INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue V May 2026

Development of a Lightweight Two-Dimensional Simulator for Behavioural Analysis Under Environmental Stimulus Conditions

Muhammad Raihaan Kamarudin[1]*, Muhammad Noorazlan Shah Zainudin[1], Zul Atfyi Fauzan[2], Sufri Muhammad[3]

[1]Fakulti Kecerdasan Buatan dan Keselamatan Siber, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[2]Fakulti Teknologi Dan Kejuruteraan Elektronik dan Komputer, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[3]Fakulti Sains Komputer dan Teknologi Maklumat, Universiti Putra Malaysia, 43400, Selangor, Malaysia

***Corresponding Author**

DOI: https://doi.org/10.47772/IJRISS.2026.100500389

Received: 08 May 2026; Accepted: 13 May 2026; Published: 01 June 2026

ABSTRACT

Simulation platforms are widely used in behavioural and environmental interaction studies due to their ability to provide flexible, low-cost, and repeatable experimental environments. This paper presents the development of a lightweight two-dimensional behavioural simulator designed for movement visualization and stimulus-based interaction analysis within a simplified virtual environment. The simulator consists of several modular components including environment modelling, behavioural network connectivity, locomotion control, environmental sensing, and real-time visualization modules. In addition, the simulator supports configurable simulation environments through a simplified file-based configuration structure. Several simulations were conducted under both stimulus and non-stimulus environmental conditions to evaluate the functionality and behavioural capabilities of the simulator. The results demonstrated that the simulator is capable of producing reproducible as well as stochastic movement behaviours depending on the simulation configuration. The simulator also successfully represented exploratory movement patterns and adaptive directional movement toward environmental stimulus regions. The proposed simulator provides a flexible platform for behavioural visualization and environmental interaction analysis within a lightweight two-dimensional environment.

Keywords—Behavioural Simulation, Two-Dimensional Simulator, Environmental Interaction, Movement Analysis, Bio-inspired Behaviour

INTRODUCTION

Simulation platforms have become an important tool in scientific and Simulation platforms have become an important tool in scientific and behavioural research due to their ability to provide flexible, low-cost, and repeatable experimental environments. Compared with real-world experimentation, simulation-based approaches enable researchers to observe and analyse system behaviour under controlled conditions without requiring expensive hardware setups or complex laboratory environments. In recent years, simulation environments have been widely applied in various fields including biological modelling, artificial intelligence, behavioural analysis, and autonomous system studies. The growing interest in simulation-based research is driven by the need for efficient experimental platforms capable of visualizing dynamic interactions and behavioural adaptation processes [1]-[3].

Biological behaviour simulation has attracted increasing attention because many living organisms demonstrate adaptive and efficient responses when interacting with their surrounding environments. Behaviours such as foraging, chemotaxis, thermotaxis, swarm coordination, and environmental exploration have inspired numerous computational and behavioural studies. Through simulation, researchers are able to analyse movement patterns, environmental interactions, and behavioural adaptation mechanisms in simplified and controllable environments. In addition, biological simulation platforms allow visualization of behavioural responses that may be difficult to directly observe in physical experiments. Several studies have highlighted the importance of simulation frameworks for studying biological interaction, collective behaviour, and adaptive movement analysis [4]-[6].

Recent advancements in lightweight simulation systems have also increased interest in two-dimensional (2D) behavioural simulation platforms. Compared with large-scale three-dimensional simulation environments, lightweight 2D simulators provide simpler implementation, lower computational requirements, and faster experimental analysis. These characteristics make 2D platforms highly suitable for exploratory behavioural studies, movement visualization, and rapid testing of environmental interaction models [7],[8]. Furthermore, simplified simulation environments enable researchers to focus more directly on behavioural patterns and movement adaptation rather than detailed physical modelling. Several recent studies have also demonstrated the importance of visualization and environmental interaction analysis within lightweight simulation frameworks [9], [10].

Despite the availability of various simulation platforms, many existing systems are designed for high-fidelity visualization, complex physical interaction, or large-scale autonomous system analysis. As a result, these platforms may require significant computational resources and can be difficult to customize for lightweight behavioural experiments. Some simulation environments also prioritize physical realism and graphical complexity over simple behavioural observation and environmental stimulus interaction [11], [12]. Consequently, there remains a need for lightweight and customizable simulation platforms capable of supporting behavioural movement analysis in simplified environments.

Therefore, this study presents the development of a lightweight 2D behavioural simulator designed for analysing movement behaviour under different environmental stimulus conditions. The simulator focuses on behavioural visualization and stimulus-based interaction within a simplified simulation environment. The proposed platform allows users to observe movement trajectories, behavioural adaptation, and environmental interaction processes in real time. Several experiments were conducted under both stimulus and non-stimulus environments to validate the functionality of the simulator and analyse the resulting movement behaviour.

The contributions of this work are as follows. First, a lightweight 2D simulation platform is developed for behavioural movement analysis under environmental stimulus conditions. Second, the simulator integrates environmental stimulus modelling and real-time movement visualization within a customizable simulation environment. Third, behavioural validation experiments are conducted under both stimulus and non-stimulus conditions to analyse movement adaptation and interaction behaviour. Finally, the proposed simulator provides a flexible preliminary platform for future bio-inspired behavioural and navigation studies.

The remainder of this paper is organized as follows. Section II presents the related works on biological behaviour simulation and lightweight simulation platforms. Section III describes the overall simulator architecture and system design. Section IV explains the experimental setup and behavioural analysis procedure. Section V presents the experimental results and discussion, while Section VI concludes the paper and highlights several directions for future work.

Related Works

Several simulation platforms have been developed in recent years to support behavioural analysis, environmental interaction studies, and biological movement visualization. Existing systems vary significantly in terms of computational complexity, visualization capability, environmental modelling, and behavioural interaction support. Some platforms focus on large-scale and physics-based simulation environments, while others emphasize lightweight behavioural modelling and simplified movement analysis. Due to these differences, the suitability of a simulation platform often depends on the specific objectives of the behavioural study. Habitat, introduced by Savva et al. [13], is among the widely known simulation platforms designed for embodied artificial intelligence and environmental interaction studies. The framework provides high-quality visualization and realistic environmental modelling for navigation-related research. Although Habitat offers detailed environmental interaction capabilities, the platform mainly focuses on large-scale three-dimensional environments and requires relatively high computational resources. Such characteristics may limit its suitability for lightweight behavioural movement analysis.Another widely used simulation environment is Gazebo, which has been extensively applied for autonomous system and robotics-related simulation studies [14].

Gazebo supports physics-based modelling, sensor integration, and dynamic environmental interaction. Similarly, Webots provides a flexible simulation environment with support for real-time visualization and multiple programmable entities [15]. Despite their flexibility, both platforms are primarily designed for detailed physical simulation and robotic system integration rather than simplified behavioural observation. In addition, their complexity may increase development overhead for exploratory behavioural studies.Several lightweight simulation frameworks have also been proposed to reduce computational complexity while maintaining behavioural visualization capabilities. Sadhwani et al. [7] presented a lightweight simulation framework focusing on behaviour-based modelling and rapid movement analysis. Their work demonstrated that simplified simulation environments can significantly reduce computational requirements while still supporting effective behavioural visualization.

However, the study mainly focused on general behavioural modelling without emphasizing environmental stimulus interaction. Zeng et al. [8] reviewed several customizable simulation frameworks for intelligent behavioural analysis and highlighted the importance of lightweight architectures for rapid experimentation. The study emphasized that simplified two-dimensional simulation systems are often more suitable for behavioural trajectory analysis due to their lower implementation complexity and faster visualization process.

Nevertheless, most reviewed frameworks primarily focused on intelligent system behaviour rather than biological movement interaction.Research on biological-inspired movement simulation has also gained increasing attention in recent years. Garnier et al. [16] discussed swarm intelligence and collective movement behaviour inspired by biological systems, demonstrating how simple local interaction rules can generate adaptive group behaviour. Similarly, Tuci et al. [17] analysed simulation tools for bio-inspired collective behaviour studies and highlighted the importance of simulation environments in understanding adaptive interaction mechanisms. While these studies provide important insights into biological behaviour analysis, most of the discussed systems focus on multi-agent coordination rather than individual movement behaviour under environmental stimulus conditions.Environmental stimulus modelling has become another important area in behavioural simulation research. López-Incera et al. [3] proposed a behaviour-driven environmental interaction model capable of analysing movement adaptation under changing environmental conditions.

Their study demonstrated that stimulus-based interaction significantly influences movement trajectories and behavioural adaptation patterns. Similarly, Dambri et al. [2] developed a behavioural simulation environment for biological interaction analysis using environmental response visualization techniques. The work successfully demonstrated adaptive movement behaviour under different interaction scenarios.

However, both studies focused mainly on interaction modelling and did not emphasize lightweight simulator architecture or simplified visualization platforms.Visualization of movement trajectories and behavioural adaptation has also been explored in several recent works. Dang et al. [4] developed a lightweight visualization framework for movement behaviour analysis and demonstrated the importance of trajectory visualization in understanding behavioural response patterns. Pitonakova et al. [18] further reviewed several simulation systems for autonomous movement studies and concluded that many existing platforms prioritize graphical realism and physical modelling over simplified behavioural analysis. Based on the reviewed literature, existing simulation platforms generally focus on either high-fidelity physical simulation or large-scale autonomous system analysis.

Although several lightweight behavioural frameworks have been introduced, limited studies specifically focus on simplified two-dimensional behavioural simulation under environmental stimulus conditions. Furthermore, many existing systems emphasize complex physical interaction and computational realism rather than lightweight movement visualization and behavioural trajectory analysis. Therefore, this work focuses on the development of

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue V May 2026

a lightweight 2D behavioural simulator capable of supporting environmental stimulus modelling, movement visualization, and behavioural analysis within a simplified and customizable simulation environment.

Simulator Design and Implementation

This section describes the overall structure and implementation of the proposed lightweight 2D behavioural simulator. The simulator was developed to support movement visualization, behavioural analysis, and environmental interaction studies within a simplified simulation environment.

As illustrated in Fig. 1, the simulator architecture consists of three major components: the worm model, the environment module, and the core simulation framework. These components interact continuously during runtime to perform environmental sensing, behavioural processing, and movement visualization.

Simulator Infrastructure

The simulator infrastructure was designed using a modular configuration approach to simplify the simulation setup and execution process. A command reader class is used to read simulation configuration files written in ASCII format and translate them into simulator-understandable instructions. Three file types are required during the simulation process:

- control file (.ini)
- connectome/network file (.ncct)
- and environment file (.nvrp)

The control file is responsible for defining the overall simulation execution sequence. Meanwhile, the connectome file describes the network topology associated with the worm model, while the environment file defines the environmental setup including food sources, temperature regions, and obstacles.

This modular file-based structure allows simulation parameters and behavioural configurations to be modified easily without changing the simulator implementation. An example of the simulation configuration used within the proposed simulator is shown in Fig. 2. The [Config] section defines the general simulator configuration including output directory and result filename.

The [Neuroscape(session1)] section initializes the environment space, loads the environmental configuration, defines the organism topology, and executes the simulation process. The modular command structure allows multiple simulation sessions with different environmental conditions and behavioural configurations to be executed independently.

Worm Structure

Within the simulator, each worm object is managed using a dedicated nested class structure where every worm possesses a unique identification label. As shown in Fig. 1, the worm is constructed from two primary modules:

- network topology module
- locomotion module.

The network topology module is responsible for defining the internal behavioural connectivity structure, while the locomotion module controls movement updates and positional chanes during simulation runtime. The organism initialization process includes defining the initial position, movement velocity, orientation angle, and associated network topology file. The initialization structure is represented as follows:

Organism (ID)=initpos(x,y,velocity,angle), topology.ncct

During simulation execution, the locomotion module continuously updates the worm position according to the current movement state and environmental interaction conditions. The resulting movement trajectory is recorded and visualized for behavioural analysis purposes.

Network Connectivity

The network topology within the simulator is represented using a directed graph model constructed from multiple node and device objects. Several node types are currently supported including:

- neuron nodes,
- sensory nodes,
- source nodes,
- and motor output devices.

Each node behaviour can be configured using predefined behavioural models and parameter settings. The connectivity information is stored within the connectome (.ncct) file, allowing flexible modification of the behavioural structure without changing the main simulator framework. The simulator allows users to define neuron connectivity and interaction using a configurable syntax structure. A simplified example of the network connectivity definition is shown below.

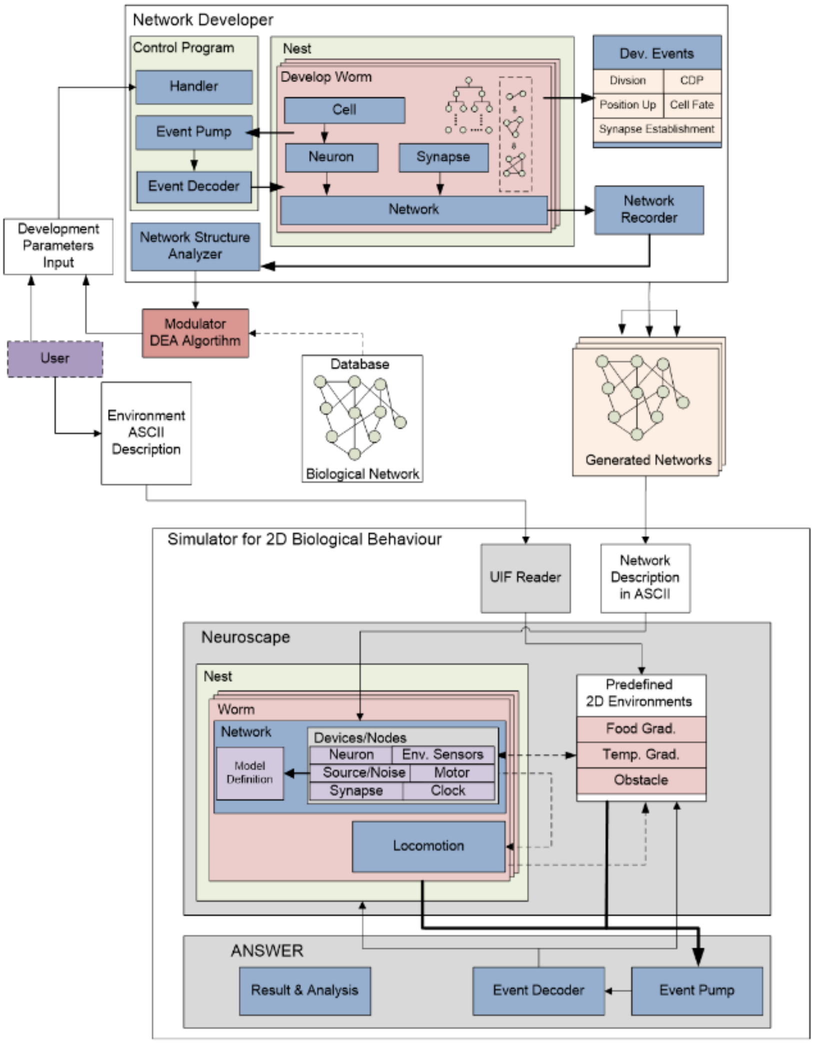


Figure. 1 Overview of Simulator Structure

```
[Config]
version     : 2.0
dir         : "..\results\"
clean       : true
filename    : Run1

[Neuroscape(session1)]
universe       = "-20",20,"-20",20
plane          = "environment.nvrp"(Food)
organism(a)    = initpos("-10","-10",0,90),"nematode_1.ncct"(Connectome)
simsetup       = 1,10000
```

Figure. 2 Example of Simulation Configuration that Used Text Based Description

src : neuron(id,model,event_t,info,param_1)

= tgt1(syn1), tgt2(syn2)

syn1 : param = v1,v2,v3

syn2 : param = v1,v2,v3

In this structure, the neuron node defines the behavioural processing unit while the connected target nodes define the outgoing interaction paths. Synapse parameters associated with each connection are defined separately to support flexible behavioural configuration. This modular connectivity structure simplifies the implementation of different behavioural models and interaction mechanisms within the simulation environment.

Environment Modelling

The environment module is responsible for defining the virtual interaction space and environmental stimulus conditions used during simulation. As illustrated in Fig. 1, the environment operates as a separate entity from the worm structure and continuously interacts with the behavioural network through environmental sensors. Three main environmental stimuli are currently supported:

- food distribution,
- temperature distribution,
- and obstacle regions.

Food distribution is generated using predefined seed commands where users specify the food source position, maximum intensity, distribution radius, and decay characteristics. A simplified example of the food configuration as follows:

[Food]
Food1 : seed = 20,10,50,1.0,1.0

Food2 : seed = -15,-10,100,2.0,2.0

The food distribution decreases gradually according to the distance from the source location and is represented in Eq. (1). Here, H represents the maximum stimulus intensity, r_0 represents the distribution radius, and $n$represents the exponential decay factor. The simulator also supports temperature distribution modelling using both linear

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue V May 2026

and circular configurations. In addition, obstacle regions can be introduced into the environment to alter movement behaviour and environmental interaction patterns during simulation execution.

$$f(r) = \begin{cases} H\left(\frac{r_0}{r}\right)^n, & r > r_0 \\ H, & r \leq r_0 \end{cases} \quad (1)$$

Environmental Interaction and Movement Update

Environmental interaction within the simulator is performed using specialized environmental sensor and motor devices embedded within the behavioural network. During runtime, the environmental sensors continuously retrieve environmental information based on the current worm position. These sensory signals are then transmitted into the behavioural network for movement adaptation processing.

The motor device is responsible for converting outgoing behavioural signals into positional movement updates within the simulation environment. After each movement update event, the environmental sensors obtain the updated environmental status corresponding to the new worm position. This interaction process enables continuous behavioural adaptation and dynamic movement response throughout the simulation execution. The movement update process is represented using a simplified directional movement model as shown in Eq. (2) and Eq. (3).

$$x_{t+1} = x_t + v\cos(\theta_t)\Delta t \quad (2)$$

$$y_{t+1} = y_t + v\sin(\theta_t)\Delta t \quad (3)$$

where x_t and y_t represent the current position, $v$represents movement velocity, θ_t represents movement direction, and Δtrepresents the simulation time step. Overall, the integration between environmental sensing, movement behaviour, and real-time visualization enables the proposed simulator to support behavioural analysis under different environmental stimulus conditions within a lightweight and customizable simulation framework.

RESULT AND DISCUSSION

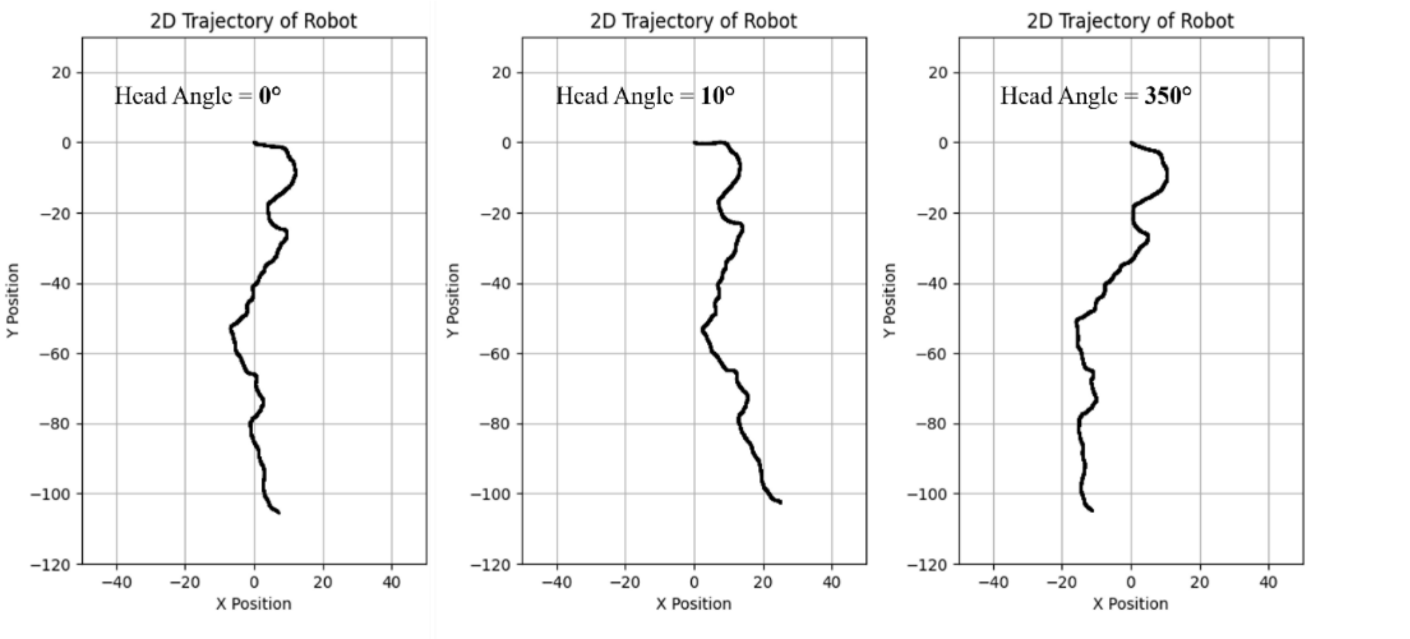
This section presents the behavioural validation and movement analysis of the proposed lightweight 2D simulator. Several simulations were conducted to evaluate the reliability of the simulation platform and to analyse movement behaviour under both non-stimulus and stimulus-based environmental conditions. The experiments focused primarily on movement trajectory visualization, behavioural adaptation, and environmental interaction within the virtual environment.

Evaluation on Simulator Reliability

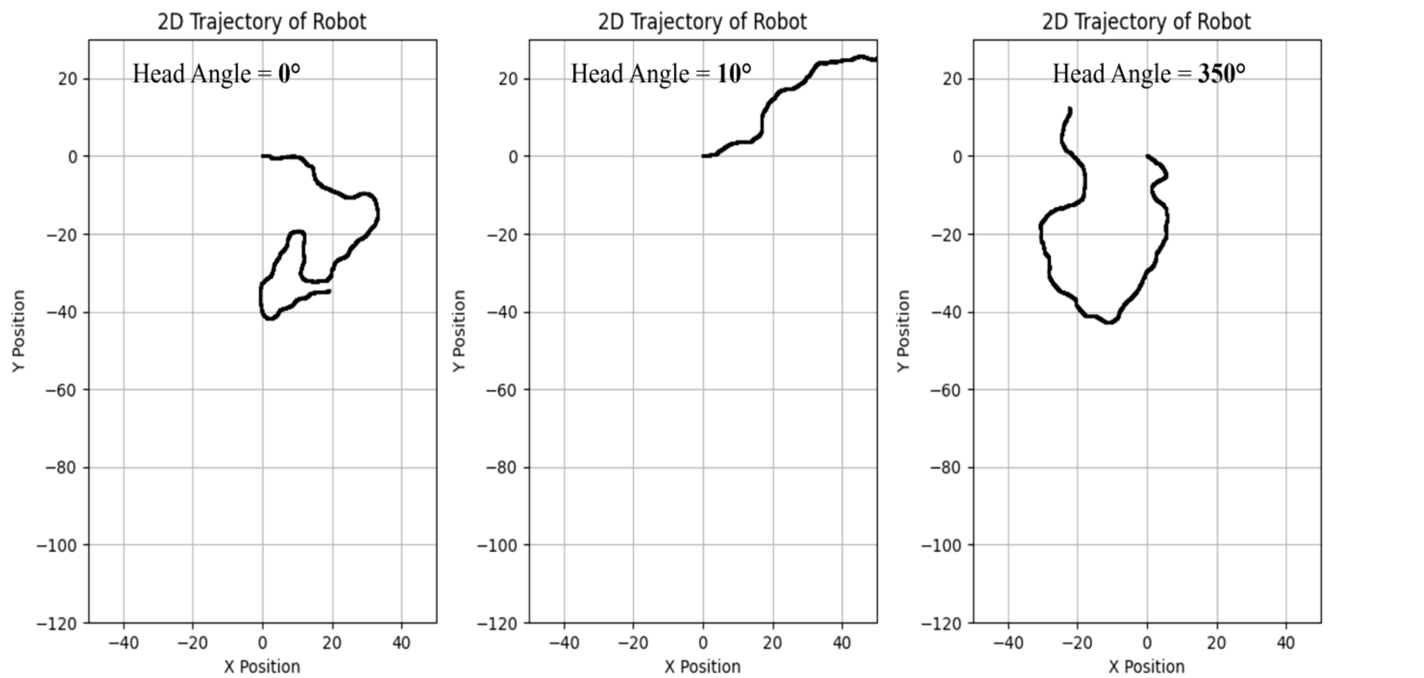
Before analysing movement behaviour under environmental stimulus conditions, the reliability and repeatability of the simulator were first evaluated. Since the movement behaviour within the simulator is partially influenced by pseudo-random number generation (PRNG), it is important to ensure that the simulator can consistently reproduce the same movement characteristics under identical conditions.

To evaluate repeatability, multiple simulations were conducted using identical initial conditions and fixed seed values. Fig. 3(a) shows the resulting movement trajectories generated under the same simulation configuration. As illustrated in the figure, the generated movement patterns demonstrate similar trajectory behaviour with only minor orientation differences caused by small variations in initial heading angles. Conversely, when randomized seed values were introduced, the simulator generated distinct movement trajectories despite using the same locomotion model. This behaviour is illustrated in Fig. 3(b), where each simulation produces a different exploration path within the environment. These results demonstrate that the simulator is capable of producing both reproducible and randomized movement behaviours depending on the selected simulation configuration.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue V May 2026



(a)



(b)

Figure. 3 Simulator Reliability Testing: (a) Reproducible Simulations Results with Fixed Seed Number and (b) Distinct Simulations Results with Randomized Seed Number

Movement Behaviour without Environmental Stimulus

The movement behaviour of the worm model was further evaluated under a non-stimulus environment where no external cues such as food distribution or temperature gradients were introduced. In this condition, movement behaviour is generated solely from the internal locomotion mechanism without environmental influence. Fig. 4 illustrates the resulting movement trajectory generated within the virtual environment. The movement pattern demonstrates exploratory behaviour characterized by alternating forward movement and directional reorientation events. In the trajectory visualization, forward movement segments are represented in blue, while turning behaviour is indicated in red. The resulting movement pattern resembles stochastic exploration behaviour commonly observed in biological locomotion systems.

Further behavioural analysis was conducted using Run-and-Turn evaluation as shown in Fig. 5. Fig. 5(a) compares the duration distribution between Run and Turn events, where Run behaviour occurs more frequently with longer average duration compared to Turn behaviour. Occasional prolonged Run behaviour can also be observed during the exploration process. Meanwhile, Fig. 5(b) presents the Turn category analysis based on the magnitude of orientation changes during movement. The results indicate the presence of both small directional adjustments and larger reorientation events throughout the movement process. Several sharp directional changes similar to omega-turn behaviour can also be observed. Overall, the generated movement characteristics demonstrate stochastic exploration behaviour suitable for behavioural movement analysis within non-cued environments.

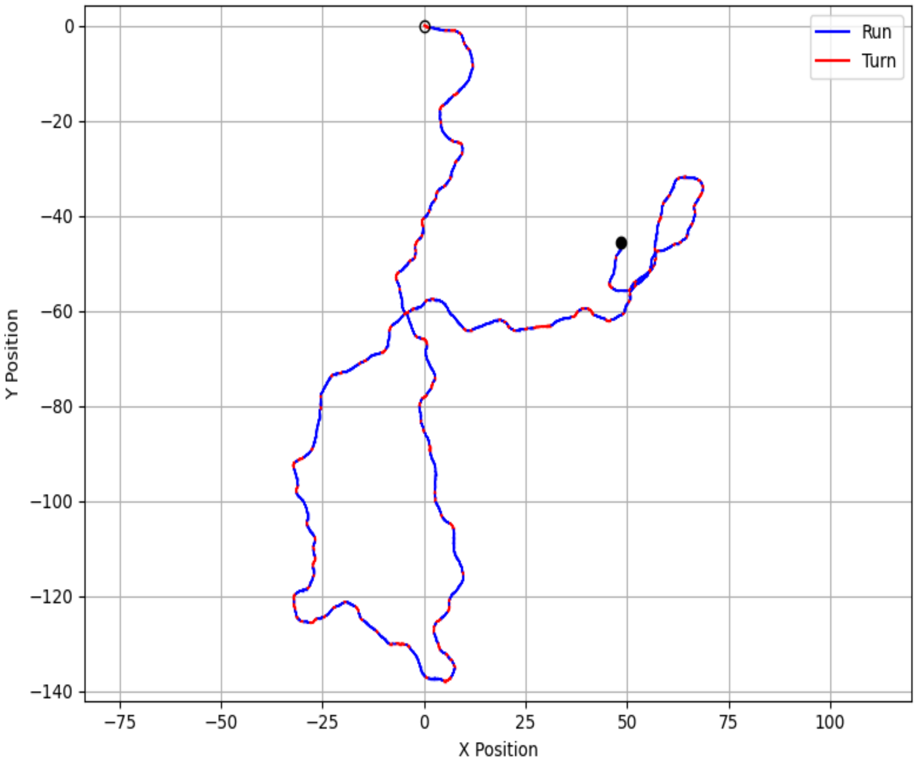
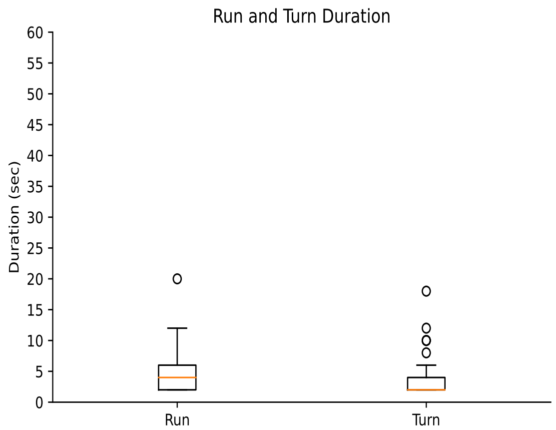
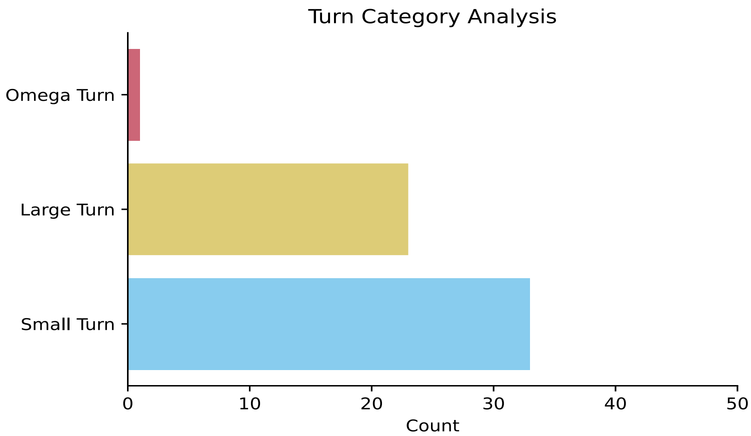


Figure.4 Movement Trajectory in a Non-Stimulus Environment



(a)



(b)

Figure. 5 Run-and-Turn Analysis in a Non-Stimulus Environment: (a) Run and Turn Duration Comparison and (b) Turn Behaviour Classification

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue V May 2026

Movement Behaviour Towards Food Resources

To evaluate behavioural response under environmental stimulus conditions, simulations were conducted using food distribution sources placed within the virtual environment. In this experiment, a single food source was positioned at the center of the environment with planar coordinates $[x, y] = [0,0]$. The environmental food distribution follows the stimulus model described in Section III-D, where the stimulus intensity decreases gradually according to the distance from the source location.

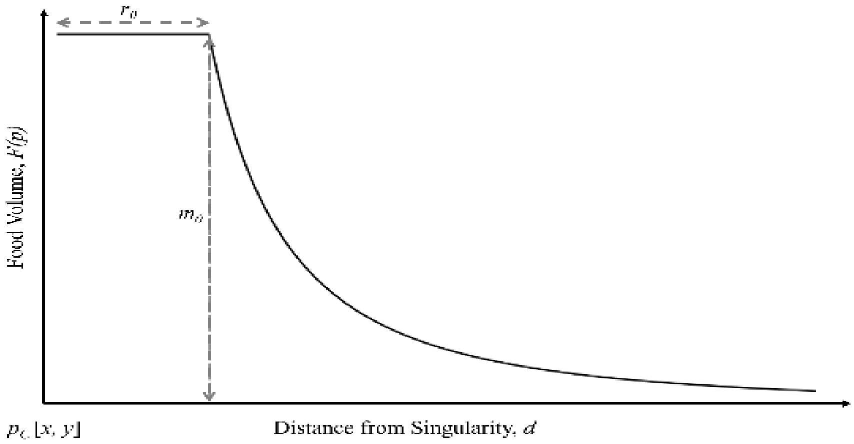


Figure. 6 Food Distribution within the Two-Dimensional Virtual Environment

Fig. 6 illustrates the food source distribution within the two-dimensional environment. During the simulation process, the worm was initialized at different positions and orientation angles to evaluate movement adaptation under varying initial conditions. Multiple simulation runs were conducted using different seed values to ensure that each movement trajectory remained unique. The resulting movement trajectories for selected simulations are shown in Fig. 7. As illustrated in the figure, the worm successfully located the food source in all simulation runs by relying entirely on environmental gradient information. During the early stage of movement, where the worm was located far from the stimulus source and the environmental gradient was weak, the movement pattern exhibited stochastic exploration behaviour characterized by frequent directional changes. However, once the worm entered the stimulus gradient region, longer forward movement behaviour became more dominant, indicating directional adaptation toward the food source.

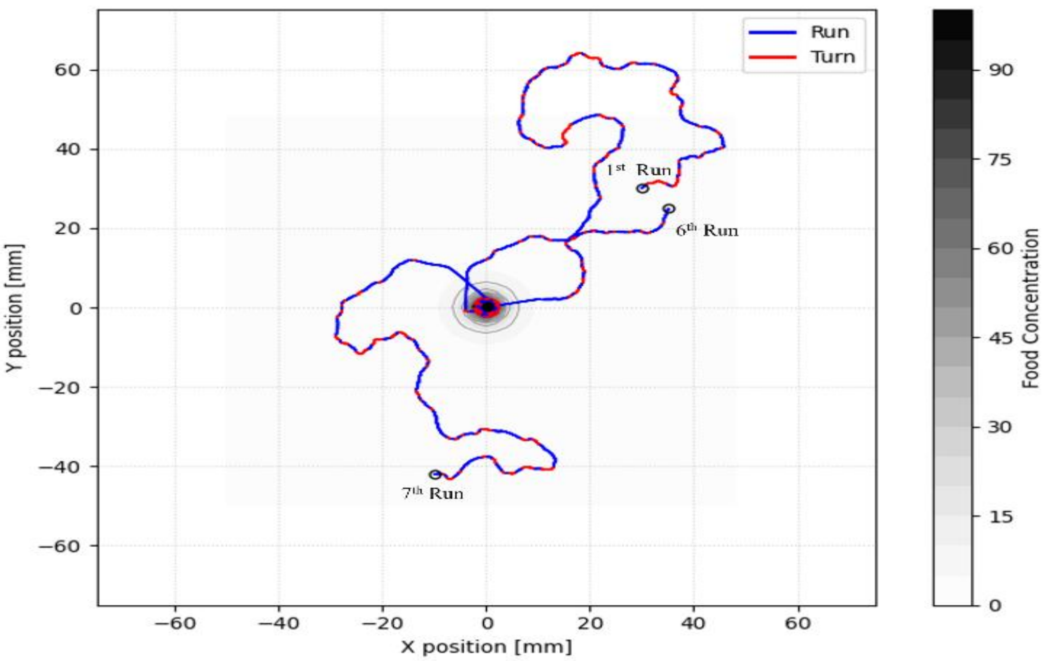


Figure. 7 Movement Trajectory in a Food-Based Environment

CONCLUSION

This paper presented the development of a lightweight two-dimensional simulation platform for behavioural analysis and environmental interaction studies. The proposed simulator was designed using a modular architecture consisting of environment modelling, behavioural network connectivity, locomotion control, and environmental sensing modules. In addition, the simulator supports configurable simulation environments through a simplified file-based configuration structure, enabling flexible behavioural experimentation and visualization.

Several simulations were conducted under both stimulus and non-stimulus environmental conditions to evaluate the functionality and behavioural response of the simulator. The results demonstrated that the simulator is capable of producing reproducible as well as stochastic movement behaviours depending on the simulation configuration. Furthermore, the simulator successfully represented exploratory movement patterns and directional adaptation toward environmental stimulus regions.

Overall, the proposed simulator provides a flexible and lightweight platform for movement visualization and behavioural analysis within a simplified two-dimensional environment. Future work will focus on extending the simulator with additional environmental interaction models and more advanced biologically inspired behavioural mechanisms.

ACKNOWLEDGEMENTS

The author would like to thank Centre for Research and Innovation Management (CRIM), Universiti Teknikal Malaysia Melaka (UTeM) for its support in the present work.

REFERENCES

1. J. Crewe, A. Humnabadkar, Y. Liu, A. Ahmed, and A. Behera, "SLAV-Sim: A Framework for Self-Learning Autonomous Vehicle Simulation," Sensors, vol. 23, no. 20, p. 8649, Oct. 2023.
2. O. A. Dambri et al., "Design and Implementation of a Simulation Framework for a Bio–Neural Dust System," Modelling, vol. 6, no. 1, p. 8, Jan. 2025.
3. A. López-Incera, K. Ried, T. Müller, and H. J. Briegel, "Development of swarm behavior in artificial learning agents that adapt to different foraging environments," PLOS ONE, vol. 15, no. 12, p. e0243628, Dec. 2020.
4. H.-T. Dang, B. Gaudou, and N. Verstaevel, "HyPedSim: A Multi-Level Crowd-Simulation Framework—Methodology, Calibration, and Validation," Sensors, vol. 24, no. 5, p. 1639, Feb. 2024.
5. Z. Talebpour and A. Martinoli, "Adaptive Risk-Based Replanning For Human-Aware Multi-Robot Task Allocation With Local Perception," IEEE Robot. Autom. Lett., vol. 4, no. 4, pp. 3790-3797, Oct. 2019.
6. A. Yildiz et al., "Experience Filter: Using Past Experiences on Unseen Tasks or Environments," in Proc. IEEE Intell. Vehicles Symp. (IV), Anchorage, AK, USA, 2023, pp. 1-7.
7. A. Sadhwani et al., "Fleet2D: A Fast and Light Simulator for Home Robotics," in Proc. 7th IEEE Int. Conf. Robot. Comput. (IRC), Naples, Italy, 2023, pp. 102-109.
8. H. Zeng, L. Kästner, and J. Lambrecht, "Efficient 2D Simulators for Deep-Reinforcement-Learning-based Training of Navigation Approaches," in Proc. 20th Int. Conf. Ubiquitous Robots (UR), Honolulu, HI, USA, 2023, pp. 275-280.
9. M. Holen, K. M. Knausgård, and M. Goodwin, "Development of a Simulator for Prototyping Reinforcement Learning-Based Autonomous Cars," Informatics, vol. 9, no. 2, p. 33, Apr. 2022.
10. M. Sasaki, J. Muguro, F. Kitano, W. Njeri, and K. Matsushita, "Sim–Real Mapping of an Image-Based Robot Arm Controller Using Deep Reinforcement Learning," Appl. Sci., vol. 12, no. 20, p. 10277, Oct. 2022.
11. J. Xu, E. Huang, L. Hsieh, R. S. Lee, T. Jia, and C. Chen, "Simulation optimization in the era of Industrial 4.0 and the Industrial Internet," J. Simulation, vol. 10, no. 4, pp. 310-320, Nov. 2016.
12. E. Rohmer, S. P. N. Singh, and M. Freese, "V-REP: A versatile and scalable robot simulation framework," in Proc. IEEE/RSJ Int. Conf. Intell. Robots Syst., Tokyo, Japan, 2013, pp. 1321-1326.

13. M. Savva et al., "Habitat: A Platform for Embodied AI Research," in Proc. IEEE/CVF Int. Conf. Comput. Vis. (ICCV), Seoul, Korea (South), 2019, pp. 9339-9347.
14. N. Koenig and A. Howard, "Design and use paradigms for Gazebo, an open-source multi-robot simulator," in Proc. IEEE/RSJ Int. Conf. Intell. Robots Syst. (IROS), Sendai, Japan, 2004, pp. 2149-2154.
15. O. Michel, "Cyberbotics Ltd. Webots™: professional mobile robot simulation," Int. J. Adv. Robot. Syst., vol. 1, no. 1, p. 5, 2004.
16. S. Garnier, J. Gautrais, and G. Theraulaz, "The biological principles of swarm intelligence," Swarm Intell., vol. 1, pp. 3-31, 2007.
17. E. Tuci, M. Alkilabi, and O. Akanyeti, "Cooperative object transport in multi-robot systems: A review of the state-of-the-art," Front. Robot. AI, vol. 5, p. 59, 2018.
18. J. Pitonakova, R. Crowder, and S. Bullock, "Feature and performance comparison of the V-REP, ARGoS and Gazebo simulators," Robot. Auton. Syst., vol. 105, pp. 43-57, 2018.