Bionic Robots as a New Alternative to Guided Dogs

Yilin Cao
School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, China
Yilin.Cao20@student.xjtlu.edu.cn

Nanlin Jin
School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, China
Nanlin.Jin@xjtlu.edu.cn

Yihong Wang
School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, China
Yihong.Wang@xjtlu.edu.cn

Chengtao Ji
School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, China
Chengtao.Ji@xjtlu.edu.cn

Yushan Pan
School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, China
Yushan.Pan@xjtlu.edu.cn

2023 9th International Conference on Virtual Reality (ICVR) | 979-8-3503-4581-0/23/$31.00 ©2023 IEEE | DOI: 10.1109/ICVR57957.2023.10169301

***Abstract*—As the robot industry grows, research into biomimetic robots continues to increase. Robot dogs are one of the more researched types. Unlike robotic arms and vehicles, robotic dogs emphasize interaction with people, and therefore their applications are more focused on daily life. Machine guide dogs are one application that makes good use of this feature. This paper describes the use of the robot dog DOGZILLA S1 for route patrol as well as obstacle recognition. Based on this, the robot dog will provide feedback to people, which can be used as pre-research for designing it into a complete guide dog.**

***Index Terms*—HRI, Robot dog, Guide, Routing, Computer vision**

I. Introduction

In recent years, several studies have revealed that robots are not solely confined to industrial applications but are increasingly integrated into people's daily lives. The first industrial robot was developed over six decades ago in 1959, and this technology has since expanded to encompass personal uses such as domestic floor sweepers and restaurant service robots [1]. These domestic robots are typically tailored to serve a specific function and have been associated with a broad range of advantages [2]. Furthermore, bio-inspired robots have emerged as an exciting field of study, whereby scientists derive inspiration from the motor characteristics or body structures of living organisms to develop machines that perform specific functions.

Research into bionic dogs has heavily relied on humanoid robots that are based on human characteristics. This approach is rooted in the innate human tendency towards interaction, leading to continued progress in humanoid robot research, especially in terms of interaction capabilities and adaptability to the environment. The past few decades have seen a surge in demand for robots, driven by the industrial sector's growth; subsequently, robots have gained traction in the market. However, using robots in everyday life has existed for a long time, necessitating human-robot interaction (HRI) in these applications. Among bionic robots, robotic dogs are particularly well-suited for this purpose as they can mimic dog behavior and interact with humans in a manner that is similar to real pets [3]. Pet dogs have a rich history of interacting with humans [4]; larger dogs are even trained to understand human commands to a certain extent. In contrast, robot dogs are low-maintenance and practical to live pets, making them ideal for use in everyday life [5]. In summary, the HRI capabilities of robot dogs offer a broad range of applications.

XJTLU RDF-21-02-008 funds this research. The corresponding author at Xi'an Jiaotong-Liverpool University. Email: Yushan.Pan@xjtlu.edu.cn.

The chosen research direction explores the feasibility of using robot guide dogs to perform the functions of traditional guide dogs. The cost of breeding and training traditional guide dogs is expensive due to the complexity of the training process. These guide dogs must be fed and maintained like other pets and are subject to the same injuries and lifespans [6]. In contrast, robot guide dogs are easier to charge and maintain and perform basic functions like guide dogs. Established procedures can replace the challenging training process of traditional guide dogs, reducing costs. Therefore, robot guide dogs present a viable and promising research direction for guide dog services.

To design a robotic guide dog, it is crucial to incorporate HRI (Human-Robot Interaction) capabilities to develop a design that assists visually impaired individuals. This entails ensuring the robot has adequate motor capabilities and excellent perception, with the sensors and mechanical limbs being the most significant components. However, other factors, such as the price, must also be considered. If alternative options to the already expensive guide dogs remain unaffordable, the usefulness of this study may be limited.

There are several well-established projects in the dog genre, such as Sony's AIBO and Boston Dynamics' spot. The functions of the different types of dogs vary and can be broadly distinguished by dog-likeness [7]. Sony's AIBO has a high degree of dog-likeness, and its main goal is to act as a smart family pet. The Boston Dynamics spot, on the other hand, is a relatively low simulation of a dog, with a moving part consisting only of a torso and limbs, without a figurative head, replaced by a camera and sensors at the front of the torso. Its powerful drive and balance system allows for difficult motor functions. In contrast, the latter can become a robotic guide dog. However, the high price of the Boston Dynamics spot, which costs 74500 dollars, is a problem. Moreover, its advantages in terms of locomotion are less likely to be used for guiding the blind. In addition, its large size could be a hindrance. We, therefore, chose Yahboom's DOGZILLA as our test subject. This product is relatively affordable and compact. The Raspberry Pi 4B motherboard is also very expandable and will allow for future research into complex functions.

Fig. 1. Robot dog see obstacle

The research problem in this project is to design the basic functions of a robotic guide dog for DOGZILLA. As a complete robotic guide dog system involves analyzing complex situations in multiple scenarios, we are implementing the basic functions of line patrol, obstacle detection, and feedback to people in this project to verify the feasibility of designing the entire robotic guide dog on this basis. As a preliminary study, we will conduct experiments on the dog's behavior and feedback in advance, including line and obstacle scenarios. These experiments will require invoking the robot dog's vision and motion modules. The design and work of the robot dog guide function will be described below.

II. Related work

Numerous studies can inspire HRI study in general and in the field of bionic robot dogs. Regarding related work on robotic guide dogs, there are two main parts: the mechanical module and the vision module.

The mechanical module of robots determines how they move and affects the performance of their movements. This means that we must consider flexibility, support strength, and other conditions to select the appropriate mechanical module. Regarding relevant research in the last decade, there are two main forms: wheeled and legged mechanical modules.

Among the wheeled constructions of guide robots is a class consisting of a grip, a three-wheeled robot, and a long pole attached to it [8]. This design weakens the robot's locomotion, allowing the user to hand-carry the robot through some situations, such as steps. This design is more akin to a guide cane with extended functionality. Another category of four-wheeled robots uses a tow rope to guide the user [9]. The designer of this robot mainly proposes a vision for a guided robot system. Still, its wheeled design has irreparable limitations in guiding, as the wheeled robot cannot pass some crossable obstacles, such as stairs, without human assistance. Additionally, normal four wheels do not provide sufficient flexibility. Although universal wheels can increase steering maneuverability, the disadvantage of barrier-crossing functionality is inevitable.

Mechanical limbs have a more complex structure than wheels, giving up a certain amount of speed for the same power in exchange for a higher degree of environmental adaptability. Insect-like robots with six mechanical limbs have greater stability and agility [10]. However, they have similar limitations to those of wheeled robots. Because of its low chassis, it is not suitable for overcoming obstacles. In contrast to the design where six outward-facing mechanical limbs are mounted on the side of the body with the angle of curvature downwards, the robot dog has limbs facing the ground with the angle of curvature backward. This design raises the torso of the dog so that it does not lose the flexibility of steering and forward maneuverability, but at the same time, has a strong ability to adjust its posture in the vertical direction so that the dog can overcome some obstacles and guide the user at the same time. After analysis of the dog's locomotor characteristics, it has become feasible to mimic its gait to achieve such an effect [10]. Some studies have designed such robotic dogs to interact with humans as a hybrid physical interaction and have conducted experiments and evaluations on guide scenarios [11].

In terms of the vision module, the most important elements are route planning and obstacle recognition. The former requires the ability to perform route patrol functions, helping the user to be routinely guided based on existing routes within the scene [12]. The latter requires a certain degree of resilience on the part of the robot dog to indicate and even re-route obstacles. For example, for a blind person, a traffic light is an imperceptible piece of environmental information that the robot can recognize and indicate to the user [8]. In addition to the scene's fixed and easily recognizable elements, other entities are moving and difficult to capture, such as pedestrians and vehicles. The robot dog also needs to respond to these distractions [13].

III. Design

A. Methodology

In the design of the robot guide dog, as its function requires the vision, movement, and other modules to operate in real-time in conjunction, we first designed the important algorithms for each module separately and then combined them for verification. Based on this approach, we call up algorithms from a number of open-source libraries and make corrections. With this approach, we do not need to start with a redundant underlying design, and we can also use some mature open-source algorithms, such as the PID algorithm and OpenCV, to avoid some routine errors. In addition, as the algorithms in the open source libraries are only basic, we still need to adapt and add to them to make the system more adaptable so that it can coordinate the various algorithm modules to meet the needs of the robot guide dog functionality.

B. System

The system design of the robot guide dog consists of the vision module, the movement module, and their interaction with the user. The hardware part of the vision module is a camera located at the front of the dog's body to recognize its route and obstacles. The scope of the system is shown in the figure below.

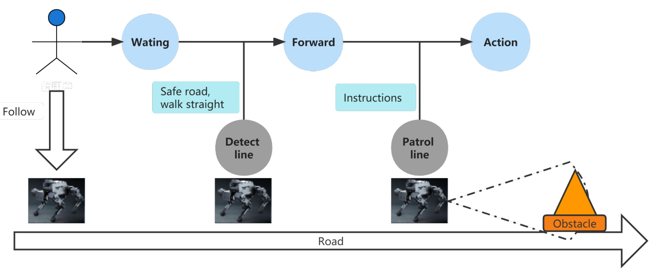

Fig. 2. Activity diagram of robot guide dog

In this experimental scenario, the dog is asked to follow a coloured line on the ground. Firstly, the dog uses colour recognition to darken the background and highlight the line. The algorithm then calculates the center of the smallest square in the obtained route and compares this center with the visual centre. On this basis the motion module combined with the PID algorithm adjusts the direction of the robot dog to keep the centre point of its route from deviating from the visual centre, thus realizing the visual line patrol function [14]. In addition to line patrol, obstacle recognition relies on a colour segmentation method to identify objects below the camera's field of view [15]. Depending on the height of the identified obstacle, the robot dog will either decide to raise its position to cross the obstacle or make instructions to guide the user around the obstacle [16].

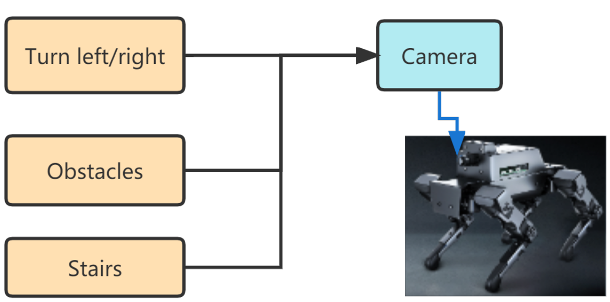

Fig. 3. The types of road condition recognized by camera

In terms of interaction modules, we focus on how the dog interacts with the user based on the existing movement modules. Due to the relatively small size of Dogzilla, it is impossible to use the same physical actions as a real guide dog, such as holding a trouser or blocking a body. Therefore, we have chosen to use a sound module for the cues. Based on a simplified design scenario, we have used three tones of sound representing 'Forward,' 'Cross,' and 'Detour.' We use short intermittent beeps at 1s intervals to indicate forward, two quick short beeps to indicate a crossing, and a long 2s beep to represent a detour. Moreover, instructions such as steering can be achieved using the 'forward' indication combined with the user listening to the sound. After the detour indication, we set three long beeps for a left turn and two long beeps for a right turn. The pronunciation of left and right inspired this. More obstacles will be identified in future studies, and different indications will be set, as shown in Figure 3.

C. Algorithm

Based on the above system design, we will elaborate on some of the algorithms in more detail in this section. The main ones are as follows:

- Proportional Integral Derivative (PID)
- Line tracking
- Colour segmentation
- Obstacle crossing

1) Proportional Integral Derivative (PID): PID control system is a widely used classical automatic control system [17]. In this experimental scenario, we use a PID control system to achieve self-stabilization of the machine guide dog and to assist in the tracking and steering function during the patrol. The PID control system can be improved with some modifications, such as gain scheduling methods, to improve its adaptability to assist the patrol and even to be able to track the moving target [18]. The PID parameters are initialized and updated in real-time during the patrol based on the PID algorithms that are now available in the library. The dog's body adjusts its position and corrects its direction of travel according to the relevant parameters.

Fig. 4. PID tracking

The image in Fig.4 demonstrates how the robot dog adjusts its pose using the PID system. In both scenarios, there is a green cube placed on top of a box and on a desk, respectively. The robot dog recognizes the cube and then locks onto the cube in its view without changing its own position. This way, the robot dog can change its pose to ensure that the object remains within its field of view. When the cube is on high ground, the dog straightens its front limbs and retracts its hind limbs to form an angle of elevation, locking onto the high cube. Conversely, when the cube is on a flat surface, the dog straightens its hind limbs and retracts them to form a pitch angle, locking it onto the lower cube. This method can also be used to control the horizontal adjustment of the robot dog during patrol.

2) Colour segmentation: In robotic vision, the accuracy of color recognition captured by the camera can be affected by various factors, including the lighting conditions, camera settings, and even the user's perception of color [19]. Therefore, color segmentation methods are often used to improve the accuracy of color recognition. We have utilized functions derived from the OpenCV library to design the color segmentation algorithm for the machine guide dog. In this module, the image obtained by recognition is transformed into a color model with three main parameters (Hue, Saturation, and Value), which is saved in an HSV file. These parameters are then synchronized with the patrol algorithm to determine the camera's target line center for visual center calibration.

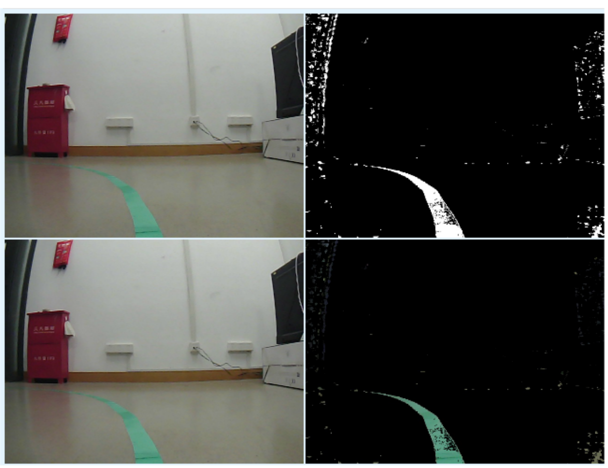

Fig. 5. Colour and line tracking

3) Line tracking: A combination of both of these algorithms is required for the robot guide dog to patrol the lines. First, the lines identified by the color segmentation method described above are stored in an HSV file.

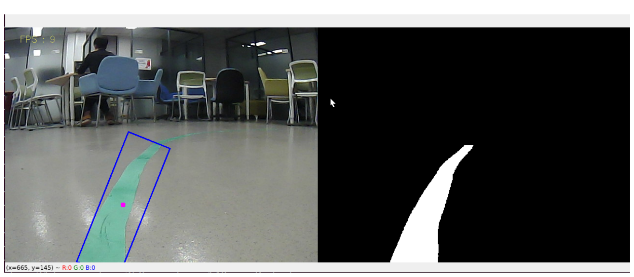

Fig. 6. Visualization of line tracking

As shown in Fig. 5, a green line with curves is arranged in the scene as a target for the robot dog to follow. In combination with the colour segmentation method mentioned earlier, the line obtained by the machine dog recognition is highlighted in white against a black background.

Next, the robot dog moves forward, and the algorithm is invoked to process the recognition results. In this process, the movement of the robot dog in the direction of rotation along the line is calculated and processed by the PID algorithm. This process is divided into three parts: initialization, identification, and tracking. During the initialization process, the line and rectangle are initialized in a color-dependent manner. The detailed line patrol algorithm is shown in Algorithm 1.

Algorithm 1: Line tracking

Input : Image parameter rgb_img, movement parameter $action$, position condition $self$

Output: Processed rgb_img

Resize the image model to (640, 480)
if *action==32* **then**
  self.Track_state = 'tracking'
else
  if *action == ord('i') or action == 105* **then**
    self.Track_state = 'identify'
  end
  if *action == ord('r') or action == 114* **then**
    self.Reset
  end
end
if *self.Track_state == "identify"* **then**
  path.exists in hsv_text
else
  self.Track_state = 'init'
end
if $self.Track\_state \neq$ 'init' *and* $len(self.hsv\_range) \neq 0$ **then**
  rgb_img, self.circle updated
  $color.line\_follow \leftarrow rgb\_img, hsv\_range$
end
if *self.Track_state == 'tracking' and* $len(self.circle) \neq 0$ **then**
  self.execute
end
return rgb_img

4) Obstacle crossing: When encountering a shorter obstacle that can be crossed, the robot dog will turn on the crossing mode to cross it. The obstacle-crossing mode of the machine guide dog is based on its own walking module, which reduces the bending of the mechanical limbs and improves the body position during high walking. Its overrun mode is switched on based on the recognition of the obstacle and is reset to the basic travel mode after the obstacle has been crossed. The basic algorithm is shown in Algorithm 2.

Algorithm 2: Obstacle crossing

Input : The parameter of obstacle captured by camera $point\_x$, $point\_y$ and $radius$
Output: Forward mode of robot dog $gait\_type$

```
if (point_y≥ 300) and (radius≥ 150) then
    Dog self stop
    gait_type =“high_walk”
    Forward
end
return gait_type
```

IV. User study

In order to ensure the proper overall functioning of the machine guide dog, we have devised criteria to evaluate its performance based on the main functions accomplished in the above design, such as visual recognition and line patrol.

To assess its effectiveness in functional completion, we designed several scenarios, including a straight-line scenario, a curve scenario, and an obstacle scenario. In the first two scenarios, we laid out different routes in the laboratory to assess the stability of the patrol algorithm and verify that it does not lose its target. In the obstacle scenario, the guide robot dog encounters low obstacles that can be crossed and high obstacles that cannot be crossed in the route. We evaluate the effectiveness of the obstacle-crossing and feedback algorithms based on whether they can give the user correct feedback depending on the situation.

Additionally, we conducted a questionnaire survey with volunteers to gather feedback on the machine guide dog's performance. The scenario we created for the user study is shown in the figure below.

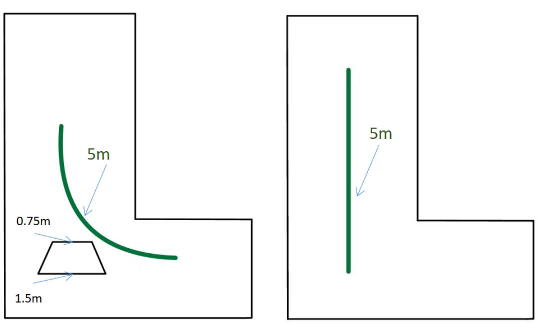

Fig. 7. User study scenario

A. Participants

Our experiments recruited 12 pairs of participants (15 females) from a local university, aged between 20 to 27. Most of the participants were studying Human-Computer Interaction. All participants had normal or corrected to normal health status.

B. Measurement

To evaluate the performance and workload of human-robot interaction, the NASA-TLX workload questionnaire and SUS questionnaire are used. NASA-TLX uses a 10-point scale, and SUS uses five point-scale. NASA-TLX measures six elements of users' workload (mental demand, physical demand, temporal demand, overall performance, effort, and frustration level). The NASA-TLX questionnaire can measure the workload of the participants when performing the blind simulation test, and we can verify the robot dog guide's effectiveness by comparing the conditions' results with and without the robot dog. SUS measures six elements of users' performance and preference (System functions, design issues, ease to use, user confidence, affordance, and usefulness). The SUS questionnaire can directly reflect the participants' feelings about the function of the robot dog itself during the test.

C. Procedure

Participants are required to perform the experiment separately according to their assigned group. The experiment was conducted in a room with tables and chairs, where a non-regular line was marked out with green tape to guide the robot dog.

Fig. 8. User study of robot guide dog

Participants in the control group were instructed to navigate the route blindfolded and under blind conditions, without the guidance of a guide dog. In contrast, participants in the experimental group were guided by the robot dog and required to follow the same requirements as those in the control group. After seven preparatory points, the robot dog leads the way along the designated route and gives instructions during the process based on the identified road conditions. The robot dog assists the experimenter throughout the entire route.

Upon completing both sets of experiments, all participants were asked to complete the above questionnaire to provide assessment data.

D. Results and analysis

A total of 12 pairs of participants completed the experiments and submitted valid data. The information collected through the NASA-TLX and SUS questionnaires indicates the participants' experience of using the robotic guide dogs, their acceptance of them, and their evaluation of the robotic guide dog system's capabilities. Most participants' data met expectations, with a few indicators showing significant individual differences. The results for both questionnaires that exhibited robotic dog guide assistance were significantly higher overall than those without robotic dog assistance. All participants agreed that the robot dog could be helpful in a guide scenario. The following analysis is based on two tables with different emphases.

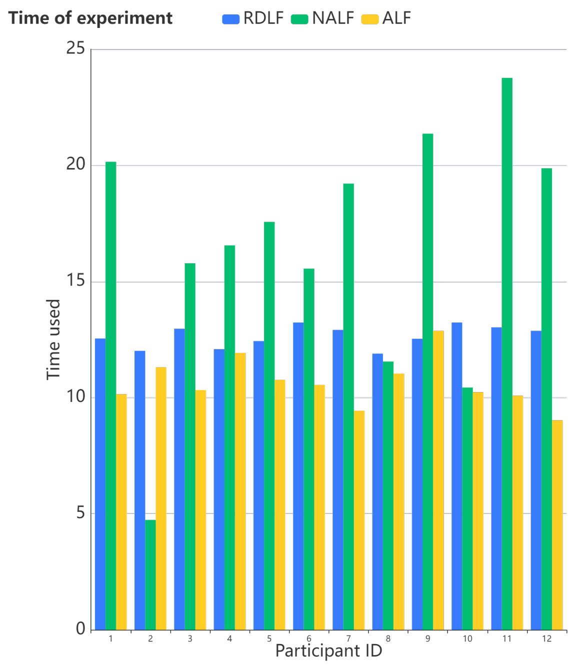

Fig. 9. Time used in the experiment with RDLF: Robot dog line following, NALF: No assistance line following, ALF: Assisted line following

1) Objective results: The bar chart above shows the time taken by a total of 12 groups of participants to complete the experiment. In our scenario, the complete path is a five-meter-long curve. As can be seen in the graph, the time taken for the robot dog itself to pass was, on average, 12.64 seconds, with a variance of 0.219, indicating high stability. We simulated the guidance of the robot dog in our experiment so that the participants were allowed to start moving again after the robot dog had advanced one meter. The graph shows that the data representing advancement assisted by a robotic guide dog is generally lower, with a mean of 10.64 and a variance of 1.104. Most of the green bars in the graph representing advancement without the assistance of a robotic dog are significantly higher, and only a few are lower than those with the assistance of a robotic dog. The variance of this part of the data is as high as 28.24, showing significant individual differences.

The group of participants, without the assistance of the robot dog, spent a lot of extra time during the experiment because some of them were looking in the wrong direction. There were a few tiny data points from individual participants who happened to walk in the right direction and passed directly and quickly. After excluding these extreme data points, it can be seen that the assistance of the robot dog saved approximately 50% of the time for the participants who were assumed to be blind. The time spent looking for directions and correcting errors was avoided by the instructions of the robot guide dogs.

2) Subjective results: In the NASA-TLX questionnaire (out of 10), the mean score for the control group without the assistance of a robot dog was 6.04, while the mean score for the experimental group with the assistance of a robot dog was 5.43, indicating that the guide dog did help. As seen in the graph, the participants' scores for overall performance were generally high. The mean score for the obstacle avoidance function was 5.79, which is lower than the mean score of 6.29 for the patrol function, and is more concentrated. This reflects the more positive and consistent feedback participants received when using the obstacle avoidance function. The variance of all data was the smallest for the temporal demand criterion, at 2.92, and was similar for mental demand and physical demand. This indicates that the performance of the dog is relatively stable and that the difficulty of use is suitable for most people and does not easily produce individual differences. In terms of the frustration level, the participants gave higher variability to obstacle recognition compared to the patrol line. This reflects the different levels of difficulty that different participants may have encountered during the experiment.

Besides, the experimental group scored approximately 11% lower on average compared to the control group, which is a relatively small margin. In addition, as this experiment was set in a room with tables and chairs that served as handrails for participants to hold on to while walking in addition to being identified as an obstacle, the level of frustration experienced by the participants may have been different depending on how well they utilized the experimental environment. Furthermore, because the participants were all sighted and may not have exercised other senses, such as hearing, as a substitute for vision for as long as the real visually impaired people did, the real visually impaired people may have been more sensitive to the robot dog's instructions when instructed to do so. They may have had higher scoring data for receiving auditory feedback.

In the SUS questionnaire (out of 5), the data showed that participants were more satisfied with the ease of use and integration of the system, with a mean score of 4.1. The mean scores for the patrol and obstacle avoidance functions were about the same, 3.78 and 3.77, respectively, higher than the mean score of 3.28 without the robot dog assistance. The mean confidence level of participants using the line patrol function was 3.44, which was lower than the mean value of 3.67 when using the obstacle recognition function. This is similar to the questions reflected in the NASA-TLX questionnaire. Participants' confidence in using a function is a reflection of how well the function is being performed, including success rate, stability, and self-correcting ability. This indicates that the participants still do not have complete confidence in the robotic dog patrol function. This may be due to the fact that the visual system of the robot dog may differ slightly from the hypothetical environment due to different lighting conditions and the fact that the participants did not have a concrete visual impression of how they expected the robot dog to move before starting the experiment, and were, therefore, less confident. In contrast, by the time the obstacle avoidance experiment was conducted, participants had already understood the effectiveness of the line patrol function and may have been more confident in this project. In addition, participants perceived obstacle recognition to be more commonly used than line walking, which may mean that obstacle avoidance was subjectively perceived to be more important to blind people when they were brought into the blind perspective.

E. Limitation

At present, there are some limitations to this robotic guide dog. Firstly, in terms of hardware, the dog cannot operate outdoors in the rain because it does not have waterproof housing. And, because the dog itself is small and cannot jump, it cannot jump over obstacles that humans can. In addition, the monocular camera used in this dog has a performance gap compared to the binocular depth camera. In terms of external factors, the real-world environment is more complex than the testing environment in the laboratory, with sunlight exposure affecting the accuracy of the recognition function and oncoming pedestrians and vehicles posing challenges to the vision system. The challenges posed by these environmental factors stem from the fact that the performance of the current algorithms is not yet robust and mature enough.

V. Conclusion

In this paper, we present a study where we develop a guiding system for a robot dog to assist people who have visual problems. Our experiments show that our proposed method can help people in walking and navigating. those findings are more of a reference point, given the personal background of the participants and the fact that they were not visually impaired but merely simulated the scenario by obscuring their vision. The actual help that this project can provide will need to be tested with real blind people at a later stage. In terms of the function of the dog itself, some parts need to be improved and enhanced. Firstly, in terms of recognition, this dog can currently achieve accurate recognition in the laboratory environment. Still, outdoors it is affected by sunlight, surrounding scenes of the same color as the lines, etc. The recognition results will be affected. Therefore, we need to improve the recognition algorithm. Secondly, the outdoor road conditions are much more complicated than the indoor situation, so we should do a good job of the emergency plan of the robot dog itself and add the function of the robot dog to get up and stabilize itself after a fall. Thirdly, modifying the intelligent voice module can upgrade the feedback module. In this way, the robot dog can make more accurate and humane reminders.

References

[1] W. Xu, X. Li, W. Xu, L. Gong, Y. Huang, Z. Zhao, L. Zhao, B. Chen, H. Yang, L. Cao, and C. Liu, "Human-robot interaction oriented human-in-the-loop real-time motion imitation on a humanoid tri-co robot," in *2018 3rd International Conference on Advanced Robotics and Mechatronics (ICARM)*, 2018, pp. 781–786.

[2] N. Fukaya and Y. Ogasawara, "Development of humanoid hand with cover integrated link mechanism for daily life work," in *2017 IEEE 6th Global Conference on Consumer Electronics (GCCE)*, 2017, pp. 1–4.

[3] M. Qin, B. Scassellati, and L. Santos, "Agency in canine-robot interaction: Do dogs (canis familiaris) understand humanoid robots pointing behavior?" in *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 2019, pp. 736–738.

[4] H. Kudo, T. Koizumi, T. Nakamura, M. Kanoh, and K. Yamada, "Behavior model for hearing-dog robot," in *2016 Joint 8th International Conference on Soft Computing and Intelligent Systems (SCIS) and 17th International Symposium on Advanced Intelligent Systems (ISIS)*, 2016, pp. 260–265.

[5] M. K. Lee, J. Forlizzi, S. Kiesler, M. Cakmak, and S. Srinivasa, "Predictability or adaptivity? designing robot handoffs modeled from trained dogs and people," in *2011 6th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 2011, pp. 179–180.

[6] L. Marques, "Mobile robot olfaction: Towards search and rescue robot dogs," in *2020 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR)*, 2020, pp. 5–5.

[7] H. Schellin, T. Oberley, K. Patterson, B. Kim, K. S. Haring, C. C. Tossell, E. Phillips, and E. J. d. Visser, "Man's new best friend? strengthening human-robot dog bonding by enhancing the doglikeness of sony's aibo," in *2020 Systems and Information Engineering Design Symposium (SIEDS)*, 2020, pp. 1–6.

[8] Q. Wang, K. Zhang, K. Zhao, and M. Liao, "Smart seeing eye dog wheeled assistive robotics," in *2021 3rd International Symposium on Robotics Intelligent Manufacturing Technology (ISRIMT)*, 2021, pp. 104–108.

[9] Y. Wei, X. Kou, and M. Lee, "Development of a guide-dog robot system for the visually impaired by using fuzzy logic based human-robot interaction approach," in *2013 13th International Conference on Control, Automation and Systems (ICCAS 2013)*, 2013, pp. 136–141.

[10] J. Homchanthanakul and P. Manoonpong, "Continuous online adaptation of bioinspired adaptive neuroendocrine control for autonomous walking robots," *IEEE Transactions on Neural Networks and Learning Systems*, vol. 33, no. 5, pp. 1833–1845, 2022.

[11] A. Xiao, W. Tong, L. Yang, J. Zeng, Z. Li, and K. Sreenath, "Robotic guide dog: Leading a human with leash-guided hybrid physical interaction," in *2021 IEEE International Conference on Robotics and Automation (ICRA)*, 2021, pp. 11 470–11 476.

[12] H. Min, L. Huang, and X. Gan, "Research and design of multi-agent model structure for embedded robot dog," in *Proceedings of the 10th World Congress on Intelligent Control and Automation*, 2012, pp. 3629–3633.

[13] R. Ichikawa, B. Zhang, and H.-o. Lim, "Voice expression system of visual environment for a guide dog robot," in *2022 8th International Symposium on System Security, Safety, and Reliability (ISSSR)*, 2022, pp. 191–192.

[14] X. Tian, J. Liu, M. Mallick, and K. Huang, "Simultaneous detection and tracking of moving-target shadows in visar imagery," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 59, no. 2, pp. 1182–1199, 2021.

[15] J. Zhu, Y. Chen, M. Zhang, Q. Chen, Y. Guo, H. Min, and Z. Chen, "An edge computing platform of guide-dog robot for visually impaired," in *2019 IEEE 14th International Symposium on Autonomous Decentralized System (ISADS)*, 2019, pp. 1–7.

[16] Y. Tan, Z. Li, Y. Chen, and H. Wang, "Bionic mechanism and kinetic characteristic for quadruped robot dog," in *Fifth Asia International Symposium on Mechatronics (AISM 2015)*, 2015, pp. 1–5.

[17] K. H. Ang, G. Chong, and Y. Li, "Pid control system analysis, design, and technology," *IEEE Transactions on Control Systems Technology*, vol. 13, no. 4, pp. 559–576, 2005.

[18] M. Rabah, A. Rohan, S. A. S. Mohamed, and S.-H. Kim, "Autonomous moving target-tracking for a uav quadcopter based on fuzzy-pi," *IEEE Access*, vol. 7, pp. 38 407–38 419, 2019.

[19] C. Liu and L. Wang, "Fuzzy color recognition and segmentation of robot vision scene," in *2015 8th International Congress on Image and Signal Processing (CISP)*, 2015, pp. 448–452.