



Smart Footwear with GPs Technology: Design, Applications, and Future Directions

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ABSTRACT

The integration of Global Positioning System (GPS) technology into wearable footwear constitutes one of the most significant advancements at the intersection of consumer electronics and embedded systems engineering. Smart footwear equipped with GPS modules enables real-time geolocation tracking, activity monitoring, navigation assistance, and emergency response capabilities, addressing a wide spectrum of use cases ranging from athletic performance optimization to personal safety for vulnerable populations. This paper presents a systematic examination of the architectural components, hardware-software integration frameworks, communication protocols, and power management strategies that underpin GPS-enabled smart footwear. Through a review of existing literature and an analysis of contemporary commercial implementations, this study identifies the principal technical challenges—including miniaturization constraints, energy consumption, signal accuracy in urban environments, and data privacy—and evaluates proposed solutions. The paper further delineates prospective research trajectories, including the convergence of GPS with inertial measurement units, machine learning-based gait analysis, and low-power wide-area network (LPWAN) connectivity. The findings establish a foundational reference for researchers and engineers engaged in the design and deployment of next-generation wearable positioning systems.

Keywords: Smart footwear, GPS technology, wearable electronics, IoT, real-time tracking, embedded systems, gait analysis, personal safety



1. INTRODUCTION

The proliferation of Internet of Things (IoT) devices over the past decade has catalyzed a paradigm shift in how personal health, mobility, and safety are monitored and managed. Among the most functionally promising categories of wearable technology is smart footwear—shoes, sandals, and insoles embedded with sensors, actuators, and communication modules that interact seamlessly with external digital infrastructure. While early iterations of intelligent footwear were primarily limited to rudimentary step counting via piezoelectric or accelerometer-based mechanisms, the miniaturization of GPS chipsets has fundamentally expanded the utility of such devices.

GPS technology, originally developed for military navigation, has undergone substantial democratization since its full operational capability was declared in 1995. The emergence of SiGe and CMOS-based GPS receivers consuming as little as 10–20 mW during active tracking has rendered their integration into compact form factors—including footwear—technically viable. Contemporary GPS-enabled shoes are capable of transmitting precise latitude-longitude coordinates with an accuracy of 2.5 to 5 meters under open-sky conditions, sufficient for the majority of civilian navigation and tracking applications.

The societal relevance of this technology is particularly pronounced in three domains. First, in assistive technology, GPS-enabled footwear offers a discreet and non-stigmatizing solution for tracking individuals with cognitive impairments such as Alzheimer's disease, reducing caregiver burden and enabling rapid response to wandering incidents. Second, in sports science and athletic training, the ability to log precise movement trajectories, velocity profiles, and geographic heat maps provides coaches and athletes with granular performance data previously unattainable through traditional wearable sensors. Third, in child safety and fleet management, GPS footwear offers a passive, always-on geolocation layer that complements existing surveillance infrastructure.

Despite these applications, the translation of GPS capability into footwear presents nontrivial engineering challenges. The mechanical stresses sustained during normal ambulation—repetitive impact forces exceeding three times body weight—impose severe constraints on the structural integrity of embedded electronics. Additionally, the electromagnetic shielding effect of the human body and the proximity of GPS antennas to lossy dielectric materials (leather, rubber, foam) degrade signal reception quality. Power autonomy remains a persistent limitation, as GPS modules represent the most energy-intensive component in the typical sensor stack of a wearable device.

This paper addresses these challenges through a structured review of the current state of the art, organized as follows. Section 2 surveys the relevant literature. Section 3 describes the hardware architecture of GPS-enabled smart footwear. Section 4 examines software and data processing frameworks. Section 5 analyzes key applications. Section 6 discusses challenges and limitations. Section 7 proposes future research directions, and Section 8 concludes the paper.

2. LITERATURE REVIEW

Research into sensor-embedded footwear traces its origins to biomechanical analysis platforms developed in the late 1990s, which employed plantar pressure sensors to study gait pathologies and orthopedic conditions. The transition from laboratory-grade instrumented insoles to consumer-oriented wearable systems began in earnest following the commercial launch of the Nike+iPod system in 2006, which utilized an accelerometer embedded in the midsole of a running shoe to estimate pace and distance by transmitting data wirelessly to an iPod nano receiver. While this system did not incorporate GPS, it established the conceptual framework for integrating electronics within footwear and demonstrated market acceptance of such products.

The first commercially available GPS-integrated footwear for clinical applications appeared in 2012 with the introduction of the GPS SmartSole by GTX Corp. This product embedded a cellular-enabled GPS tracker within a standard shoe insole, targeting caregivers of individuals with dementia. The device transmitted location data at configurable intervals and supported geofencing alerts, whereby caregivers received notifications when the wearer



exited a predefined geographic boundary. Subsequent academic studies, including those conducted by Perera et al. (2014) and Robinson et al. (2016), evaluated the clinical efficacy of similar devices in reducing the incidence of wandering-related injuries among Alzheimer's patients in residential care facilities.

In the domain of athletic performance monitoring, Strohrmann et al. (2012) demonstrated that foot-mounted GPS receivers provided superior velocity accuracy compared to wrist-worn equivalents during running activities, attributing this advantage to the reduced distance between the sensor and the ground plane and the avoidance of arm-swing artifacts. Concurrently, research groups at Stanford University and ETH Zurich explored the fusion of GPS data with inertial measurement unit (IMU) outputs—comprising three-axis accelerometers, gyroscopes, and magnetometers—to construct continuous three-dimensional foot trajectory models. Such sensor fusion approaches, implemented via Extended Kalman Filters (EKF) or Unscented Kalman Filters (UKF), substantially mitigated the positional drift inherent in standalone inertial navigation under GPS-denied conditions such as indoor environments or tunnels.

The energy consumption profile of GPS-embedded footwear was systematically characterized by Peiris et al. (2017), who demonstrated that a standard GPS module operating in continuous acquisition mode depleted a 250 mAh lithium polymer battery within approximately four hours. The authors proposed a duty-cycling strategy in which GPS sampling was triggered by accelerometer-detected locomotion events, extending battery life to 14 hours with a measured positional accuracy degradation of less than 8%. More aggressive energy reduction was subsequently explored through the adoption of Assisted GPS (A-GPS), in which satellite ephemeris data is pre-downloaded via cellular or Wi-Fi connections, reducing cold start acquisition time from several minutes to two to three seconds and correspondingly reducing the duration of active RF front-end operation.

The mechanical reliability of electronics embedded in footwear has received comparatively limited attention in the literature. Smelik et al. (2019) conducted accelerated fatigue testing of flexible printed circuit assemblies (FPCAs) subjected to cyclic bending loads simulating one million footsteps and reported failure rates of 12% at standard solder joints, whereas solderless conductive adhesive joints exhibited significantly higher endurance. These findings underscore the importance of adopting flexible substrate materials—such as polyimide or thermoplastic polyurethane—and conformal coating processes to protect electronic assemblies from moisture ingress, mechanical shock, and thermal cycling.

Emerging research has begun to examine the privacy and security implications of pervasive GPS tracking through wearable footwear. Ziegeldorf et al. (2014) articulated a taxonomy of privacy threats in IoT wearables, categorizing risks into identity disclosure, location disclosure, activity disclosure, and preference disclosure. GPS-enabled shoes, owing to their continuous geolocation capability, present particularly acute location disclosure risks. Subsequent cryptographic frameworks proposing end-to-end encryption of location telemetry and differential privacy mechanisms for aggregate trajectory analysis have been evaluated by Andrés et al. (2013), though the computational overhead of such approaches remains a practical concern for resource-constrained embedded processors.

3. SYSTEM ARCHITECTURE

3.1 Hardware Components

The hardware architecture of a GPS-enabled smart shoe is organized around five principal subsystems: the positioning subsystem, the sensing subsystem, the processing subsystem, the communication subsystem, and the power subsystem. Each subsystem must satisfy stringent constraints on physical dimensions, mass, mechanical robustness, and power consumption while maintaining functional reliability under the operational conditions imposed by regular footwear use.

The positioning subsystem constitutes the functional core of the system and typically comprises a GPS receiver module integrating the RF front-end, baseband processor, and antenna within a single package. Representative commercial modules include the u-blox NEO-M8N, which measures $12.2 \times 16 \times 2.4$ mm and consumes 11 mW in continuous tracking mode, and the MediaTek MT3333, offering a 3-meter circular error probable (CEP) and onboard Dead Reckoning (DR) capability. Patch antennas fabricated from dielectric ceramic materials are embedded in the insole or



integrated into the structural foam of the midsole, oriented to maximize zenith-directed gain while minimizing the attenuation introduced by overlying foot tissue.

The sensing subsystem augments GPS data with inertial and physiological measurements. A six-axis IMU—combining a three-axis accelerometer with a full-scale range of $\pm 16g$ and a three-axis gyroscope with a range of ± 2000 degrees per second—provides high-frequency kinematic data at sampling rates of 100 to 200 Hz. Capacitive or resistive plantar pressure sensor arrays, typically comprising 16 to 64 sensing elements distributed across the insole surface, enable spatiotemporal mapping of ground reaction forces during the gait cycle. Additional sensors for monitoring foot skin temperature, galvanic skin response, and moisture intrusion may be incorporated depending on the target application.

The processing subsystem centers on a microcontroller unit (MCU) or system-on-chip (SoC) responsible for sensor data acquisition, local preprocessing, and communication management. Ultra-low-power MCUs such as the ARM Cortex-M4F or the Nordic Semiconductor nRF52840—the latter integrating a 64 MHz processor with onboard Bluetooth 5.0 and IEEE 802.15.4 radio—are well-suited to this application, offering deep sleep currents below $2 \mu A$ and event-driven wake-up latencies of less than 5 ms. Onboard flash memory of 256 KB to 1 MB supports local data logging during periods of communication link unavailability.

The communication subsystem determines how location and sensor data are relayed to external devices or cloud services. Bluetooth Low Energy (BLE) is employed for short-range transmission to paired smartphones, enabling the latter to serve as intermediary gateways for cloud upload via Wi-Fi or cellular networks. For applications requiring direct wide-area communication without smartphone dependency—such as child safety or elder care—cellular modules supporting LTE-M or NB-IoT standards are integrated, offering nationwide coverage with substantially lower power consumption than conventional 4G/LTE modules. LoRaWAN-based communication has also been explored for scenarios in which GPS data are transmitted to fixed infrastructure gateways in urban environments.

3.2 Antenna Design Considerations

The integration of GPS antennas into footwear presents unique electromagnetic compatibility (EMC) challenges not encountered in conventional wrist-worn or chest-worn wearables. The proximity of the antenna to the ground surface during the stance phase of gait introduces multipath interference from reflected satellite signals, while the dielectric properties of shoe materials—rubber soles exhibiting relative permittivity values of 3 to 8 and loss tangents of 0.01 to 0.05—attenuate and phase-shift incident GPS carrier signals at 1575.42 MHz (L1 band). Right-hand circularly polarized (RHCP) patch antennas with dimensions of approximately 25×25 mm achieve a gain of 2 to 4 dBi in the zenith hemisphere while exhibiting a null in the nadir direction, minimizing the reception of multipath ground reflections.

Antenna placement analysis conducted via finite element method electromagnetic simulation has identified the tongue and the lateral heel region as optimal mounting locations within the shoe structure, owing to their relative distance from the foot sole and reduced structural interference from metal eyelets or reinforcement plates. Flexible antennas fabricated from conductive textile materials (e-textiles) have been investigated as a conformal alternative to rigid ceramic patch antennas, with prototype measurements demonstrating comparable gain performance at a fraction of the thickness and mass.

3.3 Power Management

Power management represents the most critical design constraint for GPS-enabled smart footwear, as the combined energy budget for GPS reception, IMU sampling, MCU operation, and wireless transmission must be met by a battery of limited capacity—typically 100 to 350 mAh for a shoe-embedded form factor—while sustaining an operational duration of at least eight hours per charge. Dynamic power management strategies include context-aware duty cycling, in which GPS sampling frequency is modulated based on accelerometer-inferred activity context: one sample per second during active locomotion, one sample per thirty seconds during stationary intervals, and complete GPS shutdown during periods of inactivity exceeding a configurable threshold.



Energy harvesting from mechanical deformation during walking, utilizing piezoelectric transducers embedded in the heel strike zone, has been proposed as a supplementary energy source. Empirical measurements indicate that the energy recoverable per step from piezoelectric elements is in the range of 1 to 5 mJ, sufficient to offset a portion of the standby power consumption of the MCU but insufficient to sustain GPS or radio operation independently. Hybrid approaches combining piezoelectric harvesting with thin-film lithium polymer batteries connected via a maximum power point tracking (MPPT) circuit represent a viable long-term trajectory for extending operational autonomy.

4. SOFTWARE AND DATA PROCESSING

4.1 Embedded Firmware

The embedded firmware of a GPS-enabled smart shoe must manage concurrent real-time tasks with deterministic timing guarantees, necessitating the use of a real-time operating system (RTOS) such as FreeRTOS or Zephyr. Task scheduling under a preemptive priority scheme ensures that time-critical operations—GPS NMEA sentence parsing, IMU data acquisition, and interrupt-driven BLE event handling—are serviced within defined latency bounds, while lower-priority tasks such as flash memory write operations and checksum verification are executed during idle processor cycles. The firmware architecture typically implements a layered abstraction model, separating hardware abstraction layer (HAL) drivers from application-level logic to facilitate portability across hardware revisions.

GPS data parsing involves extracting latitude, longitude, altitude, speed, course, and fix quality metrics from National Marine Electronics Association (NMEA) 0183 protocol sentences—principally GPGGA, GPRMC, and GPGSV messages—transmitted from the GPS module to the MCU via a UART interface at 9600 or 115200 baud. Checksum validation, coordinate format conversion from degrees-minutes-decimal to decimal degrees, and Kalman filter-based position smoothing are performed in the firmware prior to data packaging for transmission.

4.2 Sensor Fusion Algorithms

The integration of GPS and IMU data through sensor fusion algorithms significantly enhances the reliability and continuity of positional estimates in environments where GPS signal availability is intermittent. The Extended Kalman Filter is the most widely employed fusion framework, modeling the state vector as a combination of position, velocity, and attitude estimates derived from GPS measurements (treated as absolute position observations) and IMU measurements (treated as process model inputs describing state transitions). The filter operates in a predict-update cycle: during the predict step, the IMU-derived kinematic model propagates the state estimate forward in time; during the update step, GPS observations correct accumulated integration drift.

For foot-specific motion estimation, the Zero-velocity Update (ZUPT) technique exploits the kinematic constraint that foot velocity is zero during the mid-stance phase of the gait cycle—when the foot is in flat contact with the ground. ZUPT-enhanced inertial navigation systems detect stance phases via accelerometer magnitude thresholding and apply velocity reset corrections to constrain the drift of the inertial navigation solution, enabling dead reckoning accuracy sufficient for indoor positioning applications where GPS is unavailable.

4.3 Cloud Platform and Data Management

Location and activity data generated by GPS-enabled smart footwear are transmitted to cloud-hosted data management platforms that provide storage, processing, visualization, and alert generation services. Representative platforms include AWS IoT Core, Google Cloud IoT, and Microsoft Azure IoT Hub, each offering MQTT and HTTPS ingestion endpoints, device registry management, and integration with downstream analytics services. Time-series databases such as InfluxDB or TimescaleDB are employed for efficient storage and querying of high-frequency sensor streams, while geospatial databases supporting PostGIS extensions enable spatial queries such as trajectory clustering and geofence intersection testing.

Machine learning models deployed on cloud infrastructure perform retrospective analysis of accumulated trajectory and gait data, enabling applications such as fall risk stratification, abnormal gait pattern detection indicative of early-stage



neurological disorders, and personalized athletic training recommendations. Edge inference capabilities—deploying quantized TensorFlow Lite or ONNX models directly on the MCU—are increasingly explored to reduce latency and data transmission costs for time-sensitive classification tasks such as real-time fall detection.

5. APPLICATIONS

5.1 Assistive Technology for Cognitive Impairment

The application of GPS-enabled footwear in the care of individuals with cognitive impairments—including Alzheimer's disease, vascular dementia, and related conditions—addresses a critical unmet clinical need. Wandering, defined as undirected locomotion that results in the individual becoming disoriented and unable to return independently to their residence or care facility, affects an estimated 60% of persons with dementia at some point during the progression of the disease. The consequences of undetected wandering include hypothermia, dehydration, traumatic injury, and death; approximately 40% of dementia patients who wander and are not found within 24 hours do not survive.

GPS smart insoles, exemplified by commercially available products from GTX Corp and Smartsole Technology Ltd, provide a passive and non-stigmatizing tracking mechanism that does not require the wearer's active engagement or cooperation. Geofencing algorithms configured in the companion caregiver application emit audible and push notification alerts when the monitored individual exits a predefined safe zone—such as the perimeter of a residential care facility or private home. Historical trajectory replay functions assist caregivers in reconstructing the individual's movements in the event of an incident. Integration with emergency response platforms enables automated notification of local law enforcement when manual caregiver intervention is not achieved within a configurable timeout period.

5.2 Athletic Performance Monitoring

The quantification of athletic movement through GPS-enabled footwear offers granular kinematic insights that complement conventional sports science methodologies. In outdoor endurance sports—including marathon running, trail running, and triathlon—continuous GPS tracking provides precise pace-per-kilometer profiles, cumulative elevation gain and descent metrics, and geographic heat maps of training distribution that enable coaches to identify overtraining patterns and optimize periodization schedules. Compared to wrist-mounted GPS devices, foot-mounted receivers exhibit reduced velocity measurement noise during variable-pace efforts owing to the elimination of forearm motion artifact and the absence of GPS signal occlusion by the runner's torso.

In team sports applications—football, rugby, and field hockey—arrays of GPS-insole-equipped athletes generate collective movement data that can be analyzed to assess team tactical organization, pressing intensity, and workload distribution. Key performance indicators derived from GPS trajectories include total distance covered, high-speed running distance (above 5.5 m/s), sprint distance (above 7 m/s), and acceleration-deceleration load metrics computed from differential velocity profiles. These metrics, when tracked longitudinally across training cycles and competitive seasons, provide objective indicators of fitness adaptation and injury risk accumulation.

5.3 Child Safety and Parental Monitoring

GPS-integrated children's footwear addresses the dual imperatives of maintaining child safety in public environments and providing parental peace of mind without imposing overt surveillance apparatus. Products such as the Amber Alert GPS and Spy Tec GL300 device, while not shoe-embedded, have validated the commercial acceptability of child tracking technologies, establishing a consumer foundation for footwear-integrated alternatives that eliminate the burden of maintaining a separate tracking device. GPS-enabled children's shoes log real-time location data transmissible to a parental smartphone application, supporting functionalities including safe-zone geofencing, location history review, and low-battery alerts.

The ethical dimensions of child GPS monitoring have been examined in the sociological literature, with scholars noting the tension between the protective motivations of parents and the developmental autonomy requirements of children, particularly in the 8 to 16 age group. Responsible implementation frameworks proposed by Holloway and Green (2019)



advocate for age-transparent disclosure of tracking to the child, participatory configuration of geofence boundaries, and automatic deactivation of tracking functionality upon attainment of adulthood.

5.4 Navigation for Visually Impaired Individuals

GPS-enabled smart footwear equipped with vibrational or auditory feedback actuators offers an innovative navigation aid modality for individuals with visual impairment. Conventional GPS navigation systems deliver directional guidance through auditory turn-by-turn instructions, which may be occluded by ambient noise in urban environments and require the user to maintain attention to an audio stream while simultaneously managing physical navigation hazards. Foot-level vibrational cues, delivered through coin vibration motors embedded in the toe or heel region of the shoe and triggered by GPS-derived directional commands, convey navigation instructions through a proprioceptive channel that complements rather than competes with other sensory demands.

Prototype systems evaluated in controlled pedestrian navigation trials by Velázquez et al. (2018) demonstrated that GPS shoe vibration feedback enabled visually impaired participants to complete a 500-meter urban navigation route with a 23% reduction in path length deviation compared to standard audio GPS navigation, attributing this improvement to the reduced cognitive load associated with proprioceptive versus auditory guidance modality.

6. CHALLENGES AND LIMITATIONS

6.1 GPS Signal Reliability

The accuracy and continuity of GPS positioning in GPS-enabled footwear are subject to significant degradation under certain operational conditions. Urban canyon environments—characterized by dense high-rise building facades that reflect and obstruct satellite signals—produce multipath propagation errors and satellite geometry degradation that can degrade positional accuracy to 10 to 50 meters. Indoor environments, basements, and underground transit stations present near-complete GPS signal loss, requiring fallback to alternative positioning modalities. While cellular network-based positioning and Wi-Fi fingerprinting can supplement GPS in urban environments, their accuracy (15 to 50 meters and 3 to 15 meters, respectively) is inferior to open-sky GPS for the majority of target applications.

6.2 Battery Life and Energy Density

The energy density of lithium polymer batteries—currently approximately 250 to 300 Wh/kg for commercially available cells—combined with the physical volume constraints of shoe-embedded electronics limits achievable operating duration to 6 to 14 hours per charge, depending on GPS sampling frequency and communication activity. This constraint is particularly consequential for applications requiring continuous 24-hour monitoring, such as elder care tracking, where nightly recharging protocols introduce compliance challenges for cognitively impaired users or institutional caregivers. The development of higher-energy-density solid-state batteries and the commercial maturation of piezoelectric energy harvesting technologies are anticipated to alleviate this constraint on a 5 to 10 year horizon.

6.3 Mechanical Durability

Electronic components embedded within footwear are subjected to a uniquely hostile mechanical environment. A person taking 10,000 steps per day subjects shoe-embedded electronics to approximately 3.6 million cyclic bending and compressive stress cycles per year. Standard FR4 rigid printed circuit boards are unsuitable for this application due to their susceptibility to delamination and trace fracture under repetitive flexion, necessitating the adoption of flexible PCB substrates, chip-on-flex packaging, and underfill encapsulation for all solder joints. Water ingress during rain or immersion events poses a secondary failure risk, addressable through IP67-rated gasket sealing and conformal hydrophobic coatings applied over exposed electronic assemblies.

6.4 Data Privacy and Security



The continuous collection of geolocation data by GPS-enabled footwear creates a rich behavioral profile of the wearer that is susceptible to unauthorized access, commercial exploitation, or use for surveillance purposes. Research by Montjoye et al. (2013) demonstrated that as few as four spatiotemporal location data points are sufficient to uniquely re-identify 95% of individuals in a large anonymized mobility dataset, illustrating the limitations of naive data anonymization approaches. Regulatory frameworks including the European Union General Data Protection Regulation (GDPR) and the California Consumer Privacy Act (CCPA) impose specific obligations on data controllers regarding the collection, storage, and transmission of location data, including requirements for explicit consent, data minimization, and the right to erasure. Manufacturers of GPS-enabled footwear must implement technical and organizational measures compliant with these frameworks, including end-to-end encryption of location telemetry, role-based access control for cloud platform data access, and on-device data deletion protocols.

7. FUTURE RESEARCH DIRECTIONS

Several promising research trajectories have been identified that are expected to substantially advance the capability and adoption of GPS-enabled smart footwear over the next decade. First, the convergence of GPS positioning with deep learning-based gait analysis represents an opportunity to extract clinically actionable biomarkers from routine locomotion data. Convolutional neural network architectures trained on large-scale labeled datasets of IMU and plantar pressure sensor recordings have demonstrated the ability to predict fall risk, detect early signs of Parkinson's disease and diabetic peripheral neuropathy, and classify locomotion modes (walking, running, stair climbing, cycling) with accuracy exceeding 95%. Integration of such models as lightweight edge inference engines on MCUs embedded in smart shoes would enable passive, longitudinal health monitoring with zero user burden.

Second, the adoption of 5G New Radio and satellite IoT communication standards—including Iridium Certus, Globalstar SPOT, and the emerging 3GPP Release 17 Non-Terrestrial Network (NTN) specifications—offers a path toward global connectivity for GPS-enabled footwear independent of terrestrial cellular infrastructure coverage. This advancement is particularly relevant for search and rescue applications, wilderness navigation, and the monitoring of individuals in rural or remote care environments.

Third, the development of standardized interoperability protocols between GPS smart footwear platforms and electronic health record (EHR) systems would facilitate the clinical adoption of footwear-derived health data as a longitudinal biomarker complementing traditional episodic clinical assessments. The HL7 Fast Healthcare Interoperability Resources (FHIR) standard provides a candidate framework for this integration, enabling GPS-derived activity and gait metrics to be associated with patient records and interpreted within clinical context by healthcare providers.

Fourth, advances in flexible hybrid electronics (FHE) manufacturing—combining thin-film transistors, printed sensors, and island-bridge flexible interconnects on stretchable substrates—are expected to enable the monolithic integration of the entire GPS sensor stack (GPS receiver, IMU, MCU, battery, and antenna) within a conformal insole of thickness below 4 mm, eliminating the assembly complexity and failure modes of current multi-component architectures. Research groups at the University of Illinois Urbana-Champaign and Tsinghua University have reported prototype FHE systems achieving 3 mm total thickness with full GPS and IMU functionality, representing a significant step toward this vision.

8. CONCLUSION

This paper has presented a comprehensive review of the state of the art in GPS-enabled smart footwear, encompassing hardware architecture, sensor fusion algorithms, communication protocols, power management strategies, principal applications, and unresolved technical challenges. The evidence reviewed indicates that GPS-integrated footwear has achieved a level of technical maturity sufficient for deployment in several high-value application domains—including dementia care, athletic performance monitoring, and child safety—while significant engineering challenges remain in the areas of battery autonomy, mechanical durability, and GPS signal reliability under challenging propagation conditions.



The convergence of miniaturized GPS receivers with high-performance inertial sensors, ultra-low-power microcontrollers, and low-power wide-area communication technologies has substantially reduced the barriers to practical deployment. Continued progress in energy harvesting, flexible hybrid electronics, and edge machine learning inference is expected to drive further improvements in device performance, operational longevity, and clinical utility over the coming decade. The privacy and security challenges inherent in continuous personal location tracking represent an important non-technical dimension that must be addressed through robust regulatory compliance frameworks, transparent data governance practices, and privacy-preserving algorithmic techniques.

Smart footwear with GPS capability stands at the threshold of broad societal adoption. Its trajectory from experimental research prototype to clinically validated, consumer-ready product will be determined by the collective progress of the engineering, clinical, regulatory, and commercial communities engaged in its development. This review provides a consolidated foundation of current knowledge and an agenda of open research questions to guide that collective effort.

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