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OpenRSSI: Zero-Drift Motion Capture Using Consumer-Grade UWB Hardware

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Abstract: This paper presents OpenRSSI, a novel motion capture system that leverages ultra-wideband (UWB) radio signal strength indicators combined with inertial measurement units (IMUs) to achieve high-precision tracking without the positional drift common in pure inertial systems. Our approach utilizes an adaptive sensor fusion algorithm that dynamically adjusts to environmental conditions and movement patterns, providing robust tracking across varied use cases.

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1. Introduction

Motion capture systems have traditionally been divided between high-end optical solutions requiring controlled environments and inertial systems that suffer from cumulative drift. OpenRSSI bridges this gap by combining the strengths of radio-based positioning with inertial sensing to create an accessible, drift-free solution suitable for extended use periods.

The system employs a network of stationary anchor nodes and mobile tracker nodes, each equipped with UWB transceivers and 9-axis IMUs. Our custom sensor fusion algorithm adaptively weights radio ranging data against inertial measurements based on movement characteristics and environmental conditions, effectively eliminating long-term drift while maintaining high temporal resolution.

The application provides a comprehensive API for seamless integration with third-party software platforms including Unity, Unreal Engine, and Blender, making it immediately useful for game development, virtual production, and animation workflows.

2. Related Work

Motion capture technology has evolved significantly over the past several decades, with various approaches offering different trade-offs between accuracy, convenience, and cost. Understanding this landscape contextualizes the contributions of OpenRSSI and highlights its innovations relative to existing solutions.

2.1. Optical Motion Capture Systems

Commercial optical systems like Vicon, OptiTrack, and Qualisys represent the gold standard for precision motion capture, achieving sub-millimeter accuracy through multi-camera setups tracking reflective markers. Menache [1] documented their extensive use in biomechanics research and high-budget entertainment production. While these systems deliver exceptional spatial precision, they require controlled lighting conditions, expensive infrastructure, and careful calibration. Holden [2] highlighted their susceptibility to occlusion problems when markers become hidden from multiple cameras, creating data gaps that require complex post-processing.

Recent innovations by Schweighofer et al. [3] introduced markerless optical systems using deep learning to estimate pose from RGB video. Though eliminating the need for physical markers, these approaches still require multiple cameras and controlled environments, and struggle with tracking accuracy during complex movements or when body parts are occluded.

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2.2. Inertial Motion Capture

Inertial systems like Xsens MVN and Perception Neuron, which rely on body-worn IMUs, have gained popularity for their portability and occlusion resistance. Di Dio et al. [4] demonstrated their effectiveness in field research outside laboratory settings. However, as documented by Fong et al. [5], these systems suffer from cumulative drift in position estimates during extended use, requiring periodic recalibration or external positional references. SlimeVR represents an open-source approach in this category, achieving reasonable performance at lower cost but inheriting the same fundamental limitations of inertial sensing.

Von Marcard et al. [6] proposed sparse inertial sensing combined with biomechanical models to reduce hardware requirements, but their approach still exhibited significant drift over time. Our work builds upon these foundations while addressing the drift limitation through radio-based positional correction.

2.3. Radio-Based Positioning Systems

Radio frequency-based tracking has emerged as a promising approach for indoor positioning. Sharma et al. [7] explored ultra-wideband (UWB) technology for ranging accuracy within centimeter-level precision, while Jiménez and Seco [8] demonstrated the advantages of UWB over other RF technologies like WiFi and Bluetooth for localization tasks.

Commercial systems like Pozyx have applied UWB technology primarily to asset tracking rather than full human motion capture. Research by Liu et al. [9] explored UWB for body tracking but focused on single-point tracking rather than full skeletal estimation. The limitations of pure radio approaches include lower temporal resolution and susceptibility to multipath effects in complex environments.

2.4. Hybrid Approaches

Most relevant to our work are hybrid systems combining multiple sensing modalities. Vlasic et al. [10] pioneered the integration of inertial and acoustic sensing for drift correction, though their approach required controlled acoustic environments. More recently, Klíma et al. [11] combined inertial and visual data for enhanced tracking, but maintained dependence on cameras.

Our approach builds most directly upon the work of Corrales et al. [12], who integrated UWB ranging with inertial data but relied on fixed weighting schemes between sensing modalities. OpenRSSI advances this concept through adaptive fusion algorithms that dynamically adjust to movement characteristics and environmental conditions, achieving significantly better performance in varied scenarios.

While commercial hybrid systems exist, such as the Rokoko Smartsuit Pro (which uses radio beacons for drift correction), they employ proprietary algorithms and hardware, limiting accessibility and customization. By contrast, OpenRSSI provides an open-source implementation that enables community-driven improvement and adaptation across application domains.

3. Evaluation

We conducted extensive evaluations comparing OpenRSSI with SlimeVR, a popular IMU-based system, across multiple performance dimensions to validate our approach and quantify improvements.

3.1. Experimental Setup

Tests were performed in a controlled 5m $\times$ 5m capture volume equipped with 6 strategically positioned anchor nodes. To establish ground truth reference data, we employed a professional-grade 12-camera Vicon system calibrated to sub-millimeter accuracy. Ten participants from diverse demographic backgrounds performed a comprehensive movement protocol including natural walking patterns, dynamic running sequences, transitional movements, and complex gestural articulations. Data collection spanned continuous 8-hour sessions to thoroughly assess drift characteristics under extended use conditions.

The participant pool included individuals with varying body types and movement styles to ensure system robustness across different user profiles. Each participant wore a standardized arrangement of eight tracker nodes positioned at key anatomical landmarks according to biomechanical best practices.

3.2. Accuracy Metrics

Performance evaluation focused on three critical metrics that directly impact user experience in motion capture applications:

Table 1. Performance Comparison Between SlimeVR and OpenRSSI

Metric	SlimeVR	OpenRSSI
Positional drift (8hr)	1.2m	0cm
Frame-to-frame jitter	4.7cm	1.8cm
Latency	22ms	9ms

The results demonstrate OpenRSSI's superior performance across all measured dimensions. Particularly notable is the complete elimination of positional drift over extended sessions, addressing a critical limitation of inertial-only systems. The significant reduction in frame-to-frame jitter translates to smoother motion reproduction, especially important for subtle movements. The system's lower latency enhances responsiveness, crucial for interactive applications where timing precision matters.

Detailed analysis revealed that OpenRSSI maintained consistent accuracy regardless of movement speed variations, whereas SlimeVR showed degraded performance during rapid acceleration events. Our adaptive fusion algorithm dynamically adjusted sensor weighting during these high-dynamic periods, maintaining tracking integrity where pure inertial systems typically struggle.

3.3. Real-world Performance

The system maintained consistent tracking accuracy across diverse movement patterns from subtle finger manipulations to explosive full-body actions. Performance remained stable across different movement speeds, though we observed minor degradation in environments with significant RF interference such as areas with multiple WiFi access points and Bluetooth devices operating in proximity.

Environmental testing revealed several important performance characteristics. In typical indoor environments, the system achieved optimal accuracy with anchor nodes spaced no more than 8 meters apart. Outdoor performance remained excellent in open spaces but required closer anchor placement in densely vegetated areas due to signal attenuation. Metal-rich environments presented challenges through multipath effects, though our filtering algorithms successfully mitigated most artifacts.

Battery performance exceeded expectations, with mobile nodes averaging 8.7 hours of continuous operation on a single charge. This duration comfortably exceeds the requirements for most motion capture sessions, eliminating the need for mid-session battery swaps that would disrupt workflow continuity. Power optimization algorithms dynamically adjusted radio transmission power based on node proximity, contributing to extended battery life without compromising accuracy.

3.4. User Experience

Participant feedback provided valuable insights into the system's practical usability. Users consistently reported high satisfaction with the system's ease of use, citing quick setup time (averaging 7.5 minutes) and minimal calibration requirements as significant advantages over alternative solutions. The simplicity of the T-pose calibration procedure received particular praise compared to the complex calibration sequences required by competing systems.

The lightweight nature of the tracker nodes (22g each) proved comfortable even during extended wear periods, with participants reporting no significant fatigue or movement restriction during 8-hour sessions. The robust attachment mechanism maintained stable positioning without shifting during

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vigorous activities while remaining comfortable against the skin. Wireless operation eliminated the movement constraints typically associated with tethered systems, allowing natural, uninhibited motion throughout the capture volume.

Technical users appreciated the comprehensive real-time diagnostic feedback provided through the system's monitoring interface, which simplified troubleshooting and optimization. The intuitive visualization tools allowed even novice users to quickly validate tracking quality and identify optimal anchor placements.

4. Discussion

4.1. Limitations

While OpenRSSI addresses many challenges of existing motion capture systems, several important limitations require consideration when evaluating its suitability for specific applications.

Radio frequency reflective environments present particular challenges for the system's ranging accuracy. Spaces containing large metal surfaces, including industrial settings and some laboratory environments, can create multipath signal propagation that introduces positioning artifacts. While our filtering algorithms substantially mitigate these effects, users should carefully evaluate such environments before deployment. Signal attenuation through dense construction materials like concrete and metal can reduce effective range between anchors and trackers, potentially requiring additional anchor nodes for complete coverage.

The current implementation supports a maximum of 12 tracker nodes operating at the full 120Hz update rate. This limitation stems from radio channel bandwidth constraints and processing overhead in the central coordinator. While sufficient for full-body tracking, applications requiring higher node density such as detailed facial capture or multi-person tracking within the same volume may require multiple synchronized systems or reduced update frequencies.

Optimal system performance depends significantly on thoughtful anchor placement. Anchors must be positioned to maintain line-of-sight to tracker nodes throughout the capture volume whenever possible, with sufficient geometric distribution to enable accurate trilateration. This requirement necessitates a more deliberate setup process than camera-less inertial systems, though still substantially simpler than optical solutions. The system provides placement optimization tools, but users must understand basic principles of radio coverage to achieve optimal results.

4.2. Future Work

The promising results of our initial implementation suggest several valuable directions for future research and development that could extend system capabilities and application domains.

Integration with advanced machine learning techniques presents exciting opportunities for further performance enhancements. Deep learning models trained on movement patterns could predict optimal sensor fusion weights based on detected activities, potentially improving accuracy during complex or rapid movements. Recurrent neural networks could leverage temporal movement data to compensate for temporary signal degradation, maintaining tracking integrity even in challenging radio environments.

Development of automatic anchor position calibration would significantly streamline the setup process. By incorporating relative signal strength analysis and inter-anchor ranging, the system could potentially self-calibrate its geometric configuration, eliminating manual measurement and placement optimization. This advancement would particularly benefit mobile deployments where rapid setup is essential.

Miniaturization of the hardware platform would enable extension to fine-grained tracking applications. Particularly promising is the development of finger tracking capabilities using smaller form factor nodes. Preliminary prototypes demonstrate the feasibility of reducing node size by 60% while maintaining core functionality, opening possibilities for detailed hand tracking in virtual reality and animation contexts. This miniaturization pathway could eventually lead to full-body suits with integrated tracking elements, eliminating external attachment procedures entirely.

Implementation of mesh networking protocols would enable extended capture volumes beyond direct radio range constraints. By allowing tracker nodes to relay data through intermediate points, capture volumes could scale to encompass entire buildings or outdoor spaces without requiring direct anchor visibility. This advancement would particularly benefit applications in performance capture for film and large-scale virtual production.

5. Conclusion

OpenRSSI demonstrates that zero-drift motion capture is achievable with consumer-grade UWB hardware when combined with sophisticated sensor fusion algorithms. Our adaptive learning rate mechanism reduces cumulative error by 92% compared to vanilla gradient descent implementations, establishing a new performance standard for accessible motion tracking. The system is available under MIT license at https://github.com/huzpsb/OpenRSSI, encouraging community contribution and adaptation.

The combination of high accuracy, low cost, and open-source availability makes OpenRSSI suitable for a wide range of applications where traditional motion capture solutions would be prohibitively expensive or technically challenging to deploy. From independent game development to clinical movement analysis, the system provides professional-grade tracking capabilities without specialized infrastructure requirements.

By addressing the fundamental limitations of both optical and inertial tracking approaches, OpenRSSI represents a significant advance toward democratizing high-quality motion capture technology. The system's ability to maintain drift-free tracking over extended periods particularly benefits applications requiring long-duration captures, such as ergonomic studies and performance production.

As the open-source community continues to enhance and extend the platform, we anticipate the emergence of novel applications that were previously infeasible due to technical or cost constraints. The foundation established by this work creates new possibilities for human movement analysis, interactive experiences, and creative expression across numerous domains.

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