

Table 4. Comparison of various methods for visually impaired pedestrian's navigation.

Methods	Advantages	Disadvantages
GPS	Well-established and found in most smart phones and electronic gadgets	GPS signal outage and disruption of service
GPS-RTK GPS-INS tightly coupled	Sub-meter accuracy with precision Good accuracy	Subscription basis and possible for the lower income Computational expensive and required faster signal processing capability in handheld devices
GPS-INS loosely coupled	Fast and reasonable accuracy as proven in this work	Not as accurate as GPS-RTK

GPS: Global Positioning System; RTK: real-time kinetic; INS: Inertial Navigation System.

provided a mean for real-time implementation of a loosely coupled INS/GPS system using low-cost off-the-shelf sensors. This article used the EKF to aid INS with GPS measurements to compensate for IMU bias and to predict INS position and velocity during GPS outage. Based on Kalman filter noise behavior, the noise covariance and measurement noise matrices were determined. Real-time navigation algorithm was performed on the microcontroller. Experimental test and results were presented to validate the accuracy of the INS/GPS system. Based on this study, smart pedestrian positioning system can be developed with the integration of MEMS-based inertial sensors and GPS using existing low-cost solutions. This is especially useful for the hundreds of millions of visually impaired people worldwide, especially the lower income.

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Declaration of conflicting interests

The authors declare that there is no conflict of interest.

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Appendix I

Notation

C	attitude
f^b	specific force measured by accelerometer
F_k	system dynamics matrix
h	heading
H_k	observation matrix
K_k	Kalman gain
p^n	position in North–East–Down (NED) direction
P_k	error covariance matrix
Q_k	spectral density matrix
R_k	noise measurement matrix
v^n	velocity in North–East–Down direction
x^n	state vector
δx^n	error in state vector
θ	pitch
λ	longitude
φ	latitude
ϕ	roll
Φ_k	transition matrix
ψ	yaw
ω^b	angular motion measured by gyroscope