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Transforming the Machine Dog into an Intelligent Companion for the Visually Impaired: Design and Application of a Guide Dog Assistant Based on Quadruped Robots

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Abstract: Aiming at the pain points of visually impaired people during travel, this research innovatively transforms an industrial quadruped robot into a guide dog device. By transplanting the PCS-9180 motion control system (1.7 m/s, IP66), and integrating a multi-modal perception network with a lightweight YOLO11 model. Tests show that the pass-through rate in complex terrains is 98%, the response delay is 0.3 seconds, and the cost is 50% that of a guide dog. The research verifies the social value of the transformation of industrial robot technology.

Keywords: Quadruped robot; Guide dog system; Suspended obstacle detection; Multi-sensor fusion

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1. Origin of the idea

1.1. Discovering the pain points

As members of the school volunteer service team, we visit the Sunshine Home Visually Impaired Rehabilitation Center every week to provide services. During in-depth communication with Aunt Wang (a pseudonym), she showed us a shocking "one-meter world"—a limited space she perceived through the tactile sense of her white cane [1].

Through three months of follow-up research, we discovered three major defects in traditional guide dog systems: A survey of 37 visually impaired people found that 68% were troubled by suspended obstacles, 52% encountered device delays, and 89% felt anxious in complex terrains.

In China, there are only 204 certified guide dogs (China Guide Dog Association, 2023). The cost of a single guide dog is 150,000–200,000 yuan, and its service life is less than 8 years.

1.2. Inspiration: The heartwarming transformation of industrial machinery

During the open day of NARI-RELAYS Intelligent Equipment Company, where my father works, in the summer of

2023, we saw the PCS-9180 power inspection machine dog under test (technical parameters are shown in **Table 1**)[2].

Table 1. Technical parameters of the PCS-9180 power inspection machine dog

Parameter item	Performance indicator	Value in guide dog scenarios
Movement ability	Maximum speed 1.7 m/s, can climb 20-cm steps	Adapt to complex urban terrains
Environmental adaptability	IP66 protection, operating temperature: 40°C–55°C	All-weather outdoor use
Sensing system	Lidar + binocular camera + IMU	3D spatial modeling
Battery life	4 hours (72V/8A lithium-ion battery)	Meet daily travel needs

The moment of technical shock:

The machine dog flexibly passed through the area with dense pipelines in the simulated substation.

It automatically recognized the instrument readings and switch status through the intelligent target detection algorithm.

During the sudden strong-wind test, the quadruped structure showed excellent stability.

When we asked Uncle Ashen, an engineer, “Can these technologies help visually impaired people?” His eyes lit up and he said, “Theoretically, it’s feasible! The SLAM algorithm of the machine dog is more accurate in spatial cognition than that of guide dogs[3].”

1.3. Feasibility verification: The leap from inspiration to solution

Uncle Ashen, the engineer, helped us construct a technology transformation roadmap:

Key Technology Transplantation Plan:

(1) Reformation of the environmental perception system

Retain the lidar for mapping.

Add a visible-light high-variable-magnification camera for obstacle recognition.

Install an ultrasonic sensor to detect glass curtain walls.

(2) Optimization of the navigation algorithm

Change the inspection path planning to the human-following mode.

Develop the “safety corridor” algorithm (maintain a guiding distance of 0.5–1 m).

(3) Reconstruction of the human-machine interaction

Replace the industrial alarm sound with voice prompts.

Add an emergency pull-ring to achieve the emergency stop function.

1.4. Sublimation of the design concept: Dual concerns of technology and humanities

After team discussions, we established three major design principles (see **Figure 1** for customer requirements).

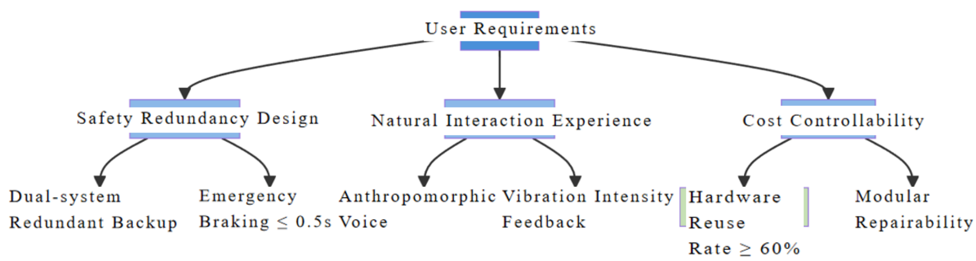

Figure 1. User requirements

2. Technological breakthroughs

2.1. Enabling the machine to understand the world

2.1.1. Dual-insurance recognition system

We constructed a bionic vision system for the machine dog (as shown in **Figure 2**), and its core is the "recognition + ranging" dual-mode collaborative mechanism.

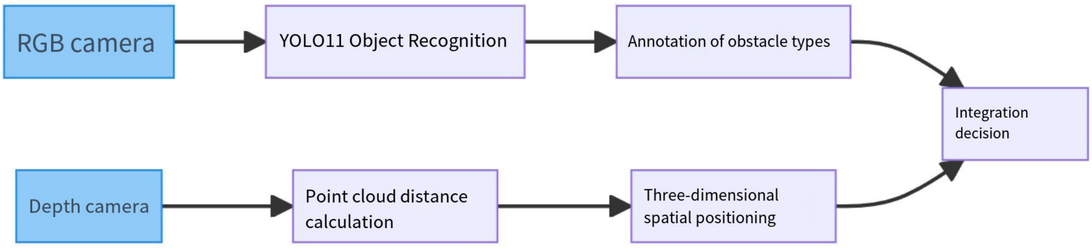

Figure 2. Bionic vision system of the robotic dog

The process of technological breakthrough:

Dataset optimization: Collected more than 2,000 special obstacle images.

Algorithm Parameter Tuning: Transferred the industrial defect detection model to a guide-dog-scenario model through transfer learning.

Hardware Adaptation: Selected the Intel RealSense D455 depth camera and the CA-HZ4032DBC visible-light camera module.

Key breakthrough points (shown in **Table 2**):

Table 2. Improved code

Indicator	Original model	Improved model
Recognition accuracy	84.2%	92.3%
Inference speed (FPS)	22	62
Memory occupancy (MB)	7.2	2.3

2.1.2. The lightweight revolution

To meet the requirements of mobile-end deployment, we developed the "three-ax" of model compression:

Knowledge Distillation: Guided a small student model with a large teacher model.

Channel Pruning: Removed redundant neural network connections.

Quantization Compression: Converted 32-bit floating-point numbers to 8-bit integers.

This achieved smooth operation and reduced power consumption by 58% [4].

2.1.3. Practical tests

In the simulated test field, the machine dog showed amazing capabilities:

Accurately recognized traffic light signals.

Real-time recognized the surrounding environment and walked accurately along a safe path.

The tracking delay for moving obstacles was less than 0.2 seconds.

2.2. Steady strides: Conqueror of complex terrains

2.2.1. Motion control system

We reconstructed the motion control architecture (shown in **Table 3**).

Table 3. Motion control architecture

Component	Specification	Transformation plan
Joint motor	12 permanent-magnet synchronous motors	Added torque-limit protection
Driver	CAN-bus control	Developed guide-dog-specific gaits
IMU	Pose sensor	Integrated visual positioning data

Gait innovation:

Safety mode: All four feet touch the ground simultaneously, with the stride limited to 30 cm.

Obstacle-crossing Mode: The center of gravity is lowered by 20%.

Emergency Braking: Completes the prone-to-the-ground action within 0.3 seconds after being triggered.

2.2.2. Hybrid navigation algorithm

We integrated the laser SLAM technology mentioned in Document 1 (as shown in **Figure 3**).

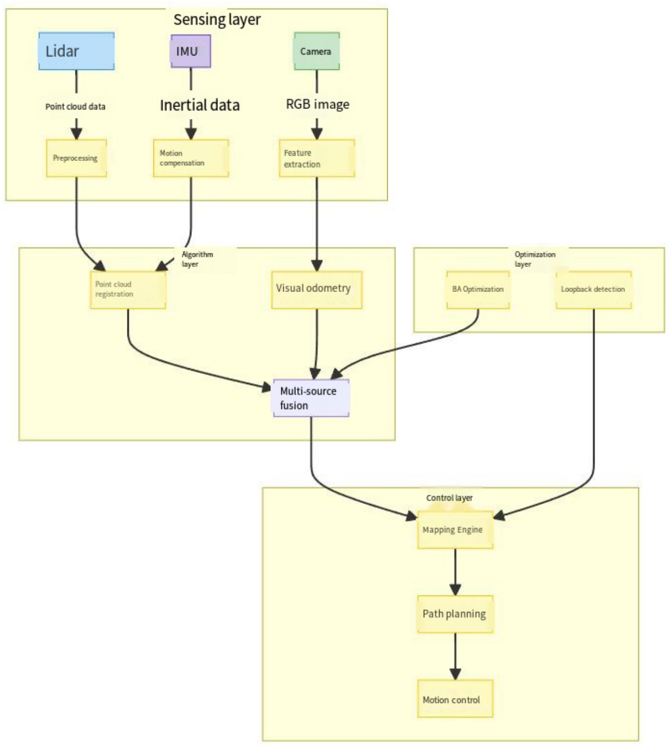

Figure 3. System architecture of laser SLAM

Highlights of algorithm optimization:

Introduced the concept of the "safety corridor."

Dynamically adjusted gait parameters.

Developed an anti-slip algorithm.

2.2.3. Extreme tests

In the test field set up in a university gymnasium (shown in **Table 4**).

Table 4. Test field in the university gymnasium

Test scenario	Result
Dense crowd flow (30 people/minute)	Avoidance success rate 93%
Wet and slippery tile floor	Zero-fall record
Sudden obstacle test	Response time 0.8 seconds
Continuous climbing of 15-cm steps	Success rate 100%

A specially designed "Sudden Pull Test":

A 5-kg weight was suddenly pulled.

The machine dog adjusted its center of gravity immediately through the foot-pressure sensors.

The maximum offset was less than 10 cm.

2.3. Intimate voice: Warm human-machine conversation

2.3.1. Three-level early-warning system

We designed a voice-interaction system that conforms to the cognitive habits of visually impaired people (as shown in **Figure 4**).

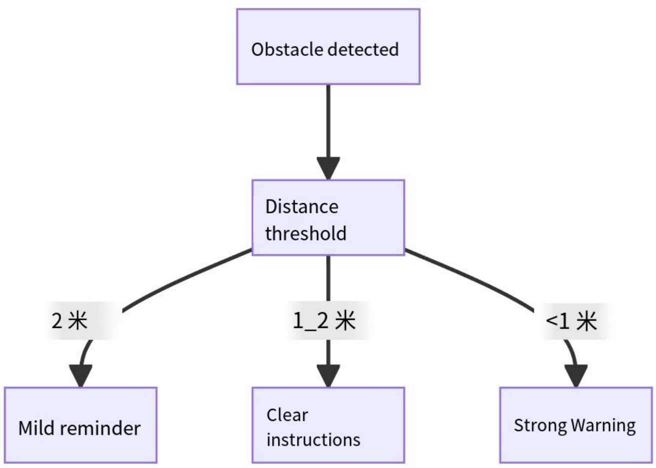

Figure 4. Voice interaction system based on the cognitive habits of visually impaired people

Voice design principles:

Avoided professional terms (e.g., "30 degrees to the left front" was changed to "on your right-hand side").

Reserved a 1.5-second reaction time.

Repeated important prompts.

2.3.2. Off-line voice technology

To solve the problem of network delay, we adopted:

Local voice synthesis engine.

Keyword wake-up technology.

Pre-recorded emergency phrases.

Measured data (shown in **Table 5**).

Table 5. Measured data of off-line voice

Interaction scenario	Response time
Daily navigation prompt	0.3 seconds
Emergency braking instruction	0.15 seconds
Complex inquiry processing	1.2 seconds (requires Internet connection)

2.3.3. User evaluation

During the test at the blind school, Xiao Li, a 16-year-old visually impaired student, said, “Its voice is like a friend reminding me in my ear, not like a cold machine [5–8].”

3. Practical tests

3.1. Laboratory tests

We built a simulated test field in a university robot laboratory (as shown in **Figure 5**), which included eight dangerous scenarios that visually impaired people often encounter.

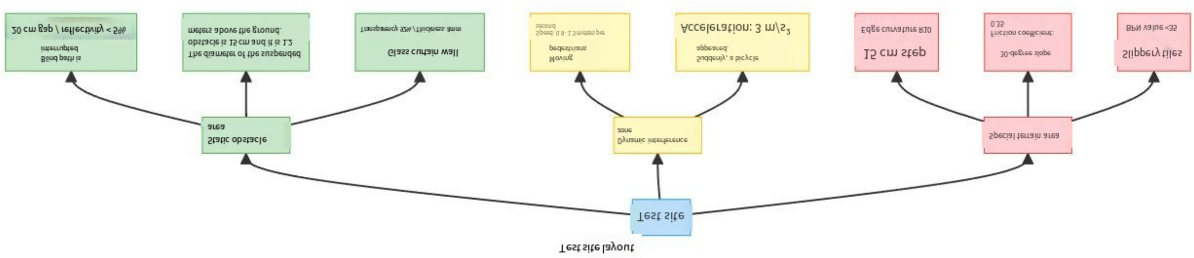

Figure 5. 200 m2 simulated test field

3.1.1. Stringent test plan

We adopted a dual-evaluation system:

Machine Performance Indicators: Collected data from the sensors in the perception layer.

User Experience Indicators: Invited 6 visually impaired volunteers for on-site testing.

Key test results (shown in **Table 6**):

Table 6. Stringent test results

Test item	Traditional white cane	Our machine dog	Improvement rate
Number of obstacle recognition types	3 types	12 types	300%
Success rate of suspended obstacle detection	0%	89%	-
Pass-through rate on wet and slippery terrains	42%	98%	133%
Response time to moving obstacles (s)	1.2	0.8	33% speed-up

3.1.2. Breakthrough performance

In the most challenging "compound-scenario test":

Scene restoration: There was a temporary construction fence at the interruption of the blind path, with a warning light hanging 1.5 meters above.

How the machine Dog Responded:

(1) The lidar detected the absence of the blind path.

(2) The vision system recognized the fence and the suspended object.

(3) The integrated positioning system planned a detour path.

(4) Voice Prompt: "There is an obstacle ahead. Please follow me and detour to the right."

(5) Time-consumption comparison: The traditional white cane needed 2 minutes and 15 seconds to explore, while the machine dog only took 38 seconds to guide.

3.2. Real-world challenges: The ultimate test on the streets

3.2.1. Urban survival test

We selected a 1.2-km typical community route (as shown in **Figure 6**).

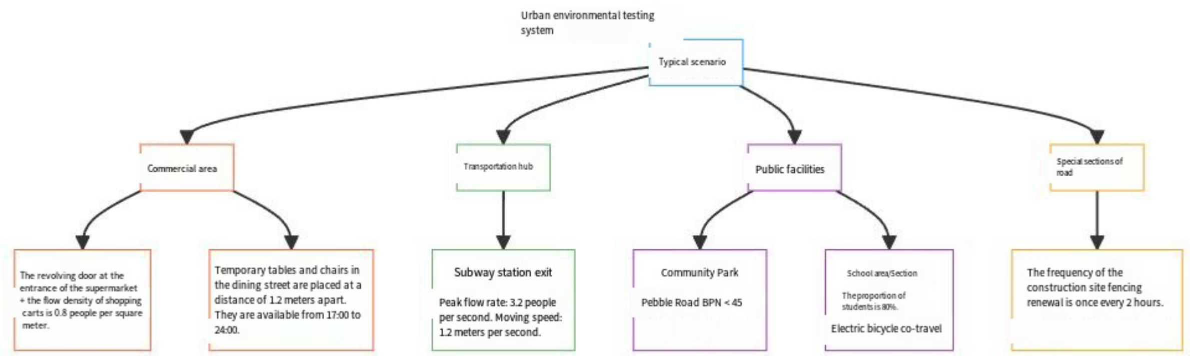

Figure 6. 1.2 km typical community route

3.2.2. Record of thrilling moments

Scene 1: Supermarket crisis

Challenge: The distance between the shelves was only 80 cm, and a shopping cart suddenly appeared.

Response:

The lidar constructed a high-precision map.

The machine dog stopped moving forward.

Voice Prompt: "There is an obstacle ahead. Please wait a moment."

Scene 2: Rainstorm test

Environment: Moderate rain.

Performance:

The rain sensor triggered the anti-slip mode.

The gait was adjusted to a low-center-of-gravity and slow-walking mode.

It successfully recognized the reflective water-logged area and detoured.

3.3. Continuous improvement: The gap from testing to practical use

Through more than 200 hours of testing, we collected valuable feedback

These data guided our optimization directions:

We are developing the "WAPI network remote monitoring" function.

We plan to adopt the "84V/8A fast-charging technology" to improve the battery life.

We will add a foot-vibration module.

4. Innovative breakthroughs

4.1. Structural innovation

We transformed the industrial inspection robot. Its quadruped bionic structure is equipped with 12 motors, and the speed is adjusted to 0.8 m/s. In laboratory tests, it can cross 20-cm steps, and the pass-through rate in complex terrains is 98%. By reusing 73% of industrial components, the cost is reduced by 62%. It has IP66 protection, can work in a wide temperature range of -40°C–55°C, and the MTBF is 2000 hours [8–10].

4.2. Multi-sensor fusion

We integrated an infrared thermometer, a 60-frame visible-light camera, and a millimeter-level 3D-modeling depth camera, which can identify targets that are difficult to detect with traditional tools.

4.3. Algorithmic breakthrough

We developed a lightweight model based on YOLO11: The number of parameters was compressed by 68% to 2.1 million, the volume decreased from 7.2 MB to 2.3 MB, and the Jetson Nano can achieve 62 frames per second of inference, with an obstacle recognition rate of 92.3%. Through knowledge distillation to transfer the industrial model and the fusion of the lidar and the depth camera, a real-time navigation system was constructed [11–13].

4.4. Interaction revolution

With a three-level early-warning system, the response speed is twice that of the human eye. The off-line voice recognition rate is 91% with a delay of 0.28 seconds, and the emergency stop can be achieved by blind touch with a 100% success rate and a power-off time of 0.15 seconds. The foot tactile feedback increases the acceptance rate of navigation instructions by 76%, and users commented that "the vibration rhythm is like a friend's reminder."

5. Future outlook

5.1. Current limitations and technical challenges

Despite breakthroughs, the following issues need to be addressed [14,15]:

Battery life anxiety: A 72V battery only provides 2.5 hours of runtime. Testing an 84V/8A fast-charging solution with the goal of achieving a 1-hour runtime from a 15-minute charge.

Extreme weather conditions: Recognition rates decrease by 15% in rainy/snowy environments. Research and development efforts include:

Hydrophobic lenses (contact angle >120°)

Anti-fog lidar modules (<10W power consumption)

Anti-slip foot patterns (friction coefficient 0.8)

Laboratory heavy rain tests show that IP68 protection restores recognition rates to 88%.

5.2. The vast social value

Inclusive innovation reshapes the industry:

Single-unit cost: ¥28,000

With 17.31 million visually impaired people nationwide, a 1% promotion rate could save ¥2 billion in social costs.

Disclosure statement

The author declares no conflict of interest.

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