BeetleBot: A Multi-Purpose AI-Driven Mobile Robot for Realistic Environments

Anh Nguyen[1], Erman Tjiputra[2], Quang D. Tran[2]

***Abstract*— We present BeetleBot, a new mobile robot that has been developed to operate in realistic environments. Different from previous state-of-the-art mobile robots, BeetleBot is designed based on the most recent advancements of actuator, mechanical design, and artificial intelligence. These advantages allow the robot to have powerful features including ultra-mobility, accurate localization, intensive AI ecosystem, and autonomous navigation in normal as well as complex and rough terrain environments. Based on its novel design, BeetleBot can be used in a variety of tasks including but not limited to autonomous delivery, exploration and surveillance, or human-robot interaction. Besides the development of the robot, we also build large-scale open-source simulation models that are fully integrated with ROS and can be used for rapid testing and deployment of any robots. Finally, we show the capability of BeetleBot and the performance of each individual AI module in various tasks and real-world scenarios.**

I. INTRODUCTION

Mobile robotics is a long-lasting research and development field in both academia and industry [1]. In general, a mobile robot is designed to autonomously move through its environment without the need of a human operator or on a fixed predetermined path. The mobile robots are usually equipped with an array of sophisticated sensors that enable them to understand, interpret, and act inside the environment, which help them to perform its tasks in the most efficient manner and possible path such as navigating around fixed or moving obstacles (e.g., building, people, and debris). Based on the natural advantages of its design, mobile robots are widely used to work independently or collaboratively with humans in various real-world applications such as logistics (e.g., autonomous delivery), inspection and maintenance (e.g., inspection robot), security and defense (e.g., surveillance robot), agriculture (e.g., fruit picking robot), or urban transportation. Especially, with the recent Coronavirus pandemic, the need of a human-friendly mobile platform that can assist patients in the hospital or be used in healthcare services in general is increasing significantly.

Although there are currently many mobile platforms available, they all share two main limitations: *i)* Most of the mobile robots are designed for a particular problem, hence it is not a trivial task to adapt and use the robot in a new task. *ii)* The integration between hardware, software, and AI for mobile platforms is still a challenge during the deployment. Motivated by these limitations, this paper aims to develop a new mobile platform for remote or autonomous operation in real-world scenarios. Our new robot - BeetleBot - has flexible maneuverability and strong performance to traverse through doorways, over obstacles or rough terrains that may be encountered in indoor, outdoor, or rough terrain environments. Coming with state-of-the-art sensor system and novel AI-driven software, BeetleBot can perform a variety of useful tasks autonomously. Fig. 1 illustrates an overview of BeetleBot and its visual sensor system.

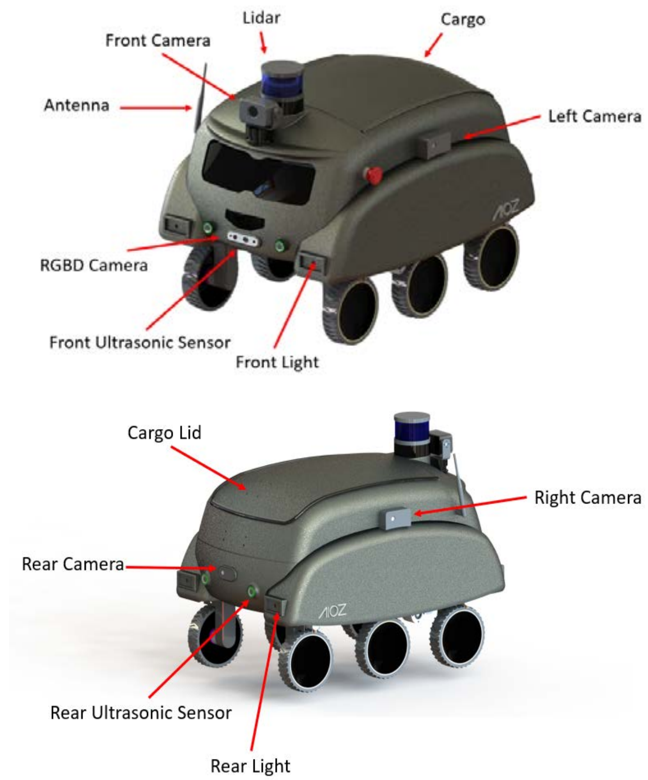


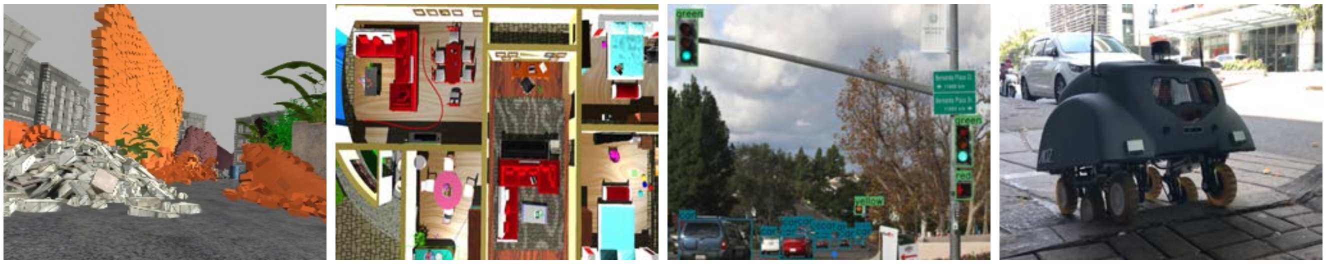
Fig. 1. An overview of BeetleBot, a multi-purpose AI-driven mobile robot and its external sensor system.

II. DESIGN METHODOLOGY

To build a robot that can perform various tasks in realistic environments, our design methodology focuses on three main aspects: *i)* Robust mechanical design, *ii)* AI-driven software framework, and *iii)* Testing and deployment. We discuss in detail each aspect below.

Design: Maneuverability is the key aspect in mechanic design of a mobile robot. Unlike most of the current mobile robots which use 4-wheels design, we adapt the rocker-bogie mechanism [2] to allow the robot to operate in different terrains. The rocker-bogie design has 6-wheels with no

[1]Department of Computing, Imperial College London, UK a.nguyen@imperial.ac.uk
[2]AIOZ Pte Ltd, Singapore quang.tran@aioz.io



(a) RGB Image (b) Sample Trajectory (c) Traffic Detection (d) BeetleBot in Action

Fig. 2. Illustrations of our simulation environments, detection results and BeetleBot in action. From left to right: **(a)** A RGB image from our city environment. **(b)** The path generated by the autonomous navigation network of the robot (denoted as the red line). **(c)** The traffic recognition result. **(d)** Our BeetleBot is in action when crossing a slope.

TABLE I
SPECIFICATIONS OF BEETLEBOT

	Specifications
Dimension	L750 × W500 × H600 mm
Environment	Indoor, outdoor, complex terrains
Payload	Max 20kg
Mobility	Max speed: 800 mm/s, 90 degree/s
Wheel	6 wheels, 4 steering drive, 150mm diameter
Battery	10 hours running time, auto charge
Interface	Mobile/Web app, joystick, voice, autonomous
Communication	Wireless 802.11 a/b/g, 4G, digital audio in/out
Computing	8-Core ARM v8.2 64-Bit CPU, NVIDA Jetson

springs or stub axles for each wheel, allowing the robot to climb over obstacles (e.g., rocks, debris) easily while keeping all 6-wheels on the ground. In order to go over an obstacle, the front wheels are forced against the obstacle by the back two wheels. The rotation of the front wheel then lifts the front of the vehicle up and over the obstacle. The middle wheel is then pressed against the obstacle by the rear wheels and pulled against the obstacle by the front until it is lifted up and over. Finally, the rear wheel is pulled over the obstacle by the front two wheels. During each wheel's traversal of the obstacle, forward progress of the vehicle is slowed or completely halted. Above the rocker-bogie, we currently design a cargo for keeping packages. Most of the visual sensors (e.g, RGB-D, Lidar) are placed in front of the robot. Note that, since we design the robot into separated modules (i.e., wheel mechanism, cargo, and sensor), we can easily customize the design based on the need of different tasks. Table I summarizes the key specifications of our BeetleBot.

AI Ecosystem: Apart from the novel hardware design, our BeetleBot is equipped with state-of-the-art AI methods. Our goal is to close the vision-control loop in robotics and enhance the autonomy of the system. The AI ecosystem of BeetleBot is split into three main applications: Autonomous navigation in normal and complex environments with deep neural network; Visual recognition and localization (e.g., face recognition, pedestrian, traffic light detection, sensor fusion); Human-robot interaction (e.g., emotion estimation and reaction, automatic question and answering). Note that the AI ecosystem of BeetleBot has state-of-the-art accuracy but is very lightweight and achieves real-time performance. Overall, we can deploy the whole software system on an NVIDA Jetson Xavier embedded board. Due to the page limitation, we refer the readers to Fig. 2 and the video on our website for the full demonstration:

https://sites.google.com/site/beetlebotrobot/

Testing Environments: Since robotics is a multidisciplinary field that requires heavy engineering, software testing before deployment plays a critical role in our framework. In particular, we perform extensive experiments to evaluate the effectiveness of the robot in both simulation and real environments. We employ Gazebo [3] simulation and build large-scale environments to test the robot. In particular, we create 539 3D object models to build three kind of simulation environments: house (indoor), city (outdoor), and natural cave (rough terrain). These objects are used to build 30 environments in total (i.e., 10 instances for each environment). In average, the simulated house environments are built with approximately 130 objects in an area of $400m^2$. The city has 275 objects and spread in $3,000m^2$ while the natural cave environments are built with 60 objects in approximately $4,000m^2$ area. These simulation environments can be used to collect data for different learning-based methods (e.g., autonomous navigation, object detection) as well as deploying the trained model. Note that all of the simulation environment, robot model, and sensors are fully compatible with ROS and Gazebo, hence ease the prototype and deployment process. To encourage further research, these large-scale environments and our collected datasets will be released upon acceptance.

To conclude, we present BeetleBot, a new multi-purpose AI-driven mobile robot. We hope that our experience and open-source resources could benefit the robotic community in the future.

REFERENCES

[1] R. Siegwart, I. R. Nourbakhsh, and D. Scaramuzza, *Introduction to autonomous mobile robots*. MIT press, 2011.
[2] D. P. Miller and T.-L. Lee, "High-speed traversal of rough terrain using a rocker-bogie mobility system," in *Space and Robotics*, 2002.
[3] N. Koenig and A. Howard, "Design and use paradigms for gazebo, an open-source multi-robot simulator," in *IROS*, 2004.