CREATE ADVENTOR Application Form

1. Applicant (Trainee) Information

First Name:	Simon
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Program:

Undergraduate student	☐ NSE	
Master's student	☒ NSE	☐ Non-NSE
Ph.D. student	☐ NSE	☐ Non-NSE

NSE: Natural Sciences and Engineering
Non-NSE: Health, Social Sciences, Humanities

Years of funding requested:

☐ 1 year ☒ 2 years ☐ 3 years ☐ 4 years

The ADVENTOR team is strongly committed to fulfilling Equity, Diversity, Inclusion, and Indigeneity (EDII) responsibilities. You may be asked to complete a self-identification survey for the purpose of assessing alignment with CREATE ADVENTOR's EDII objectives.

2. Faculty Information

Proposed supervisor and affiliation*:	Hsiu-Chin Lin, McGill University
Proposed co-supervisor(s) (and affiliations):*	James Forbes, McGill University Hiruni Gunawardana, Clearpath Robotics Joseph Bakambu, MDA Corporation

* By submitting this application, the applicant is confirming that all proposed supervisors and co-supervisors have been contacted, and this research proposal has been discussed with them.

3. Ingenuity Labs Support

For graduate trainee support only: please check here if you would like this application to be considered for the ADVENTOR Ingenuity Labs Research Fund.

☐ Yes, and I confirm that my proposed supervisor is a member of Ingenuity Labs.

4. Research Proposal (max one page, excluding references)

Title

Safe Navigation with Terrain-Preference Modeling

Background

Deploying an autonomous navigation system in real-world environments comes with a variety of complex challenges. Robots must depend on their onboard perception systems to navigate unfamiliar terrains. They need to be able to move over uneven surfaces, such as steps in urban settings or rocks, grass, and branches in natural environments. Moreover, adverse weather conditions, like floods (where terrain height is hard to determine) and snow or black ice (which are traversable but hazardous), present additional difficulties. Ensuring the safety of nearby humans is also a critical consideration on top of those problems.

Most research on terrain-aware navigation and locomotion involves transforming perceptual feedback into elevation maps [1] that model the terrain's height and/or a traversability map based on the robot's physical capabilities [2, 3, 4]. These maps are then used as input for navigation algorithms either based on optimal control or machine learning [5, 6, 7, 8]. However, when multiple traversable paths are available, the robot typically chooses the shortest route [9, 10]. In contrast, humans tend to favour pedestrian paths over walking on the snow, even if taking the path requires a slight detour. Can we embed this idea into the navigation component?

Objectives

The goal is to develop a navigation system for ground vehicles, whether wheeled or legged robots, that can operate in urban environments where humans may be present. The key requirements for this system are: (1) avoiding collisions with humans and (2) understanding the terrain surrounding the robot and prioritizing preferred terrain types when they are available.

Methodologies

The first step is to gain an understanding of the environment. Since computer vision is not the primary focus of this project, we will utilize publicly available libraries and datasets for this task [11, 12].

Secondly, we will develop a terrain map for navigation. While previous work typically models the map using elevation or traversability, our approach will include a map that integrates the concept of preferences, reflecting how humans choose their preferred terrain for walking. Instead of analyzing human selection methods, our first attempt will be based on the total energy expenditure and the duration required to traverse a particular terrain type under similar conditions.

Using the map generated in the previous step, the robot will plan a global path through trajectory optimization [13] and continuously refine the route using model-predictive control [14]. To ensure pedestrian safety, we will incorporate recent advancements in control-barrier functions [15, 16], which provide a guarantee of obstacle avoidance.

Significance

This proposal fits with ADVENTOR's research theme *2.5.1 Robots in the City* where robots need to maneuver autonomously around pedestrians. The key concepts that we would like to introduce are (1) enforcing the safety of pedestrians by embedding control-barrier-function for collision avoidance (2) navigating over various terrain types that minimize the total cost of the movement. Once this project is feasible, the next step is to incorporate a team of robots, including aerial, mobile, and legged robots.

REFERENCES

[1] P. Fankhauser, M. Bloesch, and M. Hutter, "Probabilistic terrain mapping for mobile robots with uncertain localization," *IEEE Robotics and Automation Letters*, vol. 3, no. 4, pp. 3019–3026, 2018.

[2] J.-F. Tremblay, T. Manderson, A. Noca, G. Dudek, and D. Meger, "Multimodal dynamics modeling for off-road autonomous vehicles," in *IEEE International Conference on Robotics and Automation (ICRA)*, pp. 1796–1802, IEEE, 2021.

[3] A. J. Sathyamoorthy, K. Weerakoon, T. Guan, M. Russell, D. Conover, J. Pusey, and D. Manocha, "Vern: Vegetation-aware robot navigation in dense unstructured outdoor environments," in *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 11233–11240, IEEE, 2023.

[4] X. Cai, S. Ancha, L. Sharma, P. R. Osteen, B. Bucher, S. Phillips, J. Wang, M. Everett, N. Roy, and J. P. How, "Evora: Deep evidential traversability learning for risk-aware off-road autonomy," *IEEE Transactions on Robotics*, 2024.

[5] S. Gangapurwala, M. Geisert, R. Orsolino, M. Fallon, and I. Havoutis, "Rloc: Terrain-aware legged locomotion using reinforcement learning and optimal control," *IEEE Transactions on Robotics*, vol. 38, no. 5, pp. 2908–2927, 2022.

[6] T. Miki, J. Lee, J. Hwangbo, L. Wellhausen, V. Koltun, and M. Hutter, "Learning robust perceptive locomotion for quadrupedal robots in the wild," *Science robotics*, vol. 7, no. 62, p. eabk2822, 2022.

[7] A. Agarwal, A. Kumar, J. Malik, and D. Pathak, "Legged locomotion in challenging terrains using egocentric vision," in *Conference on robot learning*, pp. 403–415, PMLR, 2023.

[8] A. J. Sathyamoorthy, K. Weerakoon, T. Guan, J. Liang, and D. Manocha, "Terrapn: Unstructured terrain navigation using online self-supervised learning," in *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 7197–7204, IEEE, 2022.

[9] T. Homberger, L. Wellhausen, P. Fankhauser, and M. Hutter, "Support surface estimation for legged robots," in *International Conference on Robotics and Automation (ICRA)*, pp. 8470–8476, IEEE, 2019.

[10] T. Guan, D. Kothandaraman, R. Chandra, A. J. Sathyamoorthy, K. Weerakoon, and D. Manocha, "Ga-nav: Efficient terrain segmentation for robot navigation in unstructured outdoor environments," *IEEE Robotics and Automation Letters*, vol. 7, no. 3, pp. 8138–8145, 2022.

[11] J. Deng, W. Dong, R. Socher, L.-J. Li, K. Li, and L. Fei-Fei, "Imagenet: A large-scale hierarchical image database," in *IEEE conference on computer vision and pattern recognition*, pp. 248–255, Ieee, 2009.

[12] M. Sohan, T. Sai Ram, R. Reddy, and C. Venkata, "A review on yolov8 and its advancements," in *International Conference on Data Intelligence and Cognitive Informatics*, pp. 529–545, Springer, 2024.

[13] J. T. Betts, "Survey of numerical methods for trajectory optimization," *Journal of guidance, control, and dynamics*, vol. 21, no. 2, pp. 193–207, 1998.

[14] T. Erez, K. Lowrey, Y. Tassa, V. Kumar, S. Kolev, and E. Todorov, "An integrated system for real-time model predictive control of humanoid robots," in *IEEE-RAS International conference on humanoid robots (Humanoids)*, pp. 292–299, IEEE, 2013.

[15] Y. Chen, A. Singletary, and A. D. Ames, "Guaranteed obstacle avoidance for multi-robot operations with limited actuation: A control barrier function approach," *IEEE Control Systems Letters*, vol. 5, no. 1, pp. 127–132, 2020.

[16] Y. Chen, U. Rosolia, W. Ubellacker, N. Csomay-Shanklin, and A. D. Ames, "Interactive multi-modal motion planning with branch model predictive control," *IEEE Robotics and Automation Letters*, vol. 7, no. 2, pp. 5365–5372, 2022.

5. Interdisciplinary Linkages (max 100 words)

The supervisor will offer the research expertise on this project. Her group is focused on safety in machine learning for robotics, and although they haven't worked with control-barrier-functions specifically, the underlying concept fits well with their research. The supervisor will also provide the equipment which includes both a mobile platform (Husky) and a legged robot (Anymal).

The next phase of the project will use a team of aerial robots to provide broader and faster visual feedback (Prof. James Forbes), helping the ground robot to map more efficiently. The project has general applications for mobile robots outdoors, which overlaps with the work in Clearpath Robotics and MDA Corporation.

6. Fit to Program (max 100 words)

The trainee has extensive experience in mobile robotics which makes him a perfect candidate for this project. He was one of the team members who won an award in 2023 for their participation in the Bosch Future Mobility Challenge, an autonomous robot competition. Through this competition, the training was in charge of navigation and control, including working with computer vision and planning using model predictive control. The trainee has also formal training on many advanced courses at McGill, including machine learning, robotics, and computer vision.

This summer, he has been preparing for the project by reading research papers and will further enhance their readiness by taking courses in control and optimization in the next academic year.

7. Commitment to Equity, Diversity, Inclusion, and Indigeneity (max 100 words)

During my time at Marianopolis College from 2018 to 2020, I actively engaged in initiatives that promoted equity, diversity, and inclusion through my engagement in the International Amnesty Club and the Montreal Chinese Hospital Club. In the International Amnesty Club, I participated in campaigns and workshops that raised awareness on human rights, fostering an inclusive culture that supports global equity and justice. At the Montreal Chinese Hospital Club, I contributed to organizing community outreach programs addressing the healthcare needs of Montreal's Chinese community, ensuring cultural sensitivity and accessibility in healthcare services. These experiences have deepened my commitment to EDI principles.

As a graduate student at McGill, I am eager to contribute to the McGill Students Chapter for Amnesty International and the Black Youth Outreach Program. My involvement in the Amnesty International club will focus on advocating for human rights through awareness campaigns and event organization, leveraging my past experience to enhance campus engagement. Also, I plan to actively participate in the Black Youth Outreach Program, aiming to support and increase the representation of black students at McGill. By making meaningful connections and fostering an inclusive academic environment, I am committed to promoting equity and diversity in our university community.

8. Training Requirements

In addition to degree requirements, all ADVENTOR *Master's and PhD* trainees must also fulfill the program requirements. By checking the box below, you agree to the following:

- Participation in internship or research exchange (12 week minimum, NSE trainees only).
- Participation in at least one site visit (half to full day).
- Competition of the core course with specialized modules (must complete 80% of the modules within Year 1 of your degree program).
- Completion of professional skills training (minimum of eight hours per year) with at least one course (during your degree) in ethics, entrepreneurship, professional development, GBA+ and EDII. These courses may be offered by MITACS, Graduate Schools of the participating universities, funding bodies, the Government of Canada, or other mechanisms approved in advance.
- Participation in the annual symposium and two-day design competition.
- Participation in the monthly seminar series, guest speaker and networking events, and the mentorship program. Please note that participation in outreach events is optional but highly encouraged.

☒ Yes, if accepted by the ADVENTOR program, I agree to fulfill my training requirements.