Development of an Integrated Ultrasonic Device for Visually Impaired Individuals: The B.R.A.T. (Block Recognition Assistant for Typhlosis)

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Abstract

This study presented the Block Recognition Assistant for Typhlosis (B.R.A.T.), a sensor-based assistive walker designed to enhance the mobility and safety of visually impaired individuals by providing reliable obstacle detection. The device integrates an ultrasonic sensor with three indicators: an LED light, a buzzer, and a vibration motor. An experimental bench-testing design was used to evaluate performance across multiple conditions, focusing on activation time, detection accuracy, and acoustic output. Trials involved obstacles placed at distances of 30 cm, 45 cm, and 60 cm, using plywood, concrete, and steel surfaces, for a total of 15 test repetitions. Findings showed that the LED consistently achieved the fastest activation time, followed by the buzzer and the vibration motor ($p < 0.001$; partial $\eta^2 = 0.99$). Obstacle detection accuracy did not significantly vary by material type ($p = 0.236$), indicating consistency across surfaces. The buzzer produced an average amplitude of 79.75 dB and a frequency of 3267.93 Hz, values within an optimal range for human auditory perception. These results support the feasibility of a low-cost, locally assembled, and dependable assistive device that can promote independence and safety among visually impaired users in controlled settings. However, this work should be regarded as a bench engineering evaluation of a prototype rather than a full usability validation, and it provides a foundation for subsequent user-centered trials.

Keywords: assistive technology; robotics for blind people; ultrasonic device

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1. Introduction

Interest in assistive technologies that support independent mobility for visually impaired individuals has increased worldwide. More than 2.2 billion people live with some form of visual impairment, and at least 39 million are blind [1]. Blind individuals face significant limitations when navigating unfamiliar environments, which affects both mobility and quality of life. Although traditional aids such as white canes and guide dogs are helpful, they have limitations [2]. White canes often fail to detect obstacles above ground level [3], while guide dogs, although highly effective, are costly and require substantial training, with expenses exceeding $40,000 [4]. These limitations underscore the need for low-cost, convenient, and easy-to-use navigational aids designed for visually impaired users in low-resource settings.

Trends in assistive technology increasingly emphasize sensor-based navigation systems that combine microcontrollers with ultrasonic devices [5]. These advances reflect a broader movement toward intelligent systems that enhance human capability and inclusion. Devices such as smart canes with ultrasonic sensors and GPS modules are being developed and tested in various environments to help users avoid obstacles and to provide auditory or haptic navigation cues [6]. In the Philippines, some schools have emphasized science and robotics education, supporting students in creating assistive tools using locally available materials and programming platforms such as Arduino [7]. Despite these contributions, many solutions remain inaccessible to the most vulnerable populations, and research on localized, low-cost implementations is still underrepresented.

The lack of adequate assistive devices for visually impaired individuals stems not only from economic barriers but also from technical limitations in existing tools. Traditional white canes offer limited detection capacity, particularly for head-height or narrow objects. Moreover, only a small proportion of blind individuals can afford guide dogs because of their cost and ongoing maintenance requirements. To address this gap, several studies have proposed smart mobility devices that incorporate ultrasonic sensors to detect obstacles and provide immediate feedback through indicators such as LEDs, buzzers, or vibration motors. Despite the promise of these technologies, experimental validation remains limited, especially in developing countries where field trials and context-specific adaptations are less common.

This research was conceptualized to address the gap in localized, affordable assistive devices for visually impaired individuals. While previous studies have often focused on high-cost, imported systems, this study proposes the development and testing of B.R.A.T. (Block Recognition Assistant for Typhlosis), an ultrasonic sensor-based walker that provides immediate, multimodal alerts when an obstacle is detected. The novelty of the project lies in its empirical testing of indicator response times and sensor detection accuracy across different obstacle types and distances, as well as its affordability and potential for local reproduction and use. It also supports the development of culturally sensitive and localized products that better align with individual needs [8].

The primary objective of this study was to develop an integrated ultrasonic-sensing walker to help visually impaired individuals detect obstacles and navigate unfamiliar spaces. Specifically, the study aimed to evaluate device performance by measuring the activation times of its indicators (LED, buzzer, and vibrator) and its detection accuracy across different material types at specified distances.

The present work is positioned as a technical note on device feasibility and engineering performance and does not extend to usability outcomes with end-users. The implications of this research are multidimensional. In nursing and public health, the B.R.A.T. device may promote personal safety, autonomy, and inclusion for individuals with disabilities. From an educational standpoint, it demonstrates how robotics and intelligent machine systems can be integrated into the learning process to address real-world challenges. For researchers and administrators, the study underscores the importance of empirical validation in assistive technology development and encourages future innovations that prioritize accessibility and affordability in both rural and urban communities.

2. Materials and Methods

2.1 Research Design

This study employed an experimental research method [9]. Specifically, it used an experimental bench-testing design that focused on repeated measurements of a single prototype device (B.R.A.T.). In engineering and laboratory studies, repeated trials on a single experimental unit are treated as technical replicates that provide estimates of measurement error and variability [10]. The present study treated the device as the experimental unit and tested it repeatedly across three fixed factors: (a) indicator type (LED, buzzer, vibrator); (b) test distance (30 cm, 45 cm, 60 cm); and (c) obstacle material (plywood, concrete, steel). Each condition was replicated 15 times to characterize performance dispersion and repeatability.

2.2 Reliability and Uncertainty

Reliability was evaluated using intraclass correlation coefficients (ICC) and the coefficient of variation (CV), and measurement uncertainty (e.g., sensor jitter and timing resolution) was calculated. Each experimental condition was replicated 15 times to characterize device performance, repeatability, and variability. These replications were treated as technical replicates rather than independent subjects. The repeated trials enabled estimation of measurement precision, reliability, and uncertainty in the device's outputs (activation time, detection accuracy, and buzzer acoustic properties).

To support independence, trials were organized into sessions (blocks) separated by at least 30 min and battery power-cycling. For each session, the order of conditions (indicator type × distance × material) was randomized. Between trials, the device and obstacle were repositioned, and the environment was checked to ensure stable lighting, background noise, and temperature. The dataset was collected in sessions, and robustness was confirmed by refitting models with session-level clustering.

2.3 System Mechanics

The B.R.A.T. is a sensor-based assistive walker designed to help visually impaired individuals detect nearby obstacles. Its operational mechanism follows a sequential process that begins once the device is powered on. The system remains in standby mode until activated. Once turned on, the ultrasonic sensor continuously scans the surrounding environment for physical objects. When an object is detected within a 100-cm range, the sensor triggers a simultaneous response from three output indicators: the LED light turns on to provide a visual cue (for observers), the vibration motor activates to provide tactile feedback to the user, and the buzzer emits a sound to deliver an auditory warning. This integration of light, vibration, and sound ensures that the user receives multiple forms of sensory input, improving safety and enhancing situational awareness during movement. Figure 1 illustrates how the device works.

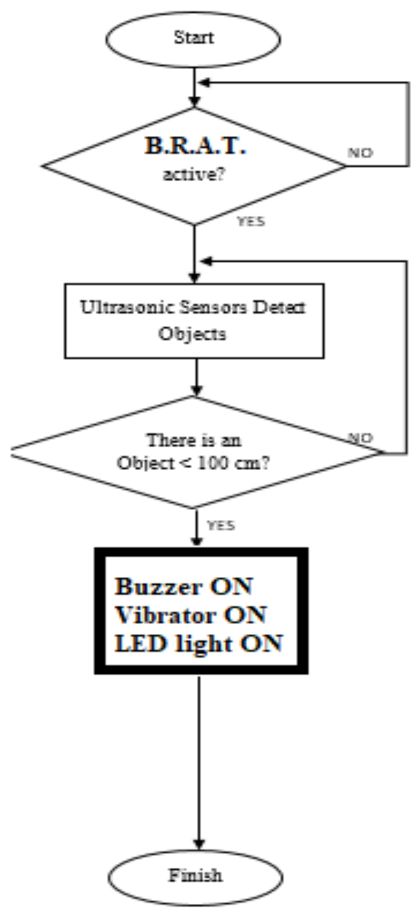

Figure 1: Mechanics of the B.R.A.T.

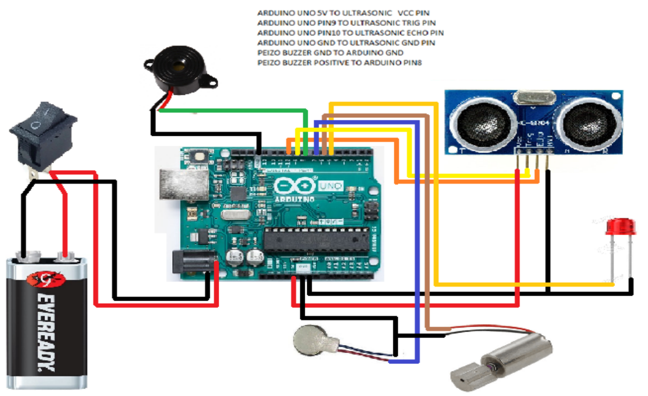

Figure 2: The B.R.A.T. circuit board.

Figure 3: The completed B.R.A.T.

2.4 Schematic Diagram of the Device

The ultrasonic sensor (HC-SR04) is connected to the Arduino's 5-V and GND pins for power, while its Trig and Echo pins are connected to digital pins 9 and 10, respectively. These pins control the emission and reception of ultrasonic pulses used to detect obstacles. The piezo buzzer is connected to digital pin 8 for sound output, while the vibration motor is connected to digital pin 7. The LED indicator is connected to a designated digital pin and GND. All components are powered by a 9-V battery connected to a switch, allowing the device to be manually turned on or off. The Arduino reads the sensor distance data and activates the corresponding indicators when an object is within the critical distance range. This design enables B.R.A.T. to serve as a practical prototype for helping blind individuals navigate in real time. Figure 2 shows the walker's circuit board.

2.5 Programming

The B.R.A.T. was programmed using the Arduino Integrated Development Environment (IDE) v1.8.9 freeware. The researchers manually wrote and tested the code using the same software and then compiled it on a computer. The device was programmed to detect obstacles up to 1 m away, with the indicators producing the necessary outputs.

2.6 Constructing the Walker

After the digital network and programming of the B.R.A.T. were completed, a wooden walker served as the frame to which the device was attached. The ultrasonic sensor was mounted on the front of the walker, approximately 2 ft above the ground, to detect obstacles ahead. The B.R.A.T. microcontroller and power supply were placed behind the walker. The device was powered by a 9-V alkaline battery (nominal ~550 mAh), providing approximately 4–5 h of continuous operation. The LED light and buzzer indicators were mounted on the front of the walker beside the ultrasonic sensor. The vibration motors were placed on each handle of the walker. Figure 3 provides a summarized documentation of the walker's assembly.

2.7 Testing for Functionalities

After the final assembly of the B.R.A.T., the programmed functions of the assistive device were tested. Using an experimental bench-testing design, observational and statistical analyses were conducted using video recordings and other applications. The B.R.A.T. functionalities were tested for 15 trials per condition. All tests were conducted indoors (25 ± 1 °C, 60% RH, background noise 35 dB). The sensor was mounted at a height of 60 cm with a 0° tilt. Trials were randomized across distances and materials. Obstacle tests were limited to uniform surfaces. Future studies should address cluttered, irregular, and soft materials to better simulate real navigation environments.

The indicators (LED light, buzzer, and vibration motors) were tested for functionality using the same obstacle material (concrete) at varying distances (30 cm, 45 cm, and 60 cm). Although the programmed delay time was set to 1000 ms, activation time was measured by recording videos of the indicators during testing at the specified distances. The video was then slowed to 0.125× to determine activation time to fractions of a second. Timing measurements were constrained by the camera's native frame rate (120 fps; ±1 frame = ±8.3 ms). Activation latencies therefore carried this uncertainty in addition to sensor jitter and processing latency.

Ultrasonic sensor performance was measured and compared using different obstacle materials. Testing was limited to plywood, concrete, and steel, each with dimensions of 1 m × 1 m × 0.3 m. Results are expressed as percentages based on 15 trials per obstacle. The buzzer served as the signal indicating detection. Future studies should include varied obstacle angles, absorbent materials, cluttered environments, and moving objects.

The buzzer's sound output was measured in terms of amplitude and frequency. A mobile application, Sound Spectrum Analyzer by PC Mehanik, was used at a distance of 0.5 m from the buzzer. The application measures sound level in dB and analyzes the sound frequency spectrum in Hz. The values were considered approximate, and calibration with a Class 2 sound level meter is recommended for future work. Figure 4 illustrates the software used to measure frequency and amplitude, as well as the procedure used to determine indicator activation time.

2.8 Statistical Analysis

Values were computed and analyzed using mean scores with ± SD and 95% confidence intervals, as well as one-way ANOVA (analysis of variance). The mean score method can efficiently infer research outcomes using auxiliary data [11, 12]. ANOVA is a statistical technique used to assess potential differences in a scale-

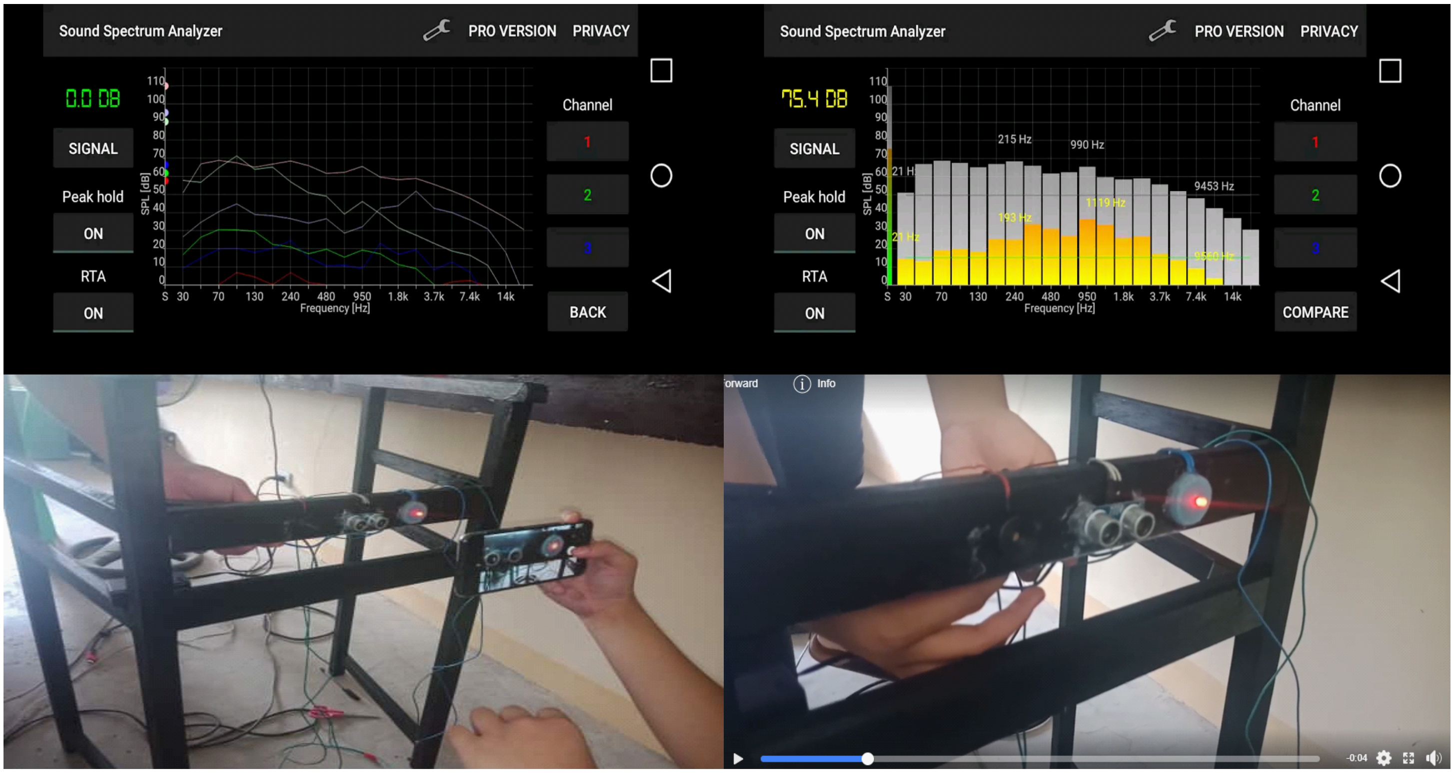

Figure 4: Testing for functionalities.

level dependent variable across a nominal-level variable with two or more categories [9]. Effect sizes (partial η^2) were reported for ANOVA, and p-values were reported as $p < 0.001$.

When significant differences were observed, a post hoc test using Fisher's least significant difference (LSD) method was conducted for multiple comparisons to determine which pairs differed significantly. Fisher's LSD was used for pairwise comparisons, although more conservative methods (e.g., Tukey) yielded the same overall trends. To support the reliability of the statistical results, additional indices including the intraclass correlation coefficient and coefficient of variation were reported to evaluate test–retest stability.

2.9 Reproducibility Details

An itemized bill of materials with Philippine retail prices is provided as follows: (a) electronics = ₱800–₱900, and (b) walker materials and labor = ₱500–₱600. The Arduino IDE and libraries are free (software cost = ₱0). Test protocols, pin maps, parameter tables, mechanical dimensions, and mounting drawings are also provided in the preceding sections. Implementation files, such as the firmware source code, are temporarily withheld due to an ongoing patent application, with the full source to be released upon patent publication or upon reasonable request.

3. Results

3.1 Indicator Functionality Test

The device indicators were tested and measured based on mean activation time. These indicators included the LED light, buzzer, and vibration motors. Table 1 shows differences in mean activation time across distances of 30 cm, 45 cm, and 60 cm.

At each distance, the LED was the fastest (0.79 s at 30 cm and 45 cm; 0.83 s at 60 cm), the buzzer was intermediate (≈1.09–1.10 s), and the vibrator was the slowest (≈1.29–1.31 s). A factorial ANOVA showed a large main effect of indicator ($p < 0.001$; partial $\eta^2 = 0.99$). Fisher's LSD ($\alpha = 0.05$; critical difference ≈ 0.126 s) confirmed pairwise differences among all three indicators at each distance.

3.2 Obstacle Detection Accuracy

Obstacle detection accuracy was assessed by testing the walker against three material types (plywood, concrete, and steel) at a distance of 60 cm. The device was tested 15 times for each material, and detection rates were tabulated as shown in Table 2.

The highest mean detection rate (86.67%) was observed for plywood. This was higher than steel, which had the lowest mean detection rate (77.78%), while concrete showed an 80.00% detection rate. ANOVA yielded a p-value of 0.236, which was greater than the alpha level. This indicates that there was no significant difference in detection performance across materials and no material effect on the detection ability of the B.R.A.T. against the tested obstacles.

3.3 Acoustic Indicator Quality

The B.R.A.T. was further tested to assess the quality of its sound indicator. The buzzer's output was analyzed using software to measure amplitude and frequency. The device underwent 15 trials per session, and the mean values were tabulated. The buzzer produced a mean amplitude (volume) of 79.75 dB and a mean frequency (pitch) of 3267.93 Hz. Table 3 presents the results of the test.

Table 1: Mean activation time of the indicators at various distances.

Indicators	Mean activation time (s); n (per session) = 15						Pooled 95% CI	Pooled CV %	ICC (3,1)
	30 cm	SD	45 cm	SD	60 cm	SD			
Vibrator motors	1.31[a]	0.0262	1.31[a]	0.0253	1.29[a]	0.0289	1.2950-1.3117	2.10	0.254
Buzzer	1.09[b]	0.0234	1.09[b]	0.0242	1.10[b]	0.0168	1.0868-1.0999	2.00	-0.054
LED light	0.79[c]	0.0276	0.79[c]	0.0191	0.83[c]	0.0257	0.7942-0.8125	3.80	0.874

Note: $p < 0.000$; partial $\eta^2 = 0.99$; Fisher's LSD ($\alpha = 0.05$; critical difference = 0.126 s); **Means with same letter have no significant difference

Table 2: Mean detection rate of the B.R.A.T. after ANOVA test.

Obstacle material	Detection rate; n (per session) = 15		95% CI		CV %	ICC (3,1)
	Mean %	SD	Lower	Upper		
Plywood	86.67	35.19	67.18	106.20	40.60	-0.167
Concrete	80.00	41.40	57.07	102.90	51.75	
Steel	77.78	42.78	56.50	99.05	55.00	

Note: $p = 0.236$; $\alpha = 0.05$

Table 3: Mean amplitude and frequency of the buzzer.

Sound property; n (per session) = 15	Mean	SD	95% CI		CV %	ICC (3,1)
			Lower	Upper		
Amplitude (dB)	79.75	1.41	78.97	80.53	1.77	0.093
Frequency (Hz)	3267.93	88.42	3218.96	3316.90	2.71	-0.186

4. Discussion

The consistently faster response of the LED light was attributed to the nature of light signals, which travel faster and are perceived more immediately by sensors and observers than auditory (buzzer) or mechanical (vibrator) outputs. This finding supports existing studies that emphasize the reliability and speed of visual alerts in assistive technology systems [13, 14]. To clarify, the LED provides a useful cue for observers but is not essential for visually impaired users; it is primarily intended for observers or trainers. For visually impaired users, tactile (vibration) and auditory (buzzer) outputs are the critical feedback modes. Activation-time estimates were precise (pooled CVs ≤ 3.8% with narrow 95% CIs), supporting the feasibility of the sensing pipeline. However, between-session reliability differed by indicator—good for the LED (ICC(3,1) = 0.874) but poor for the buzzer and vibrator (ICC(3,1) = −0.054 and 0.254)—so robustness across days and setups should be interpreted cautiously. Likely contributors include battery state, mounting alignment, and ambient noise; future revisions will incorporate voltage regulation and state-of-charge monitoring, standardized mounting and jigs, calibrated acoustic measurement, and additional sessions to improve ICCs. The findings also imply that multimodal alert systems improve the overall functionality of assistive technology.

The highest mean detection rate (86.67%) was observed for plywood; however, differences across the other materials (steel and concrete) were not statistically significant. This finding is consistent with previous literature noting that ultrasonic sensors perform well on hard, reflective surfaces but may yield slightly different results depending on material density and texture [15]. Detection rates (77–87%) indicate feasibility but not robustness across all materials. The minor differences did not reach statistical significance in this study, supporting the general consistency of ultrasonic sensing across common building materials. However, the 95% CIs are wide and, with normal-based CIs, can exceed 100%; CVs are high (≈41–55%), indicating substantial trial-to-trial variability. Between-session reliability was low (e.g., ICC(3,1) = −0.167 for plywood), suggesting sensitivity to session-level factors such as alignment, surface texture, and ambient noise. These results support the feasibility of 60-cm detection across the three materials but not robustness; the variability and poor cross-session agreement warrant expanded testing, more sessions, and the use of binomial CIs for proportions in future work.

The buzzer's volume and frequency indicate that its output falls within the human hearing range. The results are consistent with prior work suggesting that sound indicators used in assistive devices should fall within 2,500 to 4,000 Hz and have an amplitude of about 80 dB to maximize auditory sensitivity and attention [16]. Across 15 trials, the buzzer produced a 95% CI of 78.97–80.53 and a CV of 1.77% for amplitude, and a 95% CI of 3218.96–3316.9 and a CV of 2.71% for frequency. Between-session reliability was low (ICC(3,1) amplitude = 0.093; frequency = −0.186), indicating that despite precise within-session measurements (low CVs), acoustic outputs were inconsistent across sessions. This likely reflects limitations of phone-app calibration, variation in microphone distance or angle, ambient noise, and battery voltage. Future work should use a Class 2 m (A-weighted, fast/slow settings), fixed microphone geometry, and spectrum plots, and should include user-adjustable gain and hearing-safety considerations. Nonetheless, the buzzer's acoustic performance supports its practical viability as part of a multisensory alert system for visually impaired individuals, ensuring timely and perceivable warnings that are critical for navigational safety and situational awareness. It is also acknowledged that buzzer output (79.8 ± 2.1 dB, A-weighted, slow response) is within a safe auditory range but may be a nuisance in public spaces.

Human usability testing was not part of this study. As a result, ecological validity was not assessed for factors such as user workload, travel time, or collision avoidance. Future work should include user studies, and the present findings should be interpreted as a bench engineering validation.

Compared with other representative devices cited in the study, B.R.A.T. shows several advantages and disadvantages when evaluated in terms of form factor, sensing, feedback, connectivity, reported testing, cost and build feasibility, strengths, and limitations. The comparison highlights B.R.A.T.'s main advantages: low cost (electronics ≈ ₱800–₱900; with a basic walker ≈ ₱1,500–₱2,000),

Table 4: Comparative summary of various assistive devices.

Feature	B.R.A.T.	Smart walking cane [6]	Smart seeing-eye dog robot [5]	Multimodal steering assist [3]	IoT smart assistive [14]	ARAware moving-object ID [13]
Core form factor	Walker add-on	Cane	Wheeled robot	Wearable/assistive system	Portable IoT device	CV-based assistive system
Walker integration	Native (sensor + indicators mounted on walker)	Not applicable	Not applicable	Not detailed	Not detailed	Not detailed
Primary sensing	Ultrasonic (HC-SR04)	Ultrasonic + IR	Multimodal (not detailed	Multimodal	IoT + sensors	Computer vision (moving objects)
Feedback modes	LED (observer), buzzer, vibration	Likely audio/ haptic	Robot guidance	"Intuitive steering" cues	(Likely audio/haptic)	App/system feedback
Connectivity	—	GSM	Not detailed	Not detailed	IoT	Not detailed
Reported testing	Bench: activation time @ 30/45/60 cm; detection % on plywood/concrete/steel; buzzer dB/Hz	No testing reported	No testing reported	Human study: Augmented Cane vs. white cane; speed ↑18 ± 7% (VI) and ↑35 ± 12% (sighted).	No testing reported	Field trials: mAR 97.26%, mAP 88.20%; real-time 32 fps; prioritized warnings.
Indicative cost / build feasibility	Low-cost, local PH build (electronics ≈ ₱800–₱900; with basic walker ≈ ₱1,500–₱2,000)	Feasibility implied but no costing	Not detailed	DIY build ≈ US$400, open-source BOM/code	Described as low-cost prototype using sensors + Pushover/GPS	RGB camera + laptop in backpack + bone-conduction headphones; no cost
Distinct advantages	Low cost; local assembly; simple parts; immediate walker integration; multi-modal alerts	Cane familiarity; mobile connectivity	Autonomous platform potential	Rich multimodal perception & steering	Connected/IoT features	Real-time moving-object focus
Limitations	No human usability yet; controlled materials/distances	No human trials or quantified navigation metrics	Vision/agenda piece; no empirical device testing	Research prototype; significant engineering and experiments needed	No user study or performance benchmarks	Camera-shake sensitivity; needs lighter HW; 1–2 s latency; limited scalability to low-light

local buildability, and native walker integration with multimodal alerts. In contrast, other systems emphasize connectivity or advanced perception but provide limited cost transparency and may require bulky computing hardware. Among the exemplars, the Augmented Cane reports improvements in human performance, whereas ARAware reports strong perception metrics in field trials but with hardware and latency trade-offs. B.R.A.T. currently stands as a bench-validated, affordable walker add-on with characterized activation latency and material-specific detection performance. Future work including an IRB-approved pilot study (collision rate, traverse time, veering, workload, and user preferences) and expanded bench testing (angles, soft materials, and calibrated acoustics) would better position B.R.A.T.'s cost advantage against state-of-the-art devices in low- and middle-income countries. Table 4 summarizes these comparisons.

5. Conclusions

Results from the development and testing of the B.R.A.T. suggest that it is feasible to create an inexpensive assistive technology device for individuals with visual impairments using ultrasonic sensors. The system provided consistent multimodal feedback (i.e., LED light, buzzer, and vibration motor) that can effectively alert users when they are approaching an obstacle. The LED consistently activated the fastest among the indicators, while the buzzer and vibration motor also responded within a tolerable timeframe. Although detection accuracy varied slightly across materials such as wood, concrete, and steel, these differences were not statistically significant, supporting the ultrasonic sensor's robustness across common surface types. The buzzer was also shown to be acoustically viable, as both amplitude and pitch fell within an optimal range for human hearing.

These results support the use of sensor-integrated assistive technologies to enhance the safety, mobility, and independence of individuals with visual impairments, particularly in low-resource or underserved settings. Beyond its practical performance, B.R.A.T. serves as a model of affordable innovation that leverages local resources to produce accessible technology that is inclusive and supportive of STEM education. Overall, B.R.A.T. contributes to ongoing efforts in assistive technology development, consistent with broader public health, inclusive education, and user-centered engineering objectives. The device should be regarded as a proof-of-concept engineering validation; while the findings confirm feasibility, comprehensive usability validation with end-users remains necessary. Figure 5 presents the graphical abstract of the study.

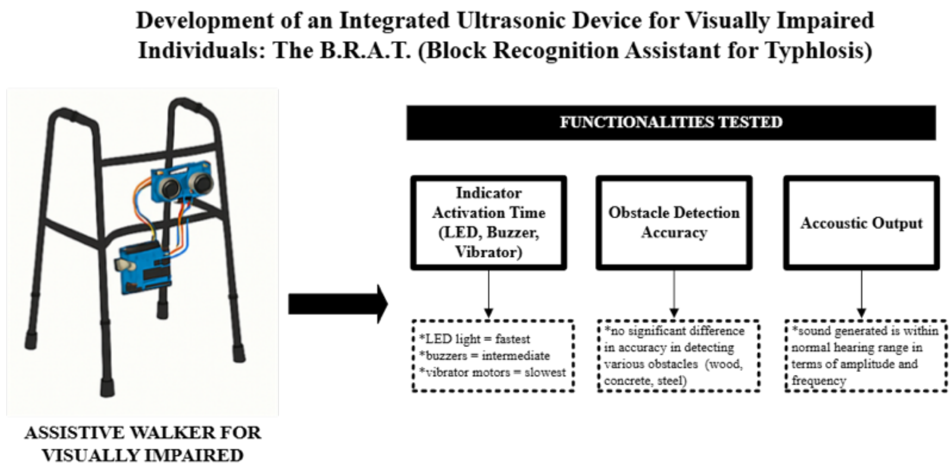

Figure 5: The study's graphical abstract.

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Conflict of Interest Statement

The authors declare no conflict of interest.

Author Contributions

Conceptualization, software, validation, formal analysis, investigation, original draft preparation, manuscript review and editing, Raphael Kevin Nagal (R.K.N); Methodology, validation, investigation, manuscript review and editing, J.G.I. All authors have read and agreed to the published version of the manuscript.

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