAR data structures, the framework enables a variety of LiDAR data processing tasks to be performed in parallel in a highly scalable distributed computing environment.

Wang, Z., & Menenti, M. (2021). Challenges and Opportunities in Lidar Remote Sensing. *Frontiers in Remote Sensing*, *2*, 641723.  <https://doi.org/10.3389/frsen.2021.641723>

The research study titled "Challenges and Opportunities in Lidar Remote Sensing" discusses the advancements, challenges, and opportunities in the field of lidar technology for remote sensing applications. The study highlights the evolution of lidar technologies over the past 60 years, emphasizing their crucial role in various scientific disciplines such as atmospheric science, terrain modeling, cryospheric discovery, terrestrial ecology, hydrology, and oceanography. Key points covered in the study include:

* The development of different lidar technologies to provide atmospheric and surface properties.
* Successful lidar operations in missions such as NASA's CALIPSO and ICESat, and ESA's Aeolus wind satellite.
* The importance of technological advancements, data assimilation methods, and synergizing multiple lidar measurements to overcome challenges in lidar data usage.
* The need for cost-effective and reliable lidar systems for operational applications, with a focus on reducing system costs and improving system stability.
* The significance of lidar networks to support research and operational activities, emphasizing the spatial variability of atmospheric properties and the value of network lidar operations.

Overall, the study underscores the growing importance of lidar technology in advancing scientific research and applications, while also highlighting the ongoing challenges that need to be addressed to fully leverage the potential of lidar remote sensing in various fields.

Zeng, Y., Duan, Q., Chen, X., Peng, D., Mao, Y., & Yang, K. (2021). UAVData: A dataset for unmanned aerial vehicle detection. *Soft Computing: A Fusion of Foundations, Methodologies and Applications*, *25*(7), 5385–5393.  <https://doi.org/10.1007/s00500-020-05537-9>

The article introduces UAVData, a dataset created for unmanned aerial vehicle (UAV) detection. The dataset includes images captured in various scenes such as blank backgrounds, workshops, laboratories, and outdoor environments with sky, trees, and buildings. It consists of 13,803 images, including uni-drone images, multi-drone images, and balloon images, with corresponding bounding boxes for targets. UAVData aims to enhance safety by detecting flying objects like drones, supporting object detection tasks, and providing data for training detectors using inexpensive sensors like cameras. The dataset is used for applications such as flying object detection to avoid collisions. Additionally, the article discusses the importance of large-scale datasets for deep learning-based methods in UAV detection and compares UAVData with other notable datasets like Microsoft COCO and Pascal VOC. The study also applies various object detection methods and convolutional neural network models to UAV detection using UAVData. Overall, UAVData serves as a valuable resource for advancing research in UAV detection and object detection fields.

Müllerová, J., Gago, X., Bucas, M., Company, Jaume, Estrany, J., Fortesa, J., Manfreda, S., Adrien, M., Mokros, M., Paulus, G., Tiskus, E., Tsiafouli, M., & Kent, R. (2021). Characterizing vegetation complexity with unmanned aerial systems (UAS) -A framework and synthesis. *Ecological Indicators*, *131*, 108156.  <https://doi.org/10.1016/j.ecolind.2021.108156>

The research study provides a comprehensive framework and synthesis on characterizing vegetation complexity using unmanned aerial systems (UAS). It outlines a general survey design for UAS-based vegetation studies, categorizing them based on the components of vegetation heterogeneity addressed, such as species composition, ecosystem structure, plant status, and dynamics. The study emphasizes the importance of designing surveys tailored to the research purpose and ecosystem characteristics, with considerations for data quality and processing algorithms. It highlights the benefits of UAS in biodiversity monitoring, ecosystem structure analysis, and vegetation dynamics assessment. The integration of UAS data with traditional field methods is proposed for a more comprehensive analysis. Overall, the study showcases the potential of UAS in advancing ecological research and conservation efforts through enhanced vegetation characterization.

Banerjee, B. P., Raval, S., Cullen, P. J., & Kumar Singh, S. (2019). *Mapping of complex vegetation communities and species using UAV-LIDAR metrics and high-resolution optical data*. IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium.  <https://doi.org/10.1109/IGARSS.2019.8899160>

The research study explores the mapping of complex vegetation communities and species in upland swamps using an integrated UAV-LiDAR system. The study details the data acquisition process, pre-processing steps, extraction of LiDAR metrics, dimensionality reduction, and classification methods. By combining LiDAR data with high-resolution optical (RGB) data, the classification accuracy was significantly improved. The Independent Component Analysis with Support Vector Machine (ICA+SVM) approach yielded the best results with a 69.9% overall accuracy and 0.62 kappa coefficient. When RGB data was added to the LiDAR data, the overall accuracy increased to 73.6% and the kappa coefficient to 0.67. The study demonstrates the effectiveness of UAV-LiDAR technology in distinguishing between swamp and non-swamp vegetation communities, offering valuable insights for managing anthropogenic impacts on sensitive ecosystems.

Sun, Z., Wang, X., Wang, Z., Yang, L., Xie, Y., & Huang, Y. (2021). UAVs as remote sensing platforms in plant ecology: review of applications and challenges. *J Plant Ecol*, *14*(6), 1003–1023.  <https://doi.org/10.1093/jpe/rtab089>

The article discusses the use of Unmanned Aerial Vehicles (UAVs) as remote sensing platforms in plant ecology, highlighting their cost-effectiveness and flexibility in acquiring high-resolution data. It emphasizes the need for better integration between plant ecology research needs and UAV remote sensing applications. The review covers various applications of UAVs in plant ecology, including mapping, measuring, and monitoring vegetation at different scales. Challenges faced by plant ecologists using UAVs include regulatory constraints, equipment costs, data processing complexity, integration of UAV data with ecological processes, and the need to stay updated on technological advancements. Collaboration between plant ecologists and remote sensing professionals is essential to overcome these challenges and advance plant ecology research using UAV technology.