



Visual Positioning Systems: Transforming Surveying and Geoinformatics

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ABSTRACT

This paper explores the pivotal role and applications of Visual Positioning Systems (VPS) in the fields of surveying and geoinformatics. Visual Positioning Systems, leveraging computer vision and image processing, provide a paradigm shift in spatial data collection and analysis. Unlike traditional systems reliant on external signals, VPS excels in challenging environments, such as urban canyons and indoor spaces. The paper discusses the precision in mapping, measurement, and the real-time capabilities of VPS in surveying, emphasizing its relevance in urban planning and infrastructure development. In geoinformatics, VPS finds applications in indoor mapping, navigation, and augmented reality integration. The paper also addresses challenges such as computational complexity and data privacy concerns, highlighting future prospects for integrating VPS with emerging technologies like Artificial Intelligence and the Internet of Things. As a transformative technology, Visual Positioning Systems promise to reshape the landscape of surveying and geoinformatics, offering new possibilities for precision, efficiency, and innovation in spatial data applications.

Keywords: Augmented Reality; Geoinformatics; Global Navigation Satellite Systems (GNSS); Surveying; Visual Positioning Systems (VPS)

1. Introduction

Surveying and geoinformatics, critical disciplines in understanding and managing our environment, have become indispensable in diverse sectors such as urban planning, environmental monitoring, infrastructure development, and disaster management. The dynamic and complex nature of these fields demands continual advancements in technology to enhance the accuracy and efficiency of spatial data collection and analysis. In this pursuit, one technological frontier has emerged as particularly transformative - Visual Positioning Systems (VPS).

Visual Positioning Systems, which harness the power of computer vision and image processing, stand at the forefront of technological innovation in surveying and geoinformatics. They offer a paradigm shift by providing a means to overcome the limitations posed by traditional methods, such as Global Navigation Satellite Systems (GNSS) and inertial navigation, especially in challenging environments where signal obstructions are prevalent.

These technological advancements have been highlighted by researchers exploring the integration of visual and inertial sensors for improved positioning accuracy in GNSS-challenged environments (Elaksher et al., 2018) and the precise location determination in urban canyons using smartphones (Gong et al., 2016). The significance of VPS in addressing challenges associated with navigation in GNSS-denied environments has been emphasized, showcasing its adaptability in scenarios where traditional satellite-based systems encounter limitations (Lohan et al., 2020).

Visual Positioning Systems play a crucial role in mapping and autonomous navigation within indoor environments (Mautz et al., 2017). Their application extends to the realm of mobile augmented reality, where the fusion of geospatial data and augmented reality enhances user experiences (Nittel et al., 2018). Moreover, the challenges associated with object detection in unmanned aerial vehicle images are addressed, highlighting the role of VPS in enhancing the accuracy of object identification in geoinformatics (Rottensteiner et al., 2018).

The advent of VPS has brought about a significant shift in handling visual and geospatial big data, showcasing its potential in managing vast amounts of visual data for geoinformatics applications (Sirmacek et al., 2016). A comprehensive survey of Visual Positioning Systems, encompassing state-of-the-art methodologies and applications, provides a foundational understanding of the technology's landscape (Tang et al., 2020).

In the context of unmanned aerial vehicles, VPS is revealed to be a powerful tool for visual positioning and simultaneous localization and mapping (SLAM), expanding its application domain (Wang et al., 2021). These research endeavors collectively underscore the transformative potential of Visual Positioning Systems in advancing the accuracy and efficiency of surveying and geoinformatics processes.

2. Visual Positioning Systems (VPS)

Visual Positioning Systems (VPS) represent a groundbreaking fusion of computer vision and spatial awareness, empowering the determination of object positions and orientations within diverse environments. At their core, these systems deploy intricate computer vision algorithms to meticulously interpret visual data captured by cameras or sensors. This interpretative prowess forms the foundation for precise spatial mapping and navigation.

The defining feature of VPS lies in its departure from the traditional reliance on external signals, setting it apart from conventional Global Navigation Satellite Systems (GNSS) and inertial navigation systems. VPS operates autonomously, making it particularly advantageous in settings where traditional navigation technologies encounter substantial challenges. This autonomy becomes especially valuable in urban canyons, characterized by towering structures that obstruct GNSS signals. Gong et al. (2016) exemplify this in their study, showcasing the adaptability of VPS in urban canyons through the use of smartphones.

Moreover, the inherent autonomy of VPS proves invaluable in indoor environments, where signal obstructions pose considerable hurdles for traditional navigation systems. Research by Mautz et al. (2017) delves into the application of VPS in mapping and autonomous navigation within indoor spaces, highlighting its efficacy in scenarios where traditional systems face limitations.

The significance of VPS extends beyond overcoming signal obstructions. Unlike inertial navigation systems that rely on accelerometers and gyroscopes, VPS augments its positional understanding with rich visual data. Li et al. (2018) delve into the challenges and opportunities of visual-inertial navigation, underscoring the potential of VPS in providing robust and comprehensive spatial information.

In environments where GNSS signals are not only obstructed but also scarce, such as dense urban landscapes, VPS emerges as a beacon of reliability. Elaksher et al. (2018) explore the integration of visual and inertial sensors to enhance positioning accuracy in GNSS-challenged environments, showcasing the versatility of VPS across a spectrum of challenging scenarios.

In essence, Visual Positioning Systems redefine spatial awareness by liberating navigation from the constraints of external signals. This departure from convention not only enables navigation in challenging environments but also opens avenues for richer spatial understanding through the fusion of visual and inertial data. VPS stands as a testament to the transformative potential of computer vision in revolutionizing the accuracy and adaptability of positioning systems.

3. Role in Surveying

Visual Positioning Systems (VPS) play a crucial role in modern surveying, offering a suite of capabilities that enhance precision, efficiency, and adaptability across various applications.

Precision in Mapping and Measurement: Visual Positioning Systems significantly contribute to the precision of mapping and measurement in surveying. By harnessing high-resolution visual data, VPS empowers surveyors to capture detailed images of the terrain, facilitating the accurate identification and measurement of features. This capability is underscored by studies such as those by Wang et al. (2021), emphasizing the role of VPS in providing detailed visual information for precise mapping and measurement.

Urban Planning and Infrastructure Development: In urban environments, where tall buildings often obstruct signals from Global Navigation Satellite Systems (GNSS), Visual Positioning Systems emerge as indispensable tools. Their ability to function independently of external signals positions VPS as a reliable solution for accurate mapping and monitoring of existing structures and topography in urban landscapes. Research by Gong et al. (2016) exemplifies the application of VPS in urban canyons, showcasing its adaptability in overcoming challenges posed by signal obstructions.

Real-Time Data Collection: The real-time capabilities of Visual Positioning Systems offer a transformative dimension to surveying practices. Surveyors can now collect data on the fly, providing a dynamic and adaptive approach to spatial data acquisition. This real-time functionality proves particularly valuable in dynamic environments or projects with rapidly changing conditions. Tang et al. (2020) elaborate on the real-time capabilities of VPS, showcasing its potential for dynamic data collection in various surveying scenarios.

Integration with Augmented Reality (AR): Visual Positioning Systems contribute to the integration of spatial data with Augmented Reality (AR) in surveying applications. By overlaying visual information onto the physical environment, VPS enhances the visualization of geospatial data. This integration is explored by Nittel et al. (2018), highlighting the synergy between VPS and AR for an immersive and contextual understanding of surveying environments.

Environmental Monitoring and Analysis: Beyond traditional surveying applications, VPS finds utility in environmental monitoring and analysis. The high-resolution visual data captured by VPS facilitates detailed assessments of land cover, vegetation health, and changes over time. Studies such as those by Rottensteiner et al. (2018) delve into the challenges and opportunities of object detection in unmanned aerial vehicle images, demonstrating the potential of VPS in environmental monitoring.

Adaptability to Indoor Environments: Visual Positioning Systems exhibit adaptability to indoor environments; a domain where traditional satellite-based systems often struggle. Research by Mautz et al. (2017) emphasizes the role of VPS in indoor mapping and navigation, extending its reach to applications within buildings and structures.

4. Application in Geoinformatics

Visual Positioning Systems (VPS) stand at the forefront of transformative applications within the realm of geoinformatics, contributing significantly to indoor mapping and navigation, augmented reality (AR) integration, and environmental monitoring and analysis.

Indoor Mapping and Navigation: Visual Positioning Systems excel in environments where conventional satellite-based systems encounter limitations, particularly indoors. Their adaptability and precision make them indispensable for indoor mapping and navigation in diverse settings such as shopping malls, airports, and museums. This versatility is underscored by the work of Mautz et al. (2017), emphasizing the role of VPS in autonomous navigation within indoor environments, thereby extending their utility beyond traditional outdoor mapping scenarios.

Augmented Reality (AR) Integration: The synergy between Visual Positioning Systems and Augmented Reality (AR) marks a pivotal advancement in geoinformatics applications. By seamlessly integrating VPS with AR, geospatial data visualization reaches new heights. This integration provides users with an immersive and contextual understanding of their surroundings. Nittel et al. (2018) delve into the challenges and opportunities of integrating Visual Positioning Systems with mobile augmented reality, highlighting the potential for enriching user experiences through the fusion of these technologies.

Environmental Monitoring and Analysis: In the domain of environmental monitoring, Visual Positioning Systems contribute significantly by capturing high-resolution imagery that facilitates detailed analysis of land cover, vegetation health, and temporal changes. This capability is crucial for ecological studies and effective natural resource management. The work of Rottensteiner et al. (2018) explores the challenges and solutions associated with object detection in unmanned aerial vehicle images, showcasing the potential of VPS in contributing to environmental monitoring initiatives.

5. Challenges and Future Prospects

Despite the remarkable advantages that Visual Positioning Systems (VPS) bring to the forefront of spatial technologies, several challenges persist, shaping the trajectory of future developments in this field.

Computational Complexity: One primary challenge confronting the widespread adoption of Visual Positioning Systems is the computational complexity associated with processing vast amounts of visual data in real-time. As the demand for high-resolution imagery and accurate positioning increases, the computational load on VPS systems intensifies. Researchers and developers are actively engaged in addressing this challenge (Tang et al., 2020) to ensure that VPS remains agile and responsive in dynamic environments.

Data Privacy Concerns: The intricacies of handling and processing visual data in real-time raise legitimate concerns about data privacy. Visual Positioning Systems, by their nature, capture detailed images of the environment, potentially including sensitive or private information. Striking a balance between the need for precision in spatial data and respecting privacy rights is a challenge that requires careful consideration (Sirmacek et al., 2016). Addressing these concerns is essential for the widespread acceptance and ethical implementation of VPS technologies.

Algorithmic Sophistication: The efficacy of Visual Positioning Systems hinges on the sophistication of the underlying algorithms. Developing algorithms capable of accurately interpreting complex visual data in diverse environments poses a significant challenge. Achieving robustness across varying lighting conditions, terrains, and structures requires continuous refinement and adaptation of algorithms. Future advancements may focus on developing more adaptive and versatile algorithms (Li et al., 2018) that can handle the nuances of different environments seamlessly.

Integration with Emerging Technologies: The future prospects of Visual Positioning Systems are intrinsically tied to their integration with other cutting-edge technologies. Artificial Intelligence (AI) and the Internet of Things (IoT) present avenues for enhancing the capabilities of VPS. AI algorithms can contribute to more efficient data processing and interpretation, while IoT connectivity can enable a networked approach to spatial awareness. The challenge lies in seamlessly integrating VPS with these technologies (Sirmacek et al., 2016) to create synergies that amplify their collective impact on spatial intelligence.

As researchers and engineers navigate these challenges, the future of Visual Positioning Systems holds exciting possibilities. Overcoming computational hurdles, addressing data privacy concerns, advancing algorithmic sophistication, and seamlessly integrating with emerging technologies will pave the way for a new era of precision, adaptability, and reliability in spatial data acquisition and analysis (Tang et al., 2020). The evolution of VPS promises not only to address current challenges but also to redefine the boundaries of what is achievable in the realm of spatial technologies.

6. Conclusion

The advent of Visual Positioning Systems (VPS) marks a watershed moment in the domains of surveying and geoinformatics, ushering in a new era of precision, adaptability, and innovation. The transformative capabilities of VPS, rooted in their capacity to provide unparalleled location accuracy even in challenging environments, position them as indispensable tools for modern spatial data collection and analysis.

The significance of Visual Positioning Systems is underscored by their ability to overcome longstanding challenges faced by traditional surveying methods, particularly in environments where Global Navigation Satellite Systems (GNSS) encounter obstructions or limitations. The adaptability of VPS to urban canyons, indoor spaces, and areas with GNSS signal challenges has broadened the scope of spatial data applications, offering unprecedented accuracy and efficiency.

As technology continues its relentless march forward, Visual Positioning Systems are poised to assume an increasingly prominent role in shaping the future landscape of surveying and geoinformatics. The ongoing advancements in computer vision, sensor technologies, and algorithmic sophistication are likely to further enhance the capabilities of VPS, unlocking new possibilities for spatial data applications.

Looking ahead, Visual Positioning Systems hold the promise of revolutionizing not only the accuracy and efficiency of surveying practices but also fostering innovation in spatial data applications. The integration of VPS with emerging technologies, such as Artificial Intelligence (AI) and the Internet of Things (IoT), presents exciting avenues for creating synergies that amplify their impact. This synergy is expected to drive a paradigm shift, enabling surveyors and geoinformatics professionals to explore novel approaches, achieve higher levels of precision, and meet the evolving demands of spatial intelligence in diverse contexts.

In essence, Visual Positioning Systems stand as vanguards of progress, offering a glimpse into a future where the boundaries of spatial data applications are continually pushed. Their transformative potential, coupled with ongoing technological advancements, positions VPS at the forefront of innovation, heralding a future where precision, efficiency, and innovation converge to redefine the landscape of surveying and geoinformatics.

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