Can Quadruped Navigation Robots be Used as Guide Dogs?

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Abstract—Bionic robots are generally considered to have strong flexibility, adaptability, and stability. Their bionic forms are more likely to interact emotionally with people, which means obvious advantages as socially assistive robots. However, it has not been widely concerned and verified in the blind and low vision community. In this paper, we explored the guiding performance and experience of bionic quadruped robots compared to wheeled robots. We invited visually impaired participants to complete a) the indoor straight & turn task and obstacle avoidance task in a laboratory environment; b) the outdoor real and complex environment. With the transition from indoor to outdoor, we found that the workload of the bionic quadruped robots changed to insignificant. Moreover, obvious temporal demand indoors changed to significant mental demand outdoors. Also, there was no significant advantage of quadruped robots in usability, trust, or satisfaction, which was amplified outdoors. We concluded that walking noise and the gait of quadruped robots would limit the guiding effect to a certain extent, and the empathetic effect of its zoomorphic form for visually impaired people could not be fully reflected. This paper provides evidence for the empirical research of bionic quadruped robots in the field of guiding VI people, pointing out their shortcomings in guiding performance and experience, and has good instructive value for the design of bionic guided robots in the future.

I. INTRODUCTION

Statistics from the World Health Organization show that around 2.2 billion people worldwide suffer from some forms of visual impairment [1]. Facing real and complex road conditions, safe and efficient navigation has become one of the biggest challenges for visually impaired (VI) groups [2]. Guide dogs are trained working dogs that provide safe navigation for VI people. Guide dog users reported enhancement in travel independence and performance [3], [4]. Other than door-to-door accurate navigation, guide dogs have biological attributes that are advantageous compared with other guiding methods, such as providing less haptic feedback from contacting environment that can reduce mental workload, providing more sense of trust and confidence, and transmitting the ground information through the harness [5], [6]. However, facing the needs of visually impaired groups, the cost of training guide dogs is high [7] and the penetration rate is low [8]. To solve this problem and reproduce guide dogs’ benefits, bionic quadruped robots can be an option.

Bionic robots refer to the combination of robotics and bionics principles to improve or innovate existing instru-

ments and machinery by imitating, replicating, and recreating the shape, function, biological mechanism, and control mechanism of biological systems. The advantage of bionic robots have been found in human-robot interaction. Due to the biophilic nature of human thinking [9], bionic robots have the potential to evoke human emotions and empathetic responses [10], and robots with bionic forms can interact directly with people [11]. In [12], a bionic robot is proposed to improve human-robot interaction and user experience through the design and evaluation of 11 emotional expressions of the animal-like robot Miro. However, whether the bionic form of the quadruped robot will bring a good emotional and navigational experience for VI has not been deeply explored.

When talking about functional advantages of walking aids, the bionic quadruped robot is an essential grounded robot form [13], [14], [15], and famous for biologically inspired dynamic gait movements, robot balance skills [16], so as to have strong flexibility and excellent adaptability even in the outside. And the wheeled robot, which is another important form of grounded robot, have been applied by researchers to guide the blind because of its efficiency and smoothness[13], [14], [15].

Regarding bionic guiding aids, preliminary research has been conducted [17], [18]. In [17], a quadruped robot based on the fuzzy control method can maintain stable performance in various road surface changes under the situational awareness of LIDAR. A hybrid physical human-robot interaction model incorporating leash tension was introduced in [18], and the ability of the belt to slack allows the internal dimensions of the robotic system, allowing the robot to guide
blind people through tight spaces. However, these attempts do not show that quadruped robots have functional and emotional advantages in guiding.

Therefore, we conducted an in-depth study comparing the quadruped robot and wheeled robot and expected to get the following answers:

- Will the benefits of quadruped robot lead to better guidance for the real blind?
- Will the bionic form of the quadruped robot bring more trust and satisfaction to real blind people?
- Will the zoomorphic robots produce empathic responses to the blind?

The contributions of this paper are summarized as follows:

- We found that the blind walking experience of wheeled robots has significant advantages in both indoor and outdoor experiments.
- We found that both the walking noise and the movement mode of the quadruped robot hinder the blind guidance.
- We demonstrated the empathy effect of bionic form in blind people in order to provide references for the form design of blind guide robots.

II. METHODOLOGY

To explore the guiding experience of different forms of robots, quadruped robots, and wheeled robots, we conducted a within-subjects experiment to compare. And the experiment includes two stages: laboratory stage and field stage, which respectively provide indoor and outdoor environments. To get more real feedback, we set up indoor tasks in different degrees of difficulty, easy and difficult, and we provided different ground conditions when finishing the outdoor tasks so that we could simulate the most realistic walking surroundings. We used the Wizard-of-Oz method to test both two forms no matter the indoor tasks or outdoor tasks. And the study was conducted with the approval of our University’s Institutional Review Board (IRB).

A. Hypotheses

We formulate the following hypotheses inspired by the questions we listed in part I.

H1: Under indoor conditions, people report better guidance and experience (lower workload, higher usability, trust, and satisfaction) when guided by the wheeled robot.

H2: Under outdoor conditions, people report better guidance and experience (lower workload, higher usability, trust, and satisfaction) when guided by the quadruped robot.

H3: Blind people prefer zoomorphic robots and empathize with them as much as discerning people do.

B. Participants

23 subjects (7 females, 16 males, 28.870 ± 6.608 years old) were invited to participate in the indoor and outdoor walking experiment (14 in indoor experiment, 9 in outdoor experiment), including 8 discerning subjects and 15 blind subjects. Given that some factors relevant to the experiment, such as the experience of orientation walking training and frequently used walking aids and so on, may affect the experimental results, we collected basic information about the subjects. The detailed information is shown in TABLE I. Besides, these subjects all filled out the recruitment questionnaire and passed the screening, whose criteria were that they did not know the experimental route and the capabilities of the two forms of robots (such as manipulation methods, etc.). The other 8 subjects with discerning eyes were expected to simulate the state of suddenly acquired blindness. Considering the safety of subjects, we didn’t invite discerning subjects to simulate in the outdoor experiment.

C. Robots and Systems used

**Guide harness**: The guide harness is a piece of the special and indispensable equipment in the training and use of guide dogs, which helps visually impaired groups to feel and command guide dogs. The guide harness is divided into two parts: a harness and a tie rod. The strap part fits the chest and neck of the guide dog and can be adjusted to adapt to the guide dog with a bust size of 640 to 940 mm. The length of the tie rod is about 450 mm, with a 100 mm long handle at one end and a distance of 220 mm between the two points of the tie rod connecting to the back at the other end. In the experiment, two quadruped robots were equipped with an entire guide harness.

**Quadruped Robot**: In the indoor experiment, we used a bionic quadruped robot produced by Xiaomi (Fig. 2A.), with a total weight of 14 kg. The size of the standing state is 771×355×400 mm (L×B×H), and the bottom surface is 50×50 mm, which can span steps with a height of 60 mm (about half of normal steps). Its maximum speed can reach 3.2 m/s. And in the outdoor experiment, we used a bionic quadruped robot produced by Unitree (Fig. 2B.), with a total weight of 19 kg. The size of the standing state is 650×310×600 mm (L×B×H). Its maximum speed is faster than 1.5 m/s, which also can cover people’s walking speed. And the slope angles they can climb are both 30°. There are 12 motors equipped on both two robots to behave several actions. During the two stages of the experiment, we focused on the effects of different forms of robots but not on a

| No. | Gender | Age | VI degree | O&M Travel /week | Aids |
|-----|--------|-----|-----------|------------------|------|
| P1  | F      | 32  | Low       | ✓                | >5 times Guide dog |
| P2  | M      | 28  | Low       | ×                | 2-3 times Guide dog |
| P3  | F      | 18  | Low       | ✓                | Uncertain |
| P4  | F      | 26  | Blind     | ✓                | 7 times White Cane |
| P5  | F      | 34  | Blind     | ✓                | 4 times Guide dog |
| P6  | M      | 32  | Low       | ×                | 1 times White Cane |
| P7  | M      | 31  | Low       | ×                | Hardly ever White Cane |
| P8  | M      | 35  | Low       | ×                | 7 times White Cane |
| P9  | M      | 30  | Blind     | ×                | 4 times White Cane |
| P10 | M      | 49  | Low       | ✓                | 5-6 times White Cane |
| P11 | M      | 34  | Blind     | ✓                | 4-5 times White Cane |
| P12 | M      | 23  | Blind     | ✓                | 5 times White Cane |
| P13 | M      | 49  | Low       | ×                | 5-6 times White Cane |
| P14 | M      | 35  | Blind     | ✓                | 4-5 times White Cane |
| P15 | M      | 32  | Low       | ×                | 2-3 times White Cane |
| P16 | F      | 22  | Sighted   |                 |      |
| P17 | M      | 22  | Sighted   |                 |      |
| P18 | M      | 24  | Sighted   |                 |      |
| P19 | M      | 22  | Sighted   |                 |      |
| P20 | F      | 24  | Sighted   |                 |      |
| P21 | M      | 26  | Sighted   |                 |      |
| P22 | F      | 26  | Sighted   |                 |      |
| P23 | M      | 26  | Sighted   |                 |      |

TABLE I

PARTICIPANTS’ DEMOGRAPHIC
particular robot. Therefore, we chose the two robots while trying to ensure they are as similar as possible.

**Wheeled Robot:** In the indoor experiment, we used a wheeled robot created by ourselves. The dimensions of the wheeled robot are almost the same as when the Cyberdog is standing, 771×355×400 mm (L×B×H). Four Mecanum wheels are installed at the four corners of the wheeled robot (Fig. 2C.), which can achieve the same vector translation function as the quadruped robot. The wheeled robot is equipped with a beam of a certain height on the chassis, which is used to connect the guide rods of the guide harness during the experiment. Before the outdoor experiment, we improved our equipment to prevent some irrelevant factors and better accommodate the outdoor complicated environment. The dimensions of the modified car (Fig. 2D.) are 770x360x300 mm (L×B×H). And the handrail of the outside car was a rigid connection structure designed referring to the guide harness. To adjust different users’ heights and various holding positions of the robot car, the installation position of the handrail was adjustable. Considering the complicated environment and security issues, we developed a remote control program to realize the Wizard-of-Oz method. HC-04 Bluetooth module was used to transfer data wirelessly. The controller was a laptop, and the input was acquired through the keyboard by an operator. In addition to the basic forward speed and steering control, there were keys set for emergency brakes. After testing, the operation delay of the remote control system was less than 100 ms, which was enough to meet the needs.

**D. Experiment Environment**

**Indoor environment:** We carved out an indoor experimental area of 8x8 m in the center of a 9×10 m lecture hall, with a 6.5x6.5 m area as the walking task area (Fig. 3). The base station of HTC VIVE was installed in the four corners of the experimental area (8x8 m), 2m from the ground to cover the entire area. Then, by tying two Trackers to the subject’s waist and the robot’s body, the Tracker was able to receive the infrared light signal emitted by the base station and give feedback. Through HTC Vive Tracker, we can obtain real-time position coordinates between participants and robots.

**Outdoor environment:** Considering the convenience of the blind and their daily walking situation, we found two areas to conduct our outdoor experiment. To control the effects of different ground conditions, we have ensured that the two walking routes both include flat brick surface, uneven brick surface, tarmac, narrow road, obstacles, and uphill/downhill. The total length is about 100 meters. The environment can be seen in Fig. 4.

**E. Procedure**

**Indoor Preparation:** Once the participants came to the laboratory, they were invited to know the detail of a consent form and sign up for it. Because of the difference in visually impaired degrees, some subjects can feel the light or see the shadow of stuff. To control the effect of sight degree, an eye-patch was worn before the experiment. We also pay attention to the disruption of sound from robots, which are controlled by wearing earphones to hear the same sound. Due
to challenges related to using the guiding harness, we set up a session to train the use of it. During this period of time, the function of the guiding harness was introduced, and they could experience how to own directions information anytime until they reported they handled the device.

Outdoor Preparation: Similar to the indoor experiment, we also invited all the participants to sign up for the consent forms. To simulate a real outdoor walking scene, we didn’t wear eye-patch and earphones anymore for them. But they also have completed the training of guide harness.

Indoor Tasks: We designed an indoor study to have 4 trials for each form of the robot. Trials combining different tasks and difficulties were presented for each participant by reverse balance method to decrease sequential effects. For the difficulty, we used easy and difficult settings. And for the task, we used the straight & Turn (S&T) and Obstacle Avoidance (OA) settings. About the definition of the difficulty of tasks, we take rotation angle and the number of obstacles into consideration. For easy S&T tasks, we just arrange the robot to lead the subject to make three 90-degree turns. For difficult S&T tasks, robots were set to turn at different angles (45 degrees, 90 degrees, and 135 degrees). For easy OA tasks, two identical chairs heading in different directions were placed in the laboratory. For difficult OA tasks, three identical chairs were placed, and subjects had to avoid the obstacles more frequently, and the arc length of avoidance was longer. (See Fig. 5)

Outdoor Tasks: During the outdoor experiment, they also went straight and turned, including right angle turn, larger and smaller angles. Avoiding obstacles is also happened naturally because of the real environment, such as pedestrians and bicycles. Besides, we set the route through a variety of road surfaces and road conditions. The detailed grounding information can be seen in Fig. 4.

After each experiment, the participants were invited to rate the usability, workload, satisfaction, and trust of each robot on relevant scales (details are in the Evaluation Metrics part). Finally, the participants were invited to accept a semi-structured interview about their general experience with robots. "what do you think of the advantages of quadruped robot and wheeled robot?" and "how do you feel when you turn or avoid obstacles with quadruped robot and wheeled robot?"

F. Evaluation Metrics

About the questionnaire, the subjective valuables were categorized into the below two aspects: subjective assessment of robots’ use (usability, workload) and personal feeling (trust and satisfaction). All the questionnaires have passed the reliability test, and their Cronbach’s alpha is acceptable.

Usability: In 1996, the questionnaire was created by Brooke et al. [19]. It assessed usability via five-point Likert scales ranging from 1, completely disagree, to 5, completely agree, replacing all the words "system" with "robot".

Workload: We used the National Aeronautics and Space Administration Task Load Index (NASA-TLX) scales for assessing the ease of use [20]. This scale includes 6 items: mental demand, physical demand, temporal demand, performance, effort, and frustration. All participants were asked to rate from 0 to 20.

Satisfaction: The level of satisfaction was measured by the Quebec User Evaluation of satisfaction with Assistive Technology Scale by Demers et al. [21]. Similar to SUS, 1-5 scores were rated as the level of satisfaction.

Trust: The questionnaire was adapted from the seven-point trust in automation scale by Jian et al. [22].

III. RESULTS

A. Indoor results of two forms of robots

During this part, we performed matched samples t-tests to determine the statistical significance of comparisons. The perceived workload of participants showed significant differences between the two forms of robots. The wheeled robot showed a lower workload than the quadruped robot (t=-2.598; p<0.05), indicating H1 could be true (see figure 6). When using a quadruped robot, they felt more temporal demand than a wheeled robot (t=-2.136; p=0.05). But we didn’t find out the statistical significance between the two forms of robots on usability, satisfaction, and trust. Notably, there were still some interesting trends observed (see Fig. 6).

Fig. 6. Results of the indoor experiment.

No matter what aspects, the wheeled robot always showed higher average scores than the quadruped robot. Moreover, we also transformed SUS grades into different levels (A+, A, A-, B+, B, B-, C+, C, C-, D, F) according to the SUS grading range of fractional curve and the level D & F can be
described as “bad” and “terrible” in the description of SUS scale. The final results showed that the quadruped robot was the higher one evaluated as the D & F (35.7% & 21.4%) followed by the wheeled robot (21.4% & 21.4%). We also analyzed the difference in the sub-scales of the SUS scale, effectiveness & learning ability, use efficiency & usability, and satisfaction. The majority of participants (78.57%) gave higher or equal scores to the wheeled robot no matter what sub-scales they rated. For satisfaction and trust, the wheeled robot was the better one or equal to the quadruped robot (64.29%). And the satisfaction result is similar to the result of the trust. The majority of participants trusted the wheeled robot more (64.29%). Besides, we also tried to explore whether the differences existed between different groups (the suddenly acquired blindness, the blind walking with a guide dog, and the normal blind), but we didn’t find out statistical significance between any. However, the trend is consistent.

B. Outdoor results of two forms of robots

After matched samples t-tests, the statistics show us that the wheeled robot gave participants significantly more usability (t=2.610; p<0.05) and trust (t=-2.562; p<0.05), but the workload and satisfaction didn’t show a significant difference between the two forms. Contrary to hypothesis 2, the quadruped robot didn’t perform better in the outside experiment. In detail, participants gave significantly higher scores to wheeled robot on effectiveness & learning ability (t=2.341; p<0.05) and use efficiency & usability (t=3.123; p<0.05). Although the total score of workload wasn’t significantly different anymore in the outdoor experiment, one of the six sub-scales scores, mental demand, was close to significant (t=2.207; p=0.058). The mental load of using the quadruped robot is bigger than the wheeled robot. (see Fig. 7)

Fig. 7. Results of the outdoor experiment.

IV. FINDINGS

Firstly, we desired to shed light on the total trend between the indoor and outdoor results. Contrary to the hypothesis, the environment did not change the trend in evaluation but rather made the differences more pronounced. Namely, the insignificant wheel advantage in evaluation became statistically significant. The most prominent advantages of the quadruped robot, performing well in complicated surroundings, were expected to remain consistent in the area of guiding. However, when the environment became complex, blind people seemed to be more dependent on the assistive robot, and the demands on the robot were higher. Thus, this showed that wheeled robots were able to maintain their stability in outdoor guiding environments, while quadruped robots do not have outstanding outdoor guiding advantages. Now we will discuss the features of the quadruped robot and show how these features possibly affect the experience of blind people during walking.

A. Walking sound

When we tried to figure out the reasons that made the quadruped robot show poor usability in this experiment, we found that walking noise could be a huge hidden problem in the guiding. The feet forms of a quadruped robot determine that it lacks the advantages of a wheeled robot to withstand impacts from different directions. Thus, The impact with the ground during the walking of the quadruped robot will recoil the motors at the joints, generating loud and unavoidable noises. The feet of a real animal is irregular, with structures such as claws and fleshy pads, and always have a strong grip and remain relatively silent. However, the truly bionic feet have not been applied to most quadruped robots [23]. And now, in the indoor interview, some participants expressed that “The dog is noisy”, although they all wore headsets. Regardless of the means used to reduce this effect, sound generated from the motors was always affecting guiding. For the blind, hearing is a really important sensory resource, which means this repeated and meaningless sound is likely to have an impact on their access to outside feedback, especially in a really quiet environment. The problems posed by the sound not only affect the effectiveness of safe walking but also affect the socialized life of the blind, and P6 said, “Whether we can stand it is one thing. Another aspect is, for example, what do we do when we sometimes go to a meeting or go out in the process of a meeting? A real dog can be very quiet (...), but if this robot is loud, this may be a problem.”

B. Way of walking

The quadruped robot’s uneven way of walking may be a significant factor affecting the guiding experience. The typical gaits of quadruped robots include walking, trotting, flying trot, bounding, galloping, free gait, and others[24], [25], [26]. And walking gait is the most possible motion in guiding. Since the walking gait of a quadruped robot is a sequential collection of the support states and shifting states of its legs over time, its motion is less smooth than that of a wheeled robot. The blind didn’t know what the dog was doing. They just could hear and feel, and P16 said, “When the dog was walking, I was particularly afraid that it stepped on my foot, I think stepping on me should
be more painful than if the wheel rolled over me, anyway, I was very anxious." This provides some insight into our interpretation of the participants’ lower trust in the quadruped robot. The uneven movement way itself and the feeling of being at risk generated by this way of going forward are both possible factors decreasing the trust scores of the quadruped robot. Furthermore, the ground vibrations generated from walking also affected the perception of the blind, although it’s tiny and imperceptible. The results indicated that the significantly higher time demands in the indoor experiment disappeared and were replaced by a higher mental load, which means they did not feel rushed and over-paced when guided outdoors. Although the real environment provided a variety of circumstances when using both two robots, including ambient bottom noise, which made the motor sounds seem more acceptable and a complex set of possible events to focus on, only the mental load of the quadruped robot substantially improved. P14 said “It seemed to be hesitating, which made me lose a little bit of confidence in it.” When the machine provided such a cue to the subjects, they added additional thinking processes and speculation, increasing the load and undermining trust.

Besides, this way of walking was affecting a significant aspect, feedback. Transverse degrees of freedom of the hip joints is essential if the robot is expected to walk as flexibly as a true animal. Degrees of freedom in the left and right directions introduce additional rocking motions to the robot, making it more difficult to control. P22 mentioned The dog wiggling from side to side may provide additional information to mislead me. Besides, according to the interview after the outdoor experiment, we concluded that a commonality of quadruped robots is that they can barely transmit ground information to the users, while wheeled robots are more sensitive in making subjects aware of the road surface information, such as roughness, up and down hills, etc. Sometimes we tend to consider feedback as a necessary thing, but when we tried to question their preferences for this feedback, disagreements emerged. Some participants think “it’s great, I need it”, but at the same time, some consider that “it doesn’t matter” or even “I don’t like the feeling, I don’t need to know what kind of surface it is, just let me pass.” The subjects seemed to have different preferences in this regard, which may also make us think about what information should be given to the blind and what kind of information should not. A discerning person’s assessment of external visual stimuli relies on all the objects that appear no matter whether they paid attention to them or not, which makes it difficult for us to empathize with what information is necessary and what is misleading.

C. Zoomorphic form

Zoomorphic robots have been confirmed by many studies to have many benefits as socially assistive robots. For example, older people preferred realistic, familiar, zoomorphic designs over mechanomorphic, and such designs increase the social presence of a device and the incidence of emotional responses and interactions.[11]. Zoomorphic robots can play games with children with autism and support the development of joint attention[27]. However, we don’t know how robots in the animal form will affect the blind. Thus, we asked whether blind people could also empathize with the animal-like robot in the interviews. One observation was that most blind people did not feel that they were more friendly or it could bring them a range of emotional experiences, such as companionship. Notably, one of the themes repeatedly emphasized by the blind group was practicality, just like P10 said, “The form is not important. It’s the function of the guide that matters, as long as it’s portable.”. The finding is consistent with the previous study that the blind expect a ”small, lightweight, portable robot” [28]. We also tried to know more from the blind with the help of the guide dogs because they owned more experience with real dogs. But they also did not express their preference for the bionic form. Instead, they tend to think it’s unnecessary. P6 mentioned “In fact, I didn’t like the dog at first, and I even resisted a little, if there would be a tool to replace it in the future, that must be good, and if I really like dogs, I will get a pet at home, why do they have to do this (guide).” Interestingly, there are still two subjects(P17 & P21) expressing the robot dog to be affectionate, which they described as if they were walking a dog, yet they were both discerning people. Similarly, previous research had organized focus groups with blind people, and when the participants expressed their vision for a guiding robot, some blind people mentioned that they might want a dog-like robot [29]. However, when the blind people in this experiment actually used the dog-like robot, they gradually realized what was most important in navigation. This provides us with the inspiration that the combination of the “animal form” and ”walking” does not seem to be a good time to talk about at the moment because we still can’t find a perfect solution to the great risks during walking for the blind.

V. CONCLUSIONS

In two studies, we conducted realistic indoor and outdoor blind walking experience experiments using quadruped robots and wheeled robots, respectively. The results showed the trend that participants are more in favor of the wheeled robot than quadruped robot in the indoor experiment, and this trend was further reinforced with statistically significant differences in the outdoor experiments. In addition, we explored the possible impacts of certain features of the quadruped robot in the field of guiding. It’s unavoidable that walking noise and motion form an obstacle to the process of guiding blind people. Also, we discussed the empathetic role of its bionic morphology in the blind group, which provided some implications for the morphological design of guide robots. However, these conclusions are preliminary and limited by the small sample size and the availability of devices, and we still need to conduct further experiments on a larger group of blind people to verify our conclusions.
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