NEW ERA AGRICULTURE MAGAZINE

Exploring Insect-Inspired Robotics: Innovations in Autonomous Systems and Bio-Inspired Technologies

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Abstract: -

This work explores key research questions in hexapod robotics, focusing on how to develop intelligent, autonomous robots capable of leveraging their biomechanics, morphology, and computational systems to achieve autonomy, adaptability, and energy efficiency akin to small living organisms such as insects. It examines whether insects, as the only animals with six legs, serve as effective models for building advanced hexapod robots. The discussion is structured into three main areas: biomechanics, emphasizing the design of efficient and adaptive legs; locomotion control, focusing on stable and versatile movement; and high-level cognitive control, addressing decision-making and interaction with complex environments. These interconnected areas are critical to enhancing energy efficiency, terrain adaptability, autonomy, and operational capabilities in hexapod robots. Additionally, this work highlights how knowledge transfer between biology and robotics can drive future advancements in the field.

Keywords: - Robots, insects, fascinating world, inspiration, Agtech

Introduction

Legged robots provide a valuable opportunity to deepen our understanding of locomotion in the animal kingdom (Aguilar *et al.*,2016). Since the advent of robotics in the 20th century, these robots have sparked significant interest and curiosity among researchers and the public alike. Beyond advancing knowledge of animal movement, legged robots present a compelling alternative to wheeled systems, excelling at navigating uneven terrains. Most animals rely on legs for movement, exploration, and adaptation to their environments, and similarly, legged robots can traverse various surfaces, including rugged terrains, jump over obstacles, and climb

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structures.

This article focuses specifically on hexapod robots, which are equipped with six actuated legs. The hexapod design is particularly motivated by the goal of creating insect-like robots to closely replicate animal models, enabling meaningful comparisons with insects in areas such as locomotion, navigation, and object manipulation. From a robotics perspective, hexapod robots achieve an optimal balance between stability and energy efficiency. Robots with fewer legs, like bipeds or quadrupeds, experience reduced stability during the leg transfer phase; for example, bipedal robots must stabilize on a single leg, while quadrupeds are inherently unbalanced due to their symmetrical leg configurations. Conversely, while octopod robots are highly stable, they are less energy efficient.

Insects and other arthropods effortlessly navigate complex environments despite having relatively simple nervous systems. Studies have shown that a spherical field of vision is particularly beneficial for estimating self-motion, potentially explaining why many flying creatures possess nearly panoramic vision. Insect navigation and motion control are of great interest to robotics, as these systems are believed to rely on computationally efficient strategies rather than complex methods like map-building and scene reconstruction. For instance, the classic example of bee-inspired corridor-centering leverages optical flow to balance inputs from the left and right walls.

InsectBot

To advance research in insect-inspired robotics, a novel mobile robotic platform named **InsectBot** has been developed. This platform stands out from more conventional robotics platforms due to two key design features. While a few mobile robots utilize this technology, such as the three-wheeled Palm Pilot Robot Kit and the four-wheeled robots of Cornell's RoboCup team, the InsectBot benefits from the added stability these wheels provide for carrying heavier payloads. This configuration also simplifies and enhances motion control (Ashmore and Barnes, 2002).

The InsectBot supports any ATX-style motherboard and accommodates various sensors, such as the SICK laser range finder. The current configuration utilizes a Mini-ITX VIA EPIA SP1300 motherboard with 1 GB of DDR400 RAM for motor and sensor communication, as well as motion control for the drive and lift systems. Visual processing tasks are managed externally by one or more high-performance computers, with communication facilitated via a 56 kbps wireless connection or a 100 Mbps wired connection when required. The robot is powered by a 24V battery system with a capacity of approximately 30 Amp-hours, providing several hours of runtime under normal operation.

Flow-based Corridor Centring

Corridor centering, inspired by observations of honeybee behavior, involves adjusting the robot's heading to balance the flow magnitudes in the peripheral regions of its visual field. It is crucial to consider such navigation subsystems in the context of the larger system they operate within, as well as the diverse range of tasks that the overall system must perform. To this end, we utilize full optical flow estimation across all flow-based subsystems instead of relying on simpler approximations like normal flow or planar models. This raises an important consideration: selecting the most appropriate optical flow method for real-time navigation tasks, such as corridor centring.

Although prior comparisons of optical flow techniques have focused on their accuracy and efficiency, they do not sufficiently address the systematic selection of methods for real-time navigation systems. Further research expanded this to include several widely cited optical flow methods (McCarthy and Barnes, 2004). Unlike previous studies, our approach emphasizes in-system comparisons of optical flow techniques within the context of their intended tasks.

Robotic pollinators

In recent years, researchers successfully developed micro-robots that replicate the behaviors of bees and spiders. One significant advancement is the creation of robotic bees by Arugga AI Farming, which leverage deep learning technology to facilitate efficient cross-pollination in plants. The potential of robotic bees, as demonstrated by Arugga AI Farming, has been further supported by studies suggesting these robots could complement the work of natural bees, whose populations are increasingly threatened by human activities. One perspective argues that robotic bees cannot replace the natural biodiversity provided by real bees (Potts *et al.*,2018). This viewpoint stems from the potential risk of robotic bees becoming an invasive species. Moreover, it is impractical for robotic bees to fully substitute natural bees, as large-scale production could have adverse ecological effects and fail to address the cultural and intrinsic value associated with natural pollinators. For instance, pollination by bees plays a crucial role in maintaining the proper functioning of the natural ecosystem.

Swarm Robotic Systems for Intelligent Pesticide Application

Researchers have also developed swarm robotic systems for pest control, building on the concept of robot bees. These methods are unsuitable for small farms or those with challenging terrains, such as mountainous areas. Additionally, large UAVs used for pesticide spraying can experience significant drift, leading to lower precision and increased pesticide waste (Gonzalez-de-Santos *et al.*, 2017)

To address these issues, there is increasing interest in equipping spraying robots with advanced features like thermal imaging for plant inspection and early disease detection, which could improve their autonomous capabilities. Recently, research has explored the development of swarm robotic systems for pesticide application. Companies like Skyx and Greenfield Robotics have made strides in creating autonomous and modular spraying robots, as well as the hardware necessary for widespread adoption of these systems.

However, a major concern remains the lack of comprehensive data on the effectiveness of swarm robotic systems for pesticide application in real-world farming conditions. Most findings are based on pilot studies and experiments, and without conclusive data, the adoption of swarm robotics for pest control may be limited. Mobility and adaptability of these systems are also challenged by unpredictable weather and obstacles, particularly on farms located in mountainous regions. Swarm robots could also face issues related to phase transitions between different operational states.

Future aspects

Future technical advancements for the Insectbot research platform will focus on enhancing communication bandwidth by incorporating multiple wireless and/or wired Network Interface Cards (NICs). Additionally, plans include increasing the degrees of motion for the vision system by introducing mechanisms for tilt and/or rotation to simulate tilt and roll.Conventional motion control algorithms in robotics are often computationally intensive, as they rely on methods like reconstruction, map-building, geometric modelling, scene depth estimation, or calculating the homography between views. These techniques can also be prone to errors stemming from inaccuracies in camera and robot calibration. Additionally, studies such as have demonstrated that any position on a ground plane can be reached using navigation algorithms based solely on the angles between image features. Future work will involve integrating these algorithms into a unified navigation system capable of handling a broad spectrum of tasks. This will enable the study of system behavior as multiple motion strategies are employed collaboratively, potentially uncovering new synergies between existing algorithms.

Conclusion

There are often multiple approaches to addressing fundamental challenges in robot vision and motion. Traditional solutions can be effective but may become impractical when real-time performance is required. Since both autonomous robots and living organisms face similar problems while performing analogous tasks, researchers continue to draw inspiration from biological solutions to develop robust, real-time methods. These efforts represent individual subsystems within an autonomous robot. As these subsystems are integrated, the focus will shift toward developing higher-level perception and cognition systems capable of identifying diverse scenarios and environments. These systems will activate the appropriate subsystems to efficiently accomplish the required tasks.

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